DEVELOPMENT AND OPTIMISATION OF AN AUTOMATED GAARI FRYING MACHINE

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CERTIFICATION

This is to certify that this research work was carried out by OZIGBO, Emmanuel Sunday under my supervision in the department of Agricultural and Environmental Engineering, Faculty of Technology, University of Ibadan, Ibadan, Nigeria.

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DEDICATION

This academic research work is dedicated to my everlasting Father, the Beginning and End, Yea and Amen, the Almighty Father, the lifter of my head and the source of my inspiration, power and wisdom. May His name be praised forever for His mercy, grace, and blessings upon my life and family. Amen. Also, the success of this my PhD journey and work is devoted to my beautiful and wonderful wife, Mrs. Elizabeth Elekebere Ozigbo who endured and tolerated all things for me towards achieving this thoughtful vision.

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ABSTRACT

Frying operation is a tedious aspect of garri processing. It is largely done manually which causes discomfort and various health challenges to the operator due to heat, smoke, and the sitting posture. Literature is sparse on the deployment of automation for garri frying and previous efforts made did not give satisfactory results. Therefore, this study was designed to develop an automated garri frying machine.

A garri fryer fitted with a heating element was developed using standard methods. Based on the existing literature and preliminary studies, Frying Time, FT (0–90 mins), Frying Temperature, FT_P (0–250 ^oC), Power Consumption, PC (0–15 kW), initial Moisture Content, MC_i (0–55% wb), and final Moisture Content MC_f (0–35% db) were programmed into an Arduino microcontroller and attached to the developed fryer to automate it. The Functional Efficiency (FE), Throughput (TP), Useful Heat Energy (Q_u) and Thermal Efficiency (η_t) of the automated fryer were determined using standard equations. The FT_P relative to different PC levels were recorded. The optimum operating conditions of the automated fryer were determined using Response Surface Methodology (RSM) at 4-factors: FT_P, FT, MC_i, Mass Quantity (M_Q) and 5-levels: 140, 160, 180, 200, 220 ^oC; 15, 30, 45, 60, 75 mins; 30, 35, 40, 45, 50% wb and 10, 20, 30, 40, 50 kg, respectively. The optimised values were validated with experimental data using standard methods. At a constant FT_P (183 ^oC) and MC_i (30% wb), 30 kg of mash sample, comparative analysis of manual, mechanical and automated fryers were carried out based on the TP, FE, FT, Number of Operators (NO_P), Production Cost (PD_C) and Operating Cost (OC). Data were analysed using ANOVA at $\alpha_{0.05}$.

The automated fryer was powered with a 2-hp, 3-phase electric-motor. Its FE, TP, Q_u and η_t were 87%, 45.0 kg/hr, 7,919.8 J and 42.7%, respectively. Increase in FT_P from 140 – 220 ^oC resulted in decreased MC_f (23.4, 19.8, 15.3, 12.6, and 9.8% db). Optimal TP (43.64 kg/hr) and MC_f (12.30% db) were obtained at operating conditions: M_Q (49.99 kg), FT (57.80 mins), MC_i (30% wb) and FT_P (183 ^oC) at PC of 7.7 kW. There was no significant difference between the experimental and predicted values, indicating that the optimised values were valid. The FE, TP, FT, PD_C and NO_P for automated, mechanical and manual were 87, 57.7, and 44%; 45.0, 18.7 and 13.2 kg/hr; 41, 55 and 62 mins; and 1, 2 and 3, respectively indicating that the automated fryer performed best. The PD_C and OC for the automated, mechanical and manual fryers were ₦609,200, ₦700,000, ₦185,400, and ₦138,000, ₦699,936, ₦61,000, respectively. The developed automated fryer was more cost-effective and efficient than the mechanical fryer. The manual fryer had the lowest production and operating costs but lowest capacity, processing time, and efficiency. There was a significant difference in the efficiency of the automated machine compared with mechanical and manual fryers.

An automated garri fryer which gave better performance than the existing fryers was developed.

Keywords: Garri frying machine, Manual garri fryer, Functional efficiency.

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DEFINITION OF TERMS

CIAT	International de Agricultural Tropical
MT	Metric Tons
IITA	International Institute of Tropical Agriculture
HQCF	High Quality Cassava Flours
HQCG	High Quality Cassava Gaari
Fw	Fresh Weight
DM	Dry Matter
mg	Miligram
USDA	United States Department of Agriculture
µg	Microgram
kg	Kilogram
ppm	Part Per Million
ha	Hectare
PPD	Postharvest Physiological Determination
PHL	Postharvest Loss
CTA	Cassava Transformation Agenda
HM	High Methylated
MJ	Mega Joules
SSF	Solid State Fermentation
R&D	Research for Development
HFS	High Fructose Syrup
FAO	Food and Agriculture Organization
HCN	Hydrogen Cyanide
ITGD	Intermediate Technology Development Group

RMRDC	Raw Materials Research and Development Council
COSCA	Collaborative Study of Cassava in Africa
MC	Moisture Content
rpm	Revolution Per Minute
RAIDS	Rural Agro-Industrial Development Scheme
UNN	University of Nigeria, Nsukka
LED	Light Emiiting Diode
PROM	Program Memory
CPU	Central Processing Unit
RAM	Random Access Memory
RISC	Reduced Instruction Set Computer
mA	Miliampre
AC	Alternating Current
V_p	Primary Input Voltage
N_p	Number of Turns on Primary Coil
I_p	Primary Input Current
V_s	Secondary Output Voltage
N_s	Number of Turns on Secondary Coil
I_s	Secondary Output Current
h_P	Horse power
RSM	Response Surface Methodology
Y	Response Dependent Variable
β_o	Model Intercept
ε	Random Error of Experimentation
ANONA	Analysis of Variance

kW	Kilowatt
wb	Wet Basis
α	Degree of Probability
m	Mass of the Shaft
g	Gravitational Constant
w1	Mass of the Shaft alone
w2	Mass of the Pulleys
w3	Mass of the Upper and Lower Bearing
V	Shear Force
M	Bending Moment
d	Diameter of the Shaft
M_b	Maximum Bending Moment on the Shaft
M_t	Maximum Torsional Moment on the Shaft
K_b	Dimensional Combined and Fatigue Factor Applied to Bending Moment
K_t	Dimensional Combined and Fatigue Factor Applied to Torsional Moment
S_x	Allowable Shear Stress for Steel Metal
ASME	American Society of Mechanical Engineers
ϒ	Electric Motor Star Connection
L	Length of the machine
r	Radius of the Frying Chamber
V_C	Volume of the Frying Chamber
ʆ	Density of the Cassava Mash
Ma	Mass of the Cassava Mass in the Cylinder

C	Specific Heat Capacity of the Mash
T_1	Initial Temperature
T_2	Final Temperature
K	Thermal Conductivity of the Mash
S	Surface Area of the Cylinder
h	Height of the Cylinder
P_P	Power required to drive the Pulley
R_P	Radius of the Pulley
W_P	Weight of the Pulley
N	Number of the Shaft
Ws	Weight of the Shaft
r_s	Radius of the Shaft
P_S	Power required to drive the Shaft
P_d	Power required to drive the Frying Paddles
τ	Torque of the Shaft
ω	Angular Speed of the Shaft
f	Total Load on the Paddles
N_1	Speed of the Driven Pulley
N_2	Speed of the Driving Pulley
D_1	Diameter of the Driven Pulley
D_2	Diameter of the Driving Pulley
C_T	Throughput Capacity of the Machine
F_E	Functional Efficiency of the Machine
ML	Material or Water Loss

MCi	Initial Moisture Content
MCf	Final Moisture Content
db	Dry Basis
BEM	Bill of Engineering Measurement
TME	Tropical Manihot Esculanta
χ^2	Chi-Square
HSS	High Stainless Steel
MS	Mild Steel
ICEs	Internal Combustion Engines
DC	Direct Current
MCLR	Master Clear
IC	Integrated Circuit
CPC	Cassava Processing Cent

CHAPTER ONE

INTRODUCTION

1.1 Background of the Study

Cassava plant (*Manihot esculenta* Crantz) is shrub farmed for its underground starchy tubers throughout the tropics and subtropics. The periderm, or outside layers of the tuber, the cortex, or thick layer immediately beneath the periderm, and the starchy fleshy, center region of the tuber, which comprises of parenchyma cells packed with starch granules are the three main areas of a cassava tuber or roots. The tuber's edible starchy flesh accounts for 80 – 90% tuber's weight, making it a major source of carbohydrates and a staple diet eaten by not less than 800 million populace worldwide (Jose-Luis *et al.*, 2020; Ecocrop, 2011; Lebot, 2009). The edible part contains about 1 – 2% protein, 30 – 35% of amyloses and amylopectins (carbohydrates) on a dry weight basis, 62% water, 1 – 2%, fibre, 1% minerals, and 3% fat and the peels are used for processing of animal feeds and generation of biogas (FAO, 1998). According to (Ashebir, 2021), about 820 millions suffered from malnutrition and hunger.

The production of cassava roots has been on the stead increase since the l960s. It surged ever since 2000 with 40% increase between 1997 and 2007 with 161 to 224 million tons. The usage of crop in livestock feeds production has also increased from 25% to 34% in 1997 and 2007 (76 million metric tons). About 15% of cassava was produced in Latin America, 33% in Asia and 52% in Africa in 2010 (FAO. 2011). Nigeria is a significant indicator to this African’s massive production as the world highest cassava producer. Nigeria produced 54 million metric tons of cassava per year in 2013 (FAO, 2013). However, according to the United Nations' FAO report stated in that year 2009, Thailand production of dried cassava (a product of cassava) was the highest ahead the total 14% production of Vietnam (FAO, 2011).

Just like the way Africa is the highest producer of cassava in the whole world, it is the highest consumer as well. Africans’ cassava consumption accounts for 62% of the world total crop production. Based on baseline data from the International Food Policy Research Institute (IFPRI) reported by Andrew Westby (2002), the world’s cassava total consumption rose from 172.7 million metric tons to 275 million metric tons between 1993 and 2020. Whereas the Scott *et al*., (2000) prediction stated that due to production growth and a greater demand, forecast 2020 production would be 291 million metric tons.

Consequently, these available statistics show that there is high utilization of cassava roots in Nigeria, the largest world producer and Africa at large (Tridge, 2021). Thus, the cause for the region's massive production. This demonstrates the feasibility and enormous potential of the business of cassava in the agricultural sector of the Nigerian’s economy. The majority of cassava tuber cultivated in Nigeria is used for human usage, with over half of it going into processed products like gaari, fufu, pellets, tapioca, tidbits, lafun, chin-chin, flour, abacha, bread, chips, and so many confectioneries. The crop is also used for starch, biogas, livestock feed, glue, and ethanol for industries (FAO, 2013). All of this has been made possible by rapid technological advancements in the agricultural sector of the Nigerian economy in the pre and post-harvest sections.

Gaari is the most frequent of the cassava products mentioned above, and it is the daily major source of food in Brazil, Nigeria and most West African nations. Garri manufacturing technology is the popular advanced cassava root processing technology. Gaari is a pre-gelatinized grit with particle sizes that range from less than 10 micrometers (fines) to more than 2000 micrometers (coarse) (Nwankpa, 2010; Ayernor, 1981). Gaari's nutritional value is carbohydrates, indicating that it is an energy-giving food. Gaari flying is a cooking and dehydration process in which the food is cooked while still moist and then dehydrated. The amount of heat applied while frying impacts the product's quality. In the rural community approach, the initial temperature for frying is kept low to prevent many lumps or caking formation. The frying temperature is further raised to dehydrate and cook the product and as the moisture content decreases, most of the lumps formed are broken down by constant agitation and pressing (Olagoke *et al*., 2014).

Gaari production process includes operations such as peeling of the roots, washing, grinding, fermenting, pressing, pulverization, shifting and roasting or frying. All these operations that lead to gaari production have been fully mechanized in majority of cassava processing industries in Nigeria, except peeling and frying. These are the major challenges the cassava processors are facing in Nigeria today. Although several efforts have been made to advance or improve the techniques and systems of these operations by IITA, Farteriod company, Niji Lukas yet, there are no complete automated systems that have meet the farmers' production requirement. This has led to the following problems in the gaari production industries; increased labour cost in the production line, reduced availability of quantity and quality of gaari in the market, increased the cost of the product in the markets, food insecurity as the gaari is the ones of the major carbohydrate food eaten by most of the populace, drudgery, tediousness in the production process and lack of interest by the farmers as there is no hope of full mechanization and automation of the gaari frying process.

Therefore, the study is aimed at designing, constructing, testing and optimizing an automated gaari frying machine to increase efficiency, throughput and production process so as to make gaari production business attractive, lucrative and sustainable.

1.2 Problem Statement

The major challenge with fresh cassava roots is the short postharvest shelflife, thus, it's expected to be consumed or converted into long-lasting products as fast as possible after harvest. The frying, which happens due to simultaneously heating and dehydrating the moisture content contained in the cassava by applying heat, is the most crucial unit of operation when turning cassava root to gaari (Akinnuli *et al.*, 2015). Gaari is traditionally fried in shallow earthenware cast-iron pans over a wood fire by women. While frying, the operator sits sideways by the fireplace, causing a variety of health problems and discomfort owing to the heat and the sitting posture. As a result, there was a need for new ideas and changes to help these women deal with their difficulties. Then Odigbo and Ahmed (1982) of UNN model was developed to authentically improve the community manual frying processes (Odigboh, 1985); Igbeka J. C improved gaari fryer made of a flying pan, and a fireplace oven with a chimney as reported by Gbasouzor and Maduabum (2012).

Further advancements go on unrelenting as the researchers were able to tackle manually associated difficulties and issues only; the Dunford model, Niji Lukas model, Newell, and Brazilian model, which range from coal firing to gas firing to diesel burner firing frying, have all substantially aided the frying operation. Though, the diesel burner type of the fryer by Niji Lukas has been proven to be the best in frying gaari technologies accessible in the country right now, yet the challenges associated with this very technology have necessitated the need for its modification and improvement. The problems with the existing burner type fryer include the following:

I. Low efficiency;
II. Low throughput capacity;
III. Low processing time;
IV. The cost of acquiring a diesel burner is expensive, which contributes to the fryer's high price;
V. Burner frequently failure or breakdown at any minor voltage surge;
VI. Loss of production time and product during the breakdown process (i. e. Increase in operational down time);
VII. Frequent change of main mechanical components of the machine like solenoid, injector nuzzles, fuel pump, transformer, electronic module, etc., which are expensive;
VIII. Frequent servicing and maintenance cost of the burner;
IX. Soot and carbon emission to the surrounding environment and global warming effect;
X. Requires regular services or attention of an expert;
XI. Littering of the processing environment with diesel fuel during repair job;
XII. Ever increasing price of the diesel fuel in the filling stations;

In view of this, the projected research is to design, construct, optimize and carry out performance evaluation of an automated electric gaari frying machine to alleviate these problems related to diesel burner to make gaari frying appealing and acquirable to the farmers. The technology is able to give gaari processing operation a full automation as a microchip (microcontroller) programming language was used to design the electronic/electrical systems of the fryer, thereby, saving the high cost of associated with diesel or gas types, hence encouraging and boosting gaari production in our country.

1.3 Objectives of the Study

The major objective of this study is to develop an automated gaari frying machine. The specific objectives are to:

a) Carry out the comparative study on the existing mechanical and manual gaari processing methods.
b) Design and Construct an automated gaari frying machine
c) Carry out the performance evaluation of the automated gaari frying machine and the comparison of the automated with the mechanical and manual fryers.
d) Optimize the machine parameters to obtain an improved efficiency.

1.4 Scope of the Study

There are many mechanized and manual gaari fryers ranging from shallow-ware cast iron pan system called "Agbada" to improved mechanized fryers available in the country. However, this research work is limited to Niji Lukas mechanized gaari fryer as a case study and IITA improved manual 8 x 4" gaari frying equipment. The design deficiencies in the Niji Lukas mechanized fryer necessitated the development and optimization of an automated gaari frying machine to improve its throughput capacity and efficiency. A comparative analysis of the automated, mechanized and manual was made to justify the choice of the machine. The research study areas were University of Ibadan, and IITA in Nigeria.

CHAPTER TWO

LITERATURE REVIEW

2.1 The Cassava Plant: Taxonomy, Morphology and Production

Cassava (*Manihot esculaenta* Crantz) is a plant that was originated from South America which was used in addition to maize, potato and rice by Amazonian Indians (Shin *et al.,* 2021). During the 16th and 17th centuries, Portuguese explorers brought cassava stem into Africa in trade with the African coasts and neighboring islands. Cassava was then introduced later to Africans, and established practically in every section of tropical Africa. Brazil (6%), Ghana (7%), Thailand (10%), Congo (13%) and Nigeria (19%) are the leading cassava producers (Tridge, 2021). Cassavas are shrubs (perennial) (Plate 2.1) which grow to a height of 1 – 4 m in cultivation. It is known by various names around the world, including tapioca, mandioca, and yuca. The Manihot genus, which belongs to the Euphorbiaceae, dicotyledon family is said to comprise of 100 species, and cassava (*Manihot esculaenta* Crantz) as the only popularly cultivated one (Jose-Luis *et al.,* 2020). There are two sorts of plants: erect (with or without branching at the top) and spreading (with or without branching at the bottom) (Alfredo, 2002).

Cassava has a wide range of morphological traits, indicating a high level of interspecific hybridization. Cassava cultivars can be found in a number of germplasm banks at both international and national research institutions. According to Bonierbale *et al.* (1997) as cited by Alfredo (2002), the biggest germplasm bank is situated at Centro International de Agricultural Tropical (CIAT) in Colombia with almost 4700 accessions. It is followed by EMBRAPA's collection in Cruz das Almas, Bahia, with 1799 accessions, depicting the

Plate 2.1: The Picture of Cassava Plants

germplasm of these Brazillian eco-systems. Lowland and highland semia Cassava genotypes are typically identified using a combination of agronomic and morphological traits (Fukuda *et al.,* 1997). The descriptors of the International Plant Genetic Resources Institute (IPGRI) were recently changed, and a new version was developed with 75 descriptors, 54 of which are morphological and 21 of which are agronomic (Alfredo, 2002). The heritability of morphological descriptors (such as lobe, form, root pulp color, and stem external) is higher than that of agronomic descriptors (like roots number per yield of the root and root length). The following morphological features were identified as the basic or minimum descriptors to consider when classifying a cultivar: i) root cortex color (ii) root exterior color (iii) shape of the central lobe (iv) color of the petiole (v) stem cortex color (vi) root epidermis texture (vii) phyllotaxis length (ix) apical leaf pubescence (x) apical leaf color (xi), color of the root pulp (xii) stem external color and flowering (xiii) (IITA, 2012). Cassava has ability to grow in a poor environmental conditions with a low soil fertility, semi-arid land and acidic soil (Shin *et al.*, 2021)

Given the enormous cassava genotypes number grown commercially and the wide range of habitats where cassava grows, it is difficult to make an accurate morphological descriptors description because of the genotype by environmental factors interaction (Alfredo, 2002). As a result, morphological characterisation, and molecular characterization based primarily on DNA molecular makers have shown to be a valuable tool for assessing germplasm genetic variation. The fruit is a trilocular capsule with aristae or noticeable longitudinal ridges, six straight in shape of globular or ovoid with a diameter of 1 to 1.5 cm. A single carunculate seed is found in each locule. The fruit features dehiscence of a biocidal, a mix of loculicidal and septicidal dehiscences with openings parallel to the dissepiments and midveins of the carpels, respectively. The fruit opens into six valves as a result of this combination of dehiscences, creating an explosive dehiscence that ejects the seed at a certain distance. Subsequent to pollination, maturation of the fruit takes 75 to 90 days (Ghosh *et al*., 1988). The seed is ovoid-ellipsoiddal in shape, measuring roughly a length of 100 mm, 6 mm width and 4 mm thickness. The weight of each seed ranges from 95 – 136 milligrams (Ghosh *et al.,* 1988). The seed coat is smooth and dark brown with grey mottling. The seed normally grows quickly later than being collected, requiring about sixteen days.

Although cassava farming is done by vegetative propagation using stem cuttings but genetically bred using "seedlings" for purposes of commercialization or livelihood, and several accesses keep the mechanism of sexual propagation active (Vieira *et al.*, 2008). Starting from an evolutionary standpoint, keeping the system of sexual propagation active during crossbreeding allows for constant recombination of gene and gene combining of multiple origins in a single genotype, resulting in a higher species' ability to adapt to environmental changes (Duputié *et al.*, 2009). Nonetheless, vegetative reproduction provides quick adaptation to environmental conditions through the fixation of higher genetic traits within the segregating population. In this regard, pre-germination therapies have been effectively evaluated for increasing the germination rate of cassava seeds (Pujol *et al.*, 2002). However, while selecting treatments of pre-germination to enhance this characteristic, it's crucial to think about how quick it is to perform and how many seeds it may be applied to. Another essential element is that pre-germination seed treatment is used to regulate seedling development and emergence, as well as improve the seedling growth, in order to make hybrid evaluations easier within genetic development projects.

Cassava roots are long, tapering and tuberous with hard homogeneous wrapped in a removable rind that is rough and brown on the exterior and about 1 mm thick. Commercial variants range in size from diameter of 5 – 10 cm at the top and length of 15 – 30 cm along the root's axis, a woody cordon runs. The flesh might be in color of yellow or white. Cassava roots have a high starch content and are high 25 mg/100 g in vitamin, 50 mg/100 g in calcium, and 40 mg/100 g in phosphorus (Montagnac *et al.,* 2009; Burns *et al.,* 2012; Safwan and Mohammed, 2016; Islamiyat *et al.,* 2016). However, they are undersupplied in other nutrients and protein. The root's physical and agronomic properties, as well as its variability in cassava are listed in Table 2.1. Although, Nigeria is the global producer of cassava, yet her roots yield ranges from 8.0 – 12.5 tonnage per hectare which is lower than those obtained in Brazil and Asia countries (FAOSTAT, 2020; and Ekeleme, 2021)

Cassava roots (Plate 2.2) are the primary storage tissue. Like dicot species, plants produced from genuine seeds establish a typical primary tap root structure. A germinating seed radicle grows vertically downwards forming a taproot, that gives rise to adventitious roots. Afterwards, the tap root and a few stray roots

Table 2.1: Some Morphological Characteristics of Cassava Roots and their Variability

Root Characteristics	Variability
Morphological	
External Colour	White or Cream; Yellow, Light brown; Dark brown
Cortex Colour	White or cream; Yellow; Pink Purple
Pulp (Parenchyma) Colour	White; Cream, yellow; Pink
Epidermis texture	Smooth; Rugose
Peduncule	Sessile; Pedunculate; both
Constriction	None or Little; Medium; Many
Shape	Conical; Conical-cylindrical; cylindrical; Irregular
Agronomic	
No. Storage roots/plant	3 – 14
Weight of storage roots/plant	0.5 – 3.4 kg FW
Weight of one storage root	0.17 – 2.35 kg
Length of storage root	15 – 100 cm
Diameter of storage root	3 – 15 cm
Diameter of fibrous root	0.36 – 0.67 mm
Depth of fibrous root	Up to 260 cm
Amylose in root starch	13 – 21% FW
Protein in whole root	1.76 – 2.68% FW
Protein in pulp (parenchyma)	1.51 – 2.67% FW; 1.0 – 6.0% FW
Protein in peel	2.79 – 6.61% FW; 7.0 – 14.0% DW
DM in whole fresh root	23 – 43%
DM in peel	15 – 34%
DM in pulp	23 – 44%
Carbohydrates in whole root	85 – 91% DW
Carbohydrates in peel	60 – 83% DW
Carbohydrates in pulp (parenchyma)	88 – 93% DW
Starch in whole root	20 – 36% FW; 77% DW
Starch in peel	14 – 25% FW; 44 – 59% DW
Starch in pulp (parenchyma)	26 – 40% FW; 70 – 91% DW
Peel in whole root	11 – 20% FW
Crude fibre in whole root	3.8 – 7.3% DW
Crude fibre in peel	9.2 – 21% FW; 5.0 – 15.0% DW
Crude fibre in pulp (parenchyma)	2.9 – 5.2% FW; 3.0 – 5.0% DW
Total sugars	1.3 – 5.3% DW

(Source: Alfredo, 2002)

Plate 2.2: Different Varieties of Fresh Cassava Roots/Tubers

develop into store roots. The roots of plants developed from stem cuttings are adventitious, arising from the stake's basal cut surface and on rare occasions, from the buds under the earth (Carvalho *et al*., 2018). A fibrous root system develops from these roots. There are a few tuberous roots (3 to 10) that begin to bulk and develop into store roots. The majority of the other fibrous roots stay thin and continue to function in the absorption of nutrients and water. When a fibrous root transforms into a store root, its capacity to take in nutrients and water through absorption process is greatly reduced. The storage roots are the consequences of secondary growth of fibrous roots; as a result, thin roots penetrate the soil and their expansion occurs later when the penetration has started. The roots of cassava are real roots, not tuberous roots, and hence will not be utilized for vegetative multiplication (Carvalho *et al.*, 2009).

The well grown cassava root has 3 separate tissues: parenchyma, bark (periderm), and peel (or cortex). Cassava roots come in both white and yellow varieties (Plate 2.3). The edible section of the fresh root, which is parenchyma makes up about 85% of overall fresh weight. This is comprised of radially dispersed xylem vessels in form of matrix cells containing starch. The peel layer, which amounts to 11–20 percent of the weight of the root, is made up of sclerenchyma, and phloem, cortical parenchyma (Alfredo, 2002). The periderm which is the 3 % of the overall weight is a thin layer that sloughs off as growth progresses (Wheatley and Chuzel, 1993). By the use of somatic embryogenesis or shoots multiplication technique, cassava in-vitro propagation can be achieved (Ashebir, 2021).

Plate 2.3: White and Yellow Species of Cassava Roots/Tubers

2.2 General Economic Importance of Cassava

2.2.1 Health Benefits

Vitamin C and B, fat, iron, protein, starch and carbohydrate are all found in the cassava tubers and roots. While, iron, lipids, protein and calcium are found in the cassava leaves. The major plant health benefits are:

1. Cassava has fibers that are not soluble in water, making it good for the digestive system. It assists in the digestion of poisons that enter into your intestines. Therefore, it promotes the health of your digestive system and keeps it running smoothly (Temesgen *et al.,* 2020)
2. Cassava has an incredible effect of preventing cancer. Cassava helps in curing of cancer. The B17 presence in the leaves aids in enhancement of the red blood cell composition that is commonly lost in cancer (Bandigin, 2019).
3. Diarrhea: Cassava is used to treat illnesses like diarrhea. Cooking several pieces of cassava in water is an option. Allow it to cool to room temperature before using. To see a difference, drink this beverage twice a day (Dorota *et al*., 2014).
4. Cassava is rich in chemicals like bakarotennya and Vitamin A that serve to boost the health of your eyes and avoid loss or bad vision in the future.
5. Aid in the Treatment of Rheumatic Diseases: Rheumatic diseases are diseases that affect the joints and muscles. Osteoporosis, lupus, spondylitis, and arthritis are just a few instances. Leaves of cassava are high in magnesium nutrient. In actuality, consuming a magnesium-rich diet decreases blood pressure, which reduces the likelihood of developing rheumatic conditions later in future (Charles *et al.,* 2004).
6. Heal Injuries: Leaves of cassava are perfect at healing injuries and wounds. It comprises of a variety of nutrients which aid in rapid recovering of wounds. Leaves are crushed in a small quantity of gel of Aloe Vera to form a smooth paste that can be applied to the injury (Bandigin, 2019).
7. Getting Rid of Worms: Cassava leaves have been shown to help get rid of worms in studies. Cassava leaves have been demonstrated to prevent parasite infection in the gastrointestinal tract. Younger farm animals were given a consistent diet of fermentative rice and cassava leaf additions in a research. Fortification was found to significantly lessen the effects of worm invasion (Bandigin, 2019).
8. Enhances Hunger: Cassava has numerous advantages, and one is hunger revival. Cassava leaves can help you regain your appetite if you're not in the mood to eat.

To do so, make a cocktail of cassava leaves and garlic and sip it immediately after getting up early (Bandigin, 2019).

9. Stimulate Strength and Enhances Brain Development: Cassava flour has a high sugar content, which aids in energy production. Not only that, but adding cassava flour to your diets will help your brain improve its performance. Every meal has an average of 80% sugars, which is more than adequate for your essential requirements (Bandigin, 2019).
10. Decreases Pulse Rate: Some other fantastic effect of cassava starch is that it dilates blood vessels dramatically. Because it is full of nutrients, this is a plus. Cassava flour adds 8 grams to your diet per cup. This adds substantially to the necessary diets for adults on a daily basis (Trinidad *et al.*, 2013).
11. The peel of leaf and seed could be used as a body exfoliant to polish and lighten the skin (Bandigin, 2019).
12. Cassava also has the ability to moisturize your skin as it makes smooth and supple. You need to make a mask at home for this. Combine the roots of the cassava plant with several honey or almond oil. It can also be combined with a fruit. A few teaspoons of lemon juice would suffice (Bandigin, 2019).
13. Eliminates Scar Tissue and Spots: Starch based solution, when carefully applied all over the injured region twice per day and, could aid in the treatment of wounds and scars (Bandigin, 2019).
14. Helps Your Hair Grow Faster: Cassava is prescribed when you really have a slow hair growth. Its roots and leaves could be blended into a new mixture and administered to lubricate hair one hour prior rinsing (Bandigin, 2019).
15. Reduces Hair Fall: Cassava feeds, hydrates, and regulates hair fall from the roots to the tips (Bandigin, 2019).
16. Supplies Nutrition: Cassava crops are a nutrient powerhouse. Consider this plant if your hair is dry or brittled and let it assist you restore the loss.

2.2.2 Nutritional Values

Cassava's proximate content varies depending on the cell type (root or leaf) and a number of parameters, including particular region, variety, plant age, and weather circumstances. The nutritionally significant components of cassava are leaves (50%) and roots (6%) composition for the mature cassava plant (Tewe and Lutaladio, 2004). Cassava roots, which are the major component of the plant utilized in developing nations, have a high nutritional value. Cassava root is an extremely high-energy meal (Jose-Luis *et al.*, 2020). Cassava has a high yield of carbohydrates per acre in this aspect. It generates roughly 250,000 calories per hectare per day, placing it ahead of sorghum, wheat, rice, and maize. The tuber/root is a metabolic food reservoir with a complex carbohydrates composition that ranges between 32 and 35 percent fresh weight (FW) and 80% to 90 percent starch content (Julie *et al.*, 2009). Maltose, fructose, sucrose, and glucose are all present in modest amounts in the roots (Tewe and Lutaladio, 2004). Starch accounts for 80% of the carbohydrates generated (Gil and Buitrago, 2002), with eighty-three percent in the manner of amyl pectin while 17% mostly in kind of amylose (Rawel and Kroll, 2003).

Cassava is available in both bitter and sweet variants. In the latter forms, the roots have sucrose (17%) and little of quantity of fructose and dextrose. Based on a gram of 100, fresh root of cassava contains less carbohydrate than rice, sorghum and yellow maize and more carbohydrate than potatoes (Charles *et al.*, 2005). The amount of fiber in tubers varies depending on the age and variety of the roots. The amount in fresh root rarely exceeds 1.5 percent, and it rarely exceeds 4 percent in powdery form of the root (Gil and Buitrago, 2002). On a dry weight basis, the concentration of roots of cassava varies from 0.1 – 0.3%. If contrasted to grains, the composition is okay, however, equivalent to rice and higher than potato. With exception of soybeans, the manganese, magnesium, calcium, zinc, iron, copper, and potassium content of roots is equivalent to that of several legumes. Table 2.2 depicts the vitamin, mineral and proximate contents of normal roots of cassava.

The calcium level is comparatively higher ranging between mg/100g of 15 and 35 nutrient content when contrasted with other major crops. Ascorbic acid (vitamin C) levels in edible proportions are also high from 15 – 45 mg/100g. Riboflavin, B vitamins, niacin, and thiamine are in insufficient provision in

Table 2.2: Proximate, Vitamin, and Mineral Composition of Cassava Roots and Leaves.

Proximate Composition	**Raw Cassava (100g)**	**Cassava Roots**	**Cassava Leaves**
Food energy (kcal)	160	110 – 149	91
Food energy (KJ)	667	526 – 611	209 – 251
Moisture (g)	59.68	45.9 to 85.3	64.8 to 88.6
Dry Matter (g)	40.32	29.8 to 39.3	19 to 28.3
Protein (g)	1.36	0.3 to 3.5	1.0 to 1.0.0
Lipid (g)	1.36	0.03 to 0.5	0.2 to 2.9
Carbohydrate, total (g)	38.06	25.3 to 35.7	7 to 18.3
Dietary fibre (g)	1.8	0.1 to 3.7	0.5 to 10.0
Ashe (g)	0.62	0.4 to 1.7	
Vitamin	**RawCassava(100g)**	**Cassava Roots**	**Cassava Leaves**
Thiamin (mg)	0.087	0.03 to 0.28	0.06 to 0.31
Riboflavin (mg)	0.048	0.03 to 0.06	0.21 to 0.74
Niacin (mg)	0.854	0.6 to 1.09	1.3 to 2.8
Ascorbic Acid (mg)	20.6	14.9 to 50	60 to 370
Vitamin A (µg)	–	5.0 to 35.0	8300 to 11800
Minerals	**RawCassava(100g)**	**Cassava Roots**	**Cassava Leaves**
Calcium (mg)	16	19 to 176	34 to 708
Phosphorus, total (mg)	27	6 to 152	27 to 211
Ca/P	0.6	1.6 to 5.48	2.5
Iron (mg)	0.27	0.3 to 14.0	0.4 to 8.3
Potassium (%)	--	0.25 (0.72)	0.35 (1.23)
Magnesium (%)	--	0.03 (0.08)	0.12 (0.42)

Copper (ppm)	--	2.00 (6.00)	3.00 (12.0)
Zinc (ppm)	--	14.00 (41.00)	71.0 (249.0)
Sodium (ppm)		76.00 (213.00)	51.0 (177.0)
Manganese (ppm)	--	3.00 (10.00)	72.0 (252.0)

Source: United States Department of Agriculture (2009) cassava roots, and most of the nutrients are wasted upon preparation. Tubers always have lower vitamin content and mineral wheat, maize and sorghum (Gil and Buitrago, 2002). The peel from the roots has a higher concentration of fiber, minerals, protein, and fat than the peeled root. The carbohydrates in the stripped root (pulp or centre cylinder), as indicated by the extract of nitrogen free are much more enriched (Gil and Buitrago, 2002). Root size and form are influenced by a greater degree of diversity in size in a cultivar than in other tuber and root crops. Cassava roots, on the other hand, are less in protein however high in energy, fat, as well as some micronutrients. As a result, their nutrient composition is lower than grains, several other crops like cocoyam, and sweet poatato (Charles *et al.*, 2004).

2.3 Post-Harvest Physiological Deterioration of Cassava Roots/Tuber

Traditionally, by hand by raising the lower part of the stem and pulling the roots out of the ground, cassava is harvested. Before harvest, top layers of stems containing leaves are removed. Cassava is subjected to postharvest losses (PHL) also known as physiological deterioration (PPD) shortly after the roots are harvested out of the major plant (Awoyale *et al.,* 2020). During harvest, the roots that are wounded usually go through a deterioration process faster. However, in harvested tubers, the same reaction, which includes acids of coumaric, starts roughly 15 minutes after disruption and does not switch off (Sánchez *et al.*, 2010). Within 2 to 3 days after harvest, the whole root is oxidized and blackened, leaving it unpleasant and unusable. PPD is one of the most significant obstructions that affect the cassava value chain and thus, discourages the producers. Implementation of efficient and inexpensive technologies and instruments that reduce processing labor hours, as well as production losses, are among the post-harvest techniques and strategies.

Tuber or roots can be stored in a variety of means, including wax covering or placing in a temperature below zero degrees (freezing). Cassava that is resistant to PPD has been developed through breeding programs. Sánchez *et al.* (2010) discovered four distinct origins of PPD tolerance (Plate 2.4). One is Walker's Manihot (M. walkerae), which can be found in southern Texas and Tamaulipas, Mexico. A second source which putatively silenced one of the genes involved in PPD genesis was induced by mutagenic levels of gamma rays.

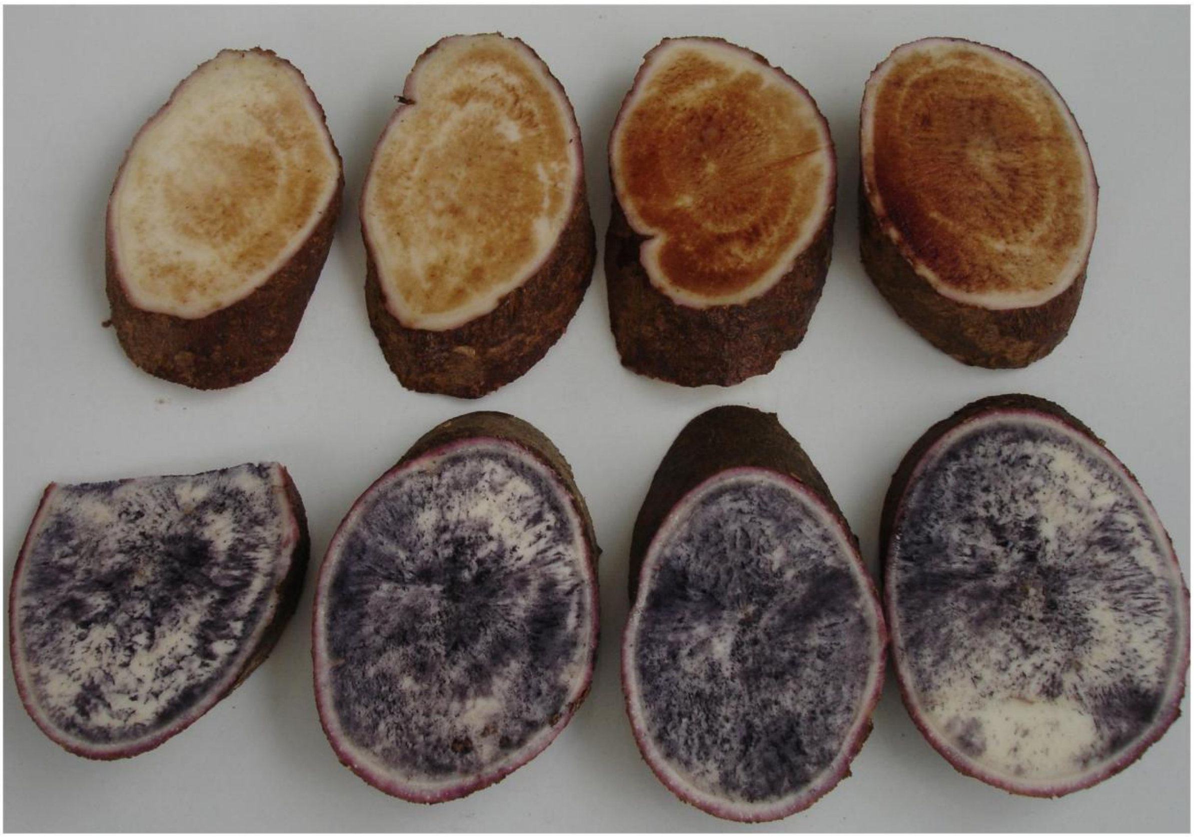

Plate 2.4: The General of Constraints of Cassava Production

(Sánchez *et al.*, 2010)

A high-carotene clones group was a third source. Carotenoids' antioxidant capabilities are intended to safeguard roots against PPD (basically an oxidative process) (Sánchez *et al.,* 2010). There are 2 kinds of postharvest degradations: primary physiological deterioration, which comprises interior discoloration and is the original reason of market rejection, while secondary deterioration which is as a result of microbial spoilage. In most cases, the interior discoloration is believed to be the result of injury when uprooting it out of the ground which manifests itself in vascular-tissue discoloration of blue-black known as vascular-streaking. One of the earliest signs is preceded by widespread darkening of the tissue containing starch.

Enzymatic processes tend to degrade the quality of the end-product immediately as the tubers are harvested, and throughout each of the subsequent phases of manufacture, it is critical to complete the entire process as quickly as possible in the processing of cassava starch (Andrew, 2002). This will necessitate a well-organized supply of tubers within a reasonable distance of the processing plant, as well as scheduling of processing stages to avoid production delays. Thus, the manufacturing of good-quality cassava flour is simple in principle, but requires a tremendous care. Tubers are usually picked up as soon as possible after harvesting and cannot be kept for more than two days (Onyenwoke and Simonyan, 2014).

2.4 Processing Techniques of Cassava Roots/Tubers

Cassava processing intends to minimize fresh tuber postharvest losses (PHL), eradicate cyanide composition, enhance the flavor of cassava products, and offer raw materials for small-scale cassava-based rural companies. Traditional cassava processing methods can be splited into three categories: (a) unfermented and fermented cassava chips and flour, (b) technologies based on fermented cassava dough, and (c) minor technologies (CTA, 1990). In Nigeria, processing of the cassava roots is minimal although the country is the major producer in Africa.

Cassava has a life span of 24 to 48 hours after harvesting, according to most sources (Tridge, 2021). Therefore, its processing is very important than in other root crop because of this rapid postharvest degradation. Cassava (*Manihot esculenta* C.) roots have a little life span because of postharvest physiological degradation (PPD) that occurs as an injury reaction soon after harvest (Reilly *et al*., 2004; Zainuddin *et al*., 2017; and Parmer *et al.*, 2017). Shortage of foods is minimized due to operation of processing as well as seasonal changes in crop availability are alleviated. Processing of cassava can alter the nutritional content of the cassava root by modifying and removing high-value elements. Despite fresh cassava root maintains a substantial amount of vitamin, it is heat sensitive and can easily be leached into water, so practically all procedures for processing have a negative impact on its composition (Onyenwoke and Simonyan, 2014).

Cassava roots cannot indeed be preserved for long periods of time since they decay within 48 hours after being harvested. They are big and hefty, with a moisture content of roughly 70%. Consequently, roots have to be prepared into a various products to extend its product shelflife, add market value, reduce cyanide content, and enhance tastelessness. PPD degrades the starch quantity and quality present in the roots, rendering them unsaleable or nonfood. PPD is a complicated practice with an unknown system (Blagbrough *et al*., 2010); nonetheless, it is known to entail enzymatic stress reactions to injuries and expression of genes. Moisture and starch loss can accompany PPD (Bayoumi *et al*., 2010; Mahmod and Beeching, 2018; Sánchez *et al.*, 2013). Nutritional value of cassava is improved by enhancing it with crops rich in protein (Hahn, 1994). Cassava roots are conventionally prepared into a variety of products (Figure 2.1) and used in a variety of ways, depending on local customs and tastes. Grating, pressing, drying, and milling, peeling, soaking or seeping, fermenting, crushing, roasting boiling, steaming, slicing, and grating are some of the production procedures.

2.4.1 Cassava Chips Processing

Cassava chips are unevenly dried chunks of root that are not more than length of 5 cm in different sizes. The chips are sliced products of tubers/roots that may be peeled or not but dried. Mostly, chips that are made from washed roots peeled are utilized by human being as well as livestock diets, and they usually last very

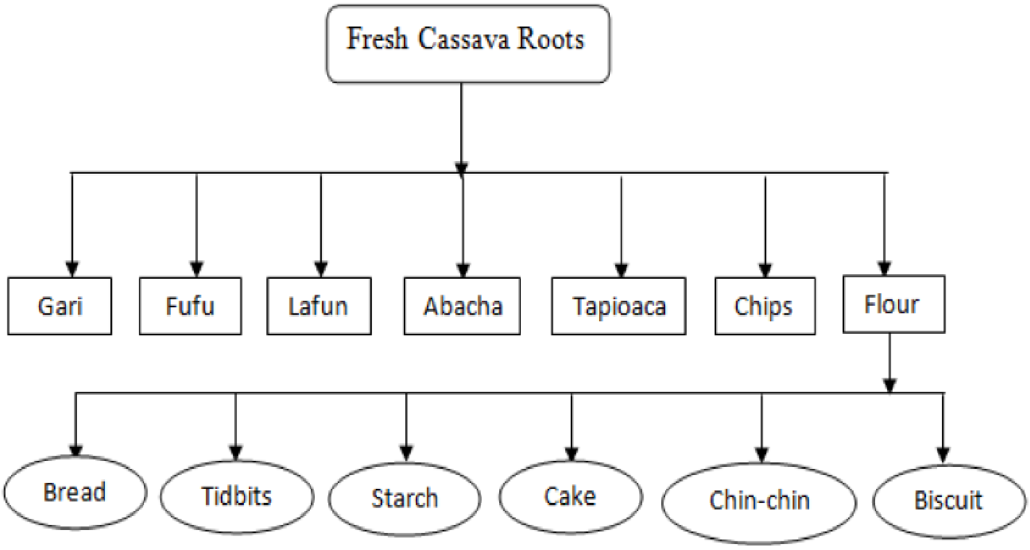

Fig 2.1: The Products Obtainable From Cassava Roots in Nigeria

longer compared to milled flour. The most ordinary form of the dried cassava tubers are sold is chip. They are produced in almost all exporting countries (CIAT, 2004). Peeling, cleaning, and slicing of tuber using machine or knife, followed by drying using oven and or sunlight, which is a traditional process of creating the dried product. Depending on the original starch composition and final wetness of the sliced tubers, rate of chips production of the tuber varies from 20 – 40% based on the original dry matter composition of the roots and the chips final wetness.

Chips from cassava in Nigeria are used to make livestock supply, and many livestock food producers were in continuous production before late 1990s, thus, roots climbed high to compete with maize. Cassava is currently not used as a raw material by any major livestock feed mill, but cassava chips or meal are locally accessible at reasonable rates by small companies and big factories which mix various feeds for their use. The livestock business in Nigeria is quickly growing, implying a consistent demand for animal feed. This trend is anticipated to continue for the rest of this decade due to the strong income elasticity of meat products. Cassava chips could be converted into cassava pellets, reducing transportation costs while also improving product quality. The best method for processing low-cyanogen cassava roots has long been known as cassava root chipping (Graffham *et al.*, 1999; Akinwande *et al*., 2013).

2.4.2 Cassava Flour Processing

In the unfermented cassava flour production, which is a good production technique for low cassava species cyanide content, the following processes occur; peeling and washing of the cassava tubers manually, then cutting of the peeled cassava into chunks, following the drying of the cassava chunks on any platform (either on the floor or high grounds/places) which usually occur between 2 to 5 days with regards to weather conditions. Lastly, the dried cassava is usually stored as chips in jute bags and marketed, or it is grounded for family use when needed. It's made from either pulverized dried chips or wet mash. Grated, crushed, or milled peeled cassava roots can be used to make mash (Figure 2.2 and 2.3) (Shittu *et al*., 2016). The cassava tubers are being cleaned, saturated in water in drums, pots, or natural ponds near cassava farms to make fermented cassava flour known as

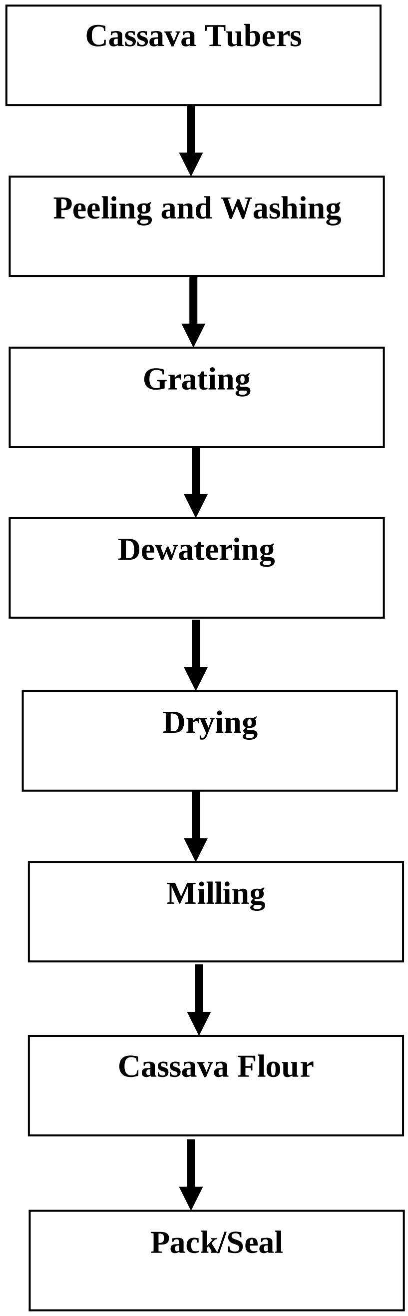

Fig. 2.2: Cassava Flour Production

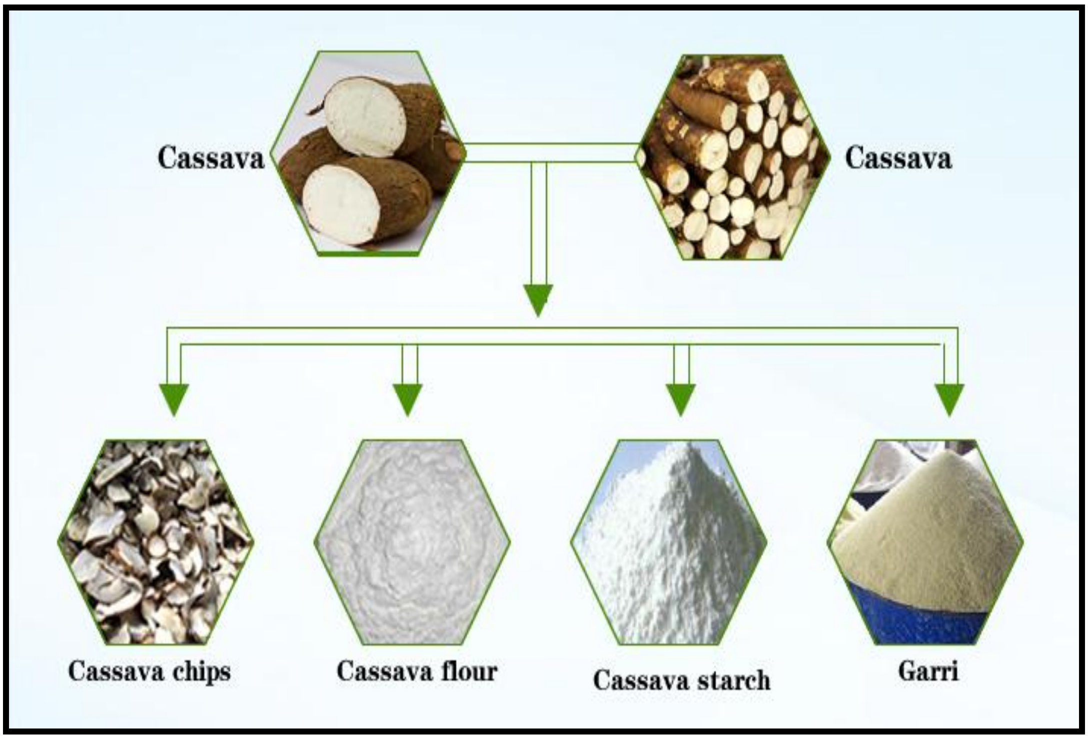

Fig. 2.3: The Primary Products of Cassava

"lafun," which is especially popular in Nigeria's south-western states of Ogun, Ondo, Oyo and Lagos. The fermentation process takes place at this point. Fermentation takes at least three days; the process takes longer in humid period than in the temperate period. The peeled cassava roots are, therefore, fermented. The peel slips off readily during fermentation due to partial dissolution of the cassava tubers. The tubers are then dried by being placed in sacks and covered with stones. The dried, pulverized mash is next dried under sun on mats, hard ground surfaces more commonly, on rocks (traditional methods) or pressed. Because the granite suck up heat in the day and releases it at night, drying the mash overnight has the advantage of enabling drying to continue. Based on the climatic condition, drying operation takes 1 to 3 days. Finally, the dehydrated mash is processed and preserved for both domestic and commercial use. In comparison to low cyanide variants, the goods are thought to have a better sensory quality (Chiwona-Karltun *et al*., 1995). According to a document by the Collaborative Study of Cassava in Africa, chip of cassava roots and flour manufacture added around 45% roots of cassava produced in the whole sub-Saharan Africa (Shittu *et al.*, 2016).

2.4.3 Fufu Processing

Fufu is a product made from cassava and fermented wet paste ranks next to gaari as a home-grown food in Southeastern part of Nigeria and Africa (Sanni *et al.,* 1998). Although, it is taken in different tribes of Africa, its unpleasant odour is disliked by some of the people. It is typically a wet, pasty meal that is manufactured and sold. The primary production for cassava fermentation for fufu processing is similar to that for gaari preparation, with the exception it's done underwater condition. Tubers are peeled, washed, and slice into sizeable piece before being immersed in water in pottery pots for 5 days at room temperature. It is then allow to undergo fermentation, where they are softened during this time, discharge CN (hydrogen cyanide) in soaking water, lowering pH levels, and contributing the retted cassava meal's distinctive flavor. The mash is sieved to get rid of the ligneous center strands using tiny baskets. The hard residues formed is crushed and shaped into little balls to drain the water. Consumers can get fufu in two forms: wet in small units wrapped in polypropylene bags, or plastic or cooked for eating. The pellets are cooked in water to make a smooth paste (Uzogara *et al*., 1990).

Fufu products were evaluated in two distinct fermentative procedures, and the results obtained were compared to the traditional meal. One approach involved grinding the tubers, fermenting/dewatering for a day, and then re-steeping for the next 2 days, and another way involved crushing or grinding roots, fermenting/ dewatering for a day, and then re-steeping for the next 2 days (Achi and Akomas, 2006). The most common microbes were Bacillus sp., yeasts and lactic acid bacteria. After 24 hours, the traditional product's microbiota was more diversified and had higher numbers. The initial count was 8.88 log cfu/g, however, after soaking and grating, the counts were 6.32 and 8.55, respectively. After 48 hours of fermentation, it climbed to 9.24 log cfu/g. In the conventional method, the pH dropped from 6.8 to 4.3, while in the modified process, it dropped from 6.6 to 4.2. The ascorbic acid content of the original product rised from 0.36 – 4.0 percent (w/w lactic acid), whereas the improved procedure improved from 0.24 – 1.0 percent. In comparison to 79.5 percent after the traditional fermented product, fermented mash lowered the cyanogenic glycosides concentration by 85.5 percent in 72 hours (Achi and Akomas, 2006).

The adjusted procedure has considerably higher odor and flavor ratings ($p<0.05$). Because of the processing techniques, there was no variation in texture or color. The grated cassava fermentation results in a product that is more palatable (Achi and Akomas, 2006). In certain states in Nigeria, fufu is also known as akpu or swallow. Animal feed is made from a fibrous by-product obtained during fufu manufacture, either dried or wet (Obadina *et al.*, 2008).

2.4.4 Abacha (Wet Cassava Chips) Processing

Abacha is a Nigerian dictator wet cassava chips also known as “Akpu-mmiri” in Igbo land, South-eastern part of Nigeria. The production procedures involved peeling and washing of the roots, then boiling with steam for 1 hour. Afterwards, it is then sliced into horizontal shapes or sizes to make abacha. Then, it is steeped in water for 24 – 48 hours, inside water changing 1 or 2 throughout that time. It is withdrawn from the fermentation and rinsed 2 or 3 periods in quality water before being consumed (Iwuoha and Eke, 1996; Sandeep and Ramesh, 2016).

2.4.5 Lafun Processing

This is a smooth granular product from the roots produced by fermentation, often eaten in Nigeria's south-western region. The conventional way of preparing lafun from cassava eliminates dangerous cyanogenic chemicals and gives the product a distinct odor (Cereda and Mattos, 1996). For 3 – 4 days, the peeled or unpeeled tubers are deeped in stationary water, stream, or a pottery pot and fermented until mushy. The pulp is broken down into minute bit and dried on the sun on house roofs, racks, and mats once the fermented roots are removed. The flour is made from dried crumbs. The flour is gradually introduced to the heated water, stirring constantly until a smooth, thick dough is produced. After cooling to around 350°C, the dough is eaten with soup (Uzogara *et al*., 1990).

Leuconostoc, Bacillus, Klebsiella, Corynebacterium, Lactobacillus and Candida are among the microorganisms involved in the lafun production (Treche and Massamba, 1995). According to Padonou *et al.* (2009) who took a research to evaluate the quality of 2 varieties of lafun food products producrd in Nigeria and Benin (ordinary lafun and Chigan lafun). Chigan lafun (which is preferred type) was distinguished by its reduced fibre content and solubility as well as its greater hot paste viscosities, as compared to conventional lafun. Both forms, Chigan lafun and regular lafun were indeed a dried, white substances with a pH of 4.5 – 8.8, high in carbs (76.0 percent starch and 3.3 percent crude fiber), low in protein (1.0 percent), and fat (0.4 percent) and ash content (1.2 percent).The sample composition are ash content and fat with 1.2% and 0.4% proportions corespondingly. Both types of lafun flour had a swelling potential of 28.9 g water/g (measured as the amount of water absorbed by 1 g of flour). Molds such as Rhizopus spp, Fusarium spp, Aspergillus spp, and Mucor spp have been found to form in lafun after many days of exposure to ambient settings (Obadina *et al.*, 2009).

2.4.6 Cassava Bread Processing

Bread is made with cassava because wheat is an overseas item, cassava flour is used instead of wheat flour to make bread in Western Nigeria and Southeast Africa. In African countries, flour made from cassava composite is used in the production of baking foods. The Nigerian government recently ordered flour companies to incorporate cassava flour (HQCF) into the conventional wheat flour with a standard of 10% quality when baking (Shittu *et al.*, 2008). In a full factorial design, the impacts of several cassavas processed (whether roasted, fermented or sun-dried) on wheat-maize-cassava composite bread quality ranging from 20 – 40% (w/w) cassava flour levels which were investigated in addition to high pectin introduced at levels of 1 – 3% (w/w). When roasted cassava was contrasted to fermented cassava and sun-dried, the volume is larger with bread containing cassava flour. The amount of pectin in the bread had a substantial impact on the volume of the high-level roasted cassava bread. The roasted cassava flours and Sun-dried produced crumb hardness comparable to wheat bread. The bread with a color close to wheat flour was roasted cassava bread (Eduardo *et al*., 2013). Figure 2.4 depicts the steps involved in making cassava bread.

2.4.7 Fermented Starch Processing

Thailand is the highest producer of starch with a capacity of 2 million tons of production per year, followed by Brazil, Nigeria and Indonesia respectively (Tridge, 2021). Brazil consumes roughly 50, 000 tonnes of fermented cassava starch (polvilhoazedo) and carbohydrate foods (biscuits, "cheese" bread, etc.) annually. Starch is a historical Latin American manufactured goods made from the moist starch being taken from tuber of cassava (Cereda and Vilpoux, 2006). It is particularly popular in Columbia and Brazil. Starch is obtained by peeling, washing and grinding the tubers, saturating the wet substance with water to isolate the starch particles from the fibers and soluble constituents (Figure 2.5). The starch is collected and sun-dried after a fermentation period of 20 to 70 days. In Brazil, there is request for starch flour for fried foods, typical breads, baked products and cheese (Lacerda *et al*., 2005). Podequeijo, a bread comprised of cheese, and eggs, sweet and sour cassava starches, is the most acceptable cassava-based fast food in Latin America's southern, central, and western areas, and it is devoured by each and every family. Traditionally, in Colombia, gluten-free cheese breads called pan de bono and pan de yucca are made from sour starch (Sandeep and Ramesh, 2016). Sweeteners such as glucose, sorbitol, and high fructose syrup (HFS), can be made with cassava starch and HQCF as a basic material. Cassava starch, or wet cake or flour are hydrolyzed to produce sugar (glucose) that subsequently refined to generate HFS for sorbitol production.

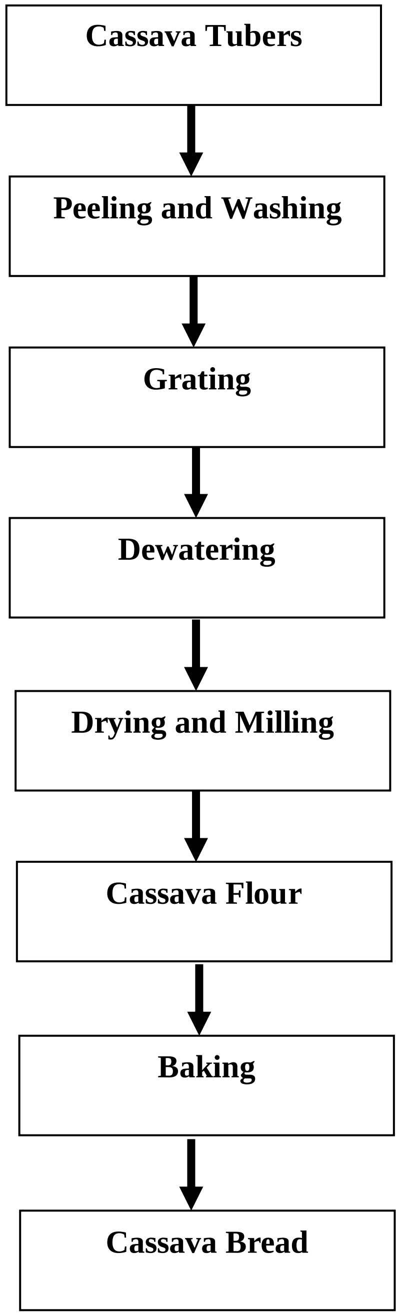

Fig. 2.4: Cassava Bread Production Process

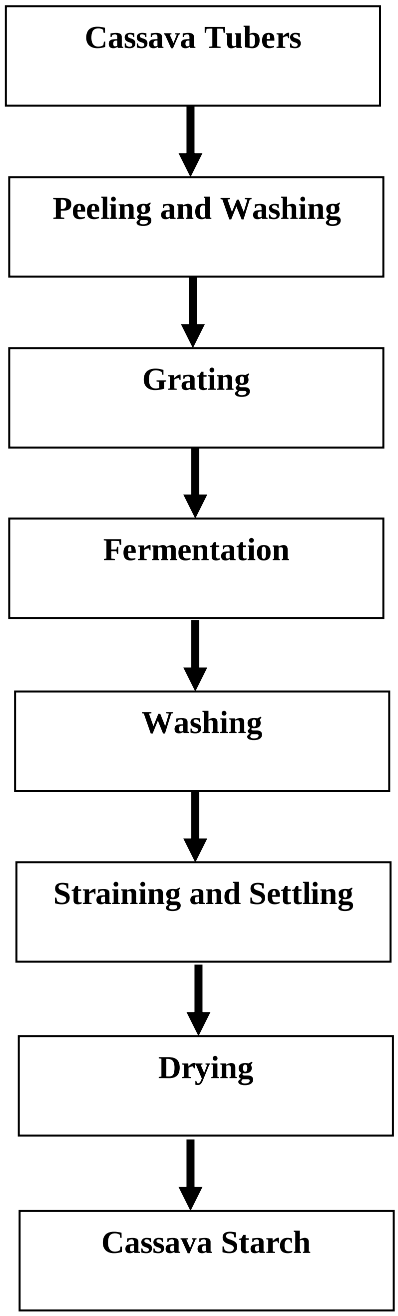

Fig.2.5: Production of Cassava Starch

Glucose containing 900 kilograms, 1.1 ton of sorbitol (seventy percent clarity) and 550 tons of HFS (fifty-five percent clarity), are produced from a ton of sour-Starch (Cassava Master Plan, 2006). In Nigeria, soft drink and juice industries require HFS of one hundred and fifty thousand metric tons in a partial alternative for international sugar, glucose of forty thousand metric tons per year, and sorbitol of fourteen thousand per year according to FAO (2011). Industry of starch is like a burgeoning industry which is assumed to expand by more than 50% in the 10 years to come. The Cassava processor supplying Guinness with starch sweeteners presently working is Ekha Agro Nigeria Limited (FAO, 2011).

2.4.8 Cassava Peels for Processing Livestock Feed (Pellets)

In African and Asian countries, cassava has been widely used for livestock feeds, starch production and other processed foods (Shin *et al.*, 2021). Linear programming was used to replace maize with cassava in animal feed, resulting in a 10% reduction in chicken foods prices or a 20% reduction in swine foods costs. Because the livestock industry in Nigerian consumes up to 1.2 tons of maize per year, replacing 10% percent that amount with tuber might well necessitate the construction of at least 200 cassava chip processing plants capable of handling up to 10 tons of cassava tuber each day. Pellets could be made from either cassava flour or chips. Figure 2.6 depicts the pellets manufacturing process. B & T Ventures, Ibadan, a Nigerian firm, has designed and built a pelleting technology that can manufacture pellets in partnership with the cassava project at IITA. Hard pellets are used to feed poultry, while the soft pellets are used to feed ruminants, and the floating pellets are used to feed fish. The technology, however, is currently undergoing research and development but not like those pelleting machines bought from abroad. Despite the fact that tuber food has been successfully fed to foul and livestock as a main energy source (Saparattananan *et al.*, 2005), more demand for its industrial uses such as flour and starch production and crop for food will minimize its availability for chicken feeding at an affordable price in future (Diarra, 2015).

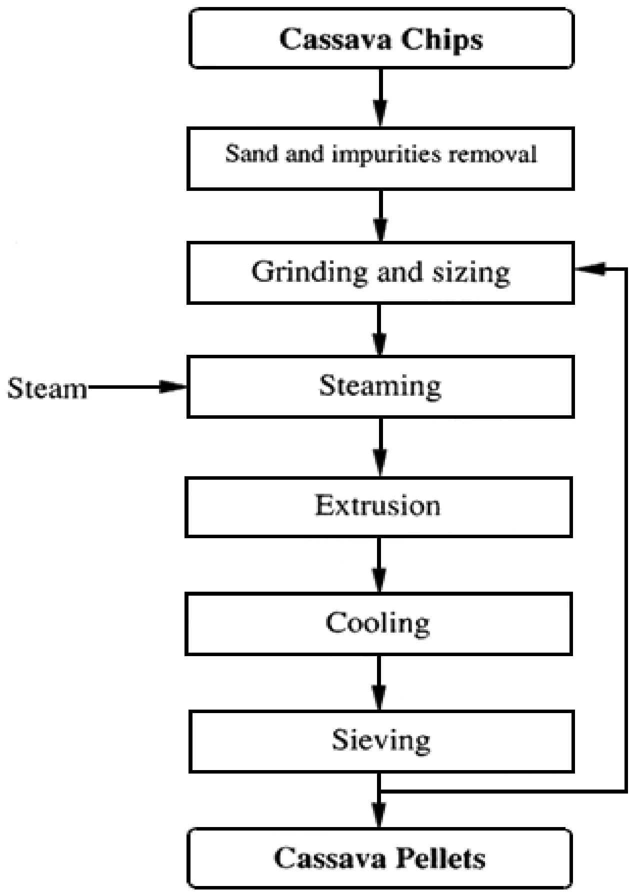

Fig 2.6: Cassava Pellets Production

2.4.9 High Quality Gaari Processing

Gaari is the most acceptable fermented dish being produced cassava roots with about 200 million populace in Africa countries eating it (Okafor and Ejiofor, 1990) such as Nigeria, Ghana, Benin and Togo. Gaari is commonly eaten as a main course in the manner of thin porridge or a dough. Both are made in the home by combining dry gaari with cold or hot water and boiling, then serving with soup or stew. Gaari can also be served as junk food when blended with milk, sugar and cold water (Awoyale *et al.*, 2020). When mixed with cold water, it expands 3 to 4 times its original size. Gaari is the fine or coarse particles flour produced from cassava tuber. It is a perfect illustration of solid state fermentation (SSF) fermented food (Akinwande *et al*., 2013). Gaari will remain dominant to the cassava sector in the short term, with a portion above seventy percent for all the total tubers/roots collected (Figure 2.7). Gaari's annual growth rate has been estimated to be between 4 and 6 percent, owing to population increase and urbanization, as well as export to the regional West African market (Ekwu and Ehirim, 2008). While the gaari from the roots samples contains identical protein, carbohydrate, and calorie levels, the gaari from chips had a lower cyanide composition (Ekwu and Ehirim, 2008). It already supports over 5,000,000 cultivators and producers in Nigeria (many of whom are village women), and a plethora of technology producers, both retail and wholesale dealers, as well as transportation companies. Furthermore, retail gaari production is fast becoming a principal means of business in several nations. Gaari of good sensory quality and acceptable chemical and might be made from chips fortified with fermented mixture, according to research (Oluwole *et al.*, 2004).

2.5 Storage Techniques for Cassava Products

2.5.1 Cassava Roots Storing Methods

Food processing requires the preservation of agricultural raw materials to ensure available food within and out of shortage. To avoid root perishability, traditional marketing and storage procedures have been modified (Aristizabal and Sánchez, 2007). Preparation close to the processing industries assures a regular access to raw materials, and handling into durable food substance (by fermentation or dried under the sun). Prevalent practice of exchanging small

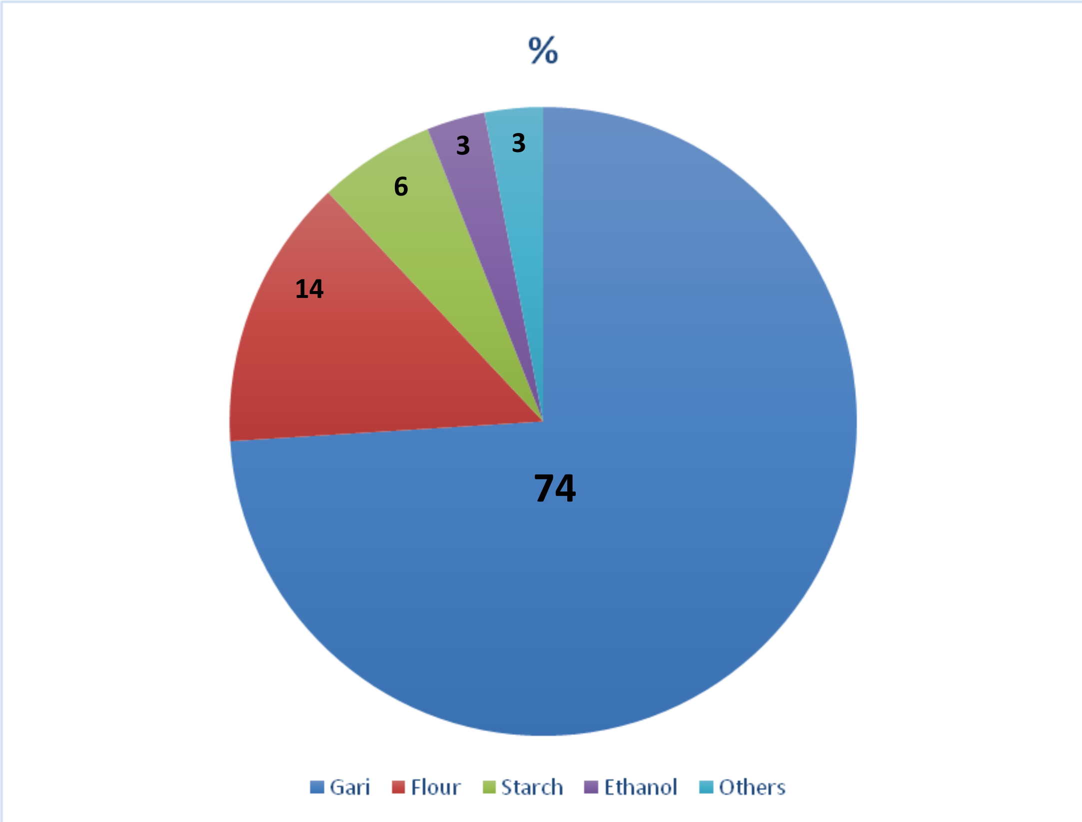

Fig. 2.7: Proportion of Different Commodities Produced from Cassava Roots by SME

quantities of roots are examples of these adaptations (Andrew, 2002). Leaving the tubers without being harvested till they can be marketed or utilized is a frequent approach to reduce root losses due to PPD. Tubers have been observed to endure up to 3 years in soil. This approach has drawbacks because the standing crop takes up a lot of land that could otherwise be used for agriculture. Furthermore, if the roots are maintained more than the suggested period of harvest 10 to 12, thereafter, they grow or advance in fibrous and woody nature, which reduces the dry matter content and lengthens boiling period. Another negative impact of prolonged cassava root storage in the field is increased vulnerability to disease infection as well as a decrease in recoverable sweetener (Ravi *et al.*, 1996). The roots of cassava cannot be preserved for long periods of time since they decay within 24 to 48 hours following harvesting. Because the tubers are large and contain roughly 70% moisture, transporting them to metropolitan markets is complex and costly.

The moisture content of the products, as well as the relative humidity temperature of the prevailing environment, all contribute a role in proper storage. Gaari has a moisture content of 12.7 percent for safe storage and if the relative humidity and temperature exceed 70% and 27°C, respectively it spoils (Osunde and Fadeyibi, 2011). The kind of packaging adopted has an impact on shelf life, as it depends on the material's ability to retain storable moisture content levels (Onyenwoke and simonyan, 2014). Over the last two decades, some advancements have been made in preservating technologies that can increase the shelflife of roots of cassava in less than 2 weeks. These benefits include the ability to market the crop more effectively and the ability to store fresh cassava stocks at a processing factory for a longer period of time, even if only for a few days. Alternative storage approaches to standard reburial procedures were investigated in CIAT.

Storage options include pits, field clamps, and wet sawdust-filled boxes. All of the storage strategies studied favored remedial setting in a high humidity and temperature atmosphere to lower the effect of microbiological deterioration and physiological (Osunde and Fadeyibi, 2011). They all, nevertheless, necessitate meticulous root harvesting and selection prior to storage, as mending is useless if the roots have significant root damage (Crentsil *et al.*, 1995). Starting with a layer of sawdust and finishing with a layer of sawdust, cassava roots are stored in boxes packed with damp sawdust or wood shavings. Any form of acceptable material apart from wood shavings might be adopted instead of sawdust. The packaging material, on the other hand, must be damped but not wet.

When the material was too dry, it deteriorated physiologically, and when it was too wet, it increased microbiological degradation. This storage strategy was explored in Uganda in conjunction with the use of polyethylene to line the box (Nahdy and Odong, 1995). According to the study, 75 percent of the roots stayed healthy after 4 weeks in storage if they were packed shortly after harvest. Only half of the roots were deemed satisfactory after a one-day wait. This strategy has been employed for some international markets, but due of the higher transportation costs associated with the use of box vessels, it has not been used for domestic markets (Osunde and Fadeyibi, 2011). The most economical and effective technique of storing or keeping tubers for city markets appears to be in plastic film wraps or plastic bags. Several findings showed tubers treated with sufficient chemicals and stored in a plastic film wrap or in closed plastic bag may be saved for 2 to 3 weeks. For the preservation of fresh cassava, chemical treatments, deep freezing, a controlled atmosphere, refrigeration, and waxing were all mentioned as sophisticated technologies (Osunde and Fadeyibi, 2011). In Europe and America, waxing and freezing have primarily been utilized for international markets where buyers of Latin American and African descent are willing to pay a premium. Such approaches necessitate devices and abilities, as well as a significant investment in finance (Crentsil *et al*., 1995).

Following fungicide treatment at a temperature of 55 – 65°C for less a minute by immersing cassava roots in paraffin wax is a more prevalent current method of reducing PPD. The addition of wax can improve the storage life of tuber upto two months, according to Ravi *et al.* (1996). Roots of cassava can be stored at 0 to 4 degrees Celsius for two weeks without deterioration. Although 3°C is the optimal temperature for preserving fresh roots, microbial infection develops after a month and rises with storage time. The segment of the root that hasn't rotted is usually in good shape and appropriate for human consumption following 6.5 storage periods at 0 to 4°C (Aristizabal and Sánchez, 2007; Oirschot *et al*., 2000). PPD symptoms occur quickly in tubers at temperature above 4 ^{o}C and must be removed after 14 days of preservation (Ravi *et al*., 1996). Typically, portions of tuber may be frezeed in polyethylene bags in extreme circumstances, and the roots, despite some sponginess, are quite tasty after thawing and could be stored for another 4 days. Puerto Rico, Colombia, Brazil and Costa Rica in Latin American countries, have commercialized this technology (Ravi *et al*., 1996).

2.5.2 Gaari Product Preservation Methods

The ultimate goal of any food preservation technique is to inhibit the biochemical reactions of the food substance by restricting or resisting the entry of pathogens (bacteria and fungi) which further improves and extends the shelf life of the product (Adithya *et al.,* 2020). Gaari should not be stored for more than 3 months, based on microbiological and sensory considerations. Proper packaging items should be used for storage. A research concluded that there are three kinds of packaging materials tested, namely: polypropylene, polyester and hessian. Polypropylene and polyester are the most microbiologically and sensorially suitable, but bags of hessian are not (Adejumo and Raji, 2012). Based on the ingredients and length of fermentation added to gaari, it is classified into different types; white, red and Ijebu. Palm oil is frequently used in the frying (roasting) process in the Eastern part of Nigeria. The inclusion of palm oil minimizes burning during gaari frying while also changing the color of the result to a yellowish hue (Jekayinfa and Olajide, 2007).

Yeasts species such as Saccharomyces cerevisiae, and lactic acid bacteria like Lactobacillus, and Streptococcus) likewise the other bacteria (Alcaligenes and Corynebacterium) are all involved in fermentation of cassava to gaari (Akingbala *et al.,* 2005). Lacto bacillus plantarum provided the most typical gaari flavor and acidity among the microbes identified from fermenting cassava, according to studies, thus increasing its sweetness (Ngaba and Lee, 1979). Gaari is a pre-cooked meal product with a good flavor that urban African consumers love (Jekayinfa and Olajide, 2007). The protein composition of gaari was enhanced by 7.3 percent and 6.3 percent, respectively, when cassava was fermented with Saccharomyces cerevisae and Aspergillus niger (Oboh and Akindahunsi, 2003). Extracellular enzymes were secreted into the mash of cassava to allow starch to be used as a carbohydrate source, which increased protein concentration. The rise in fermented cassava products protein content can potentially be explained by the growth of fungus in the cassava in the production of discrete proteins (Akindahunsi *et al.*, 1999). The length of time that gaari is fermented has an impact on the result quality. In the animal model (weaning rats), the highest protein efficiency ratio (0.22) was found in rats fed a control diet (corn starch), whereas the lowest was found in rats fed a 24 hour fermented product diet (0.15). The presence of a high quantity of cyanogenic glucoside intermediates – cynohydrin, quickly interacts with glucosidase in the stomach and causes a wide range of biological effects which could be linked to the rats' inferior performance on the 24 hour fermented diet. As a result, fermenting gaari for longer than 24 hours makes it safe to eat (Owuamanam *et al*., 2010).

2.6 Garri Processing Technologies and Operations

2.6.1 Peeling and Washing Machine

To remove the uneatable exterior sections of the root, such as the corky periderm and cortex, cassava must be peeled. They contain the majority of the poisonous cyanogenic glucosides, with a glucocide-to-starchy-flesh ratio of 5 to 10:1. As a result, peeling removes 83 percent of the whole cyanide in a 15 percent peel root with a cyanide concentration of 950 mg/kg (fresh wb) and 35 mg/kg in the fresh (Bencini, 1991). Peeling process is frequently done by hand using a kitchen knife at the domestic stage. The peel is cut along the length side of the root in simple kinds. The knife or blade and fingers are being used to roll back the layers from the fleshy part of the root. The two layers of peel are cut with a knife in a manner similar to sharpening a pencil in more difficult varieties to peel. This procedure is less acceptable because it usually involves some flesh removal as well as the peels with some peels remaining on the root (Oluwole and Adio, 2013).

Hand peeling takes longer and requires more effort, but it produces the greatest results. One person can produce roughly the peeled roots of 25 kg per hour, with a 25 - 30% weight loss peels (Bruinsma *et al.*, 1983). Several efforts to improve the peeling process by employing simple machinery or chemical treatment have been undertaken, however, most have been considered to be unsuccessful and wasteful. Abrasive or cutting mechanisms are used to peel the skin. These designs have been claimed to exhibit peeling efficiencies of 75–97% (Plate 2.5a–2.5b) (Ozigbo *et al*., 2020).

Plate 2.5a: Peeling and Washing Machine: Sharving Technique

(Ozigbo *et al.*, 2020)

Plate 2.5b: Peeling and Washing Machine: Abrasive Method

(Ozigbo *et al.*, 2020)

2.6.2 Grating Machine

Traditionally, grating is done by hand, however, electrically operated grating machine with variety of designs are becoming more popular.

1. Traditional Method

Manual grating or Hand method is typically regarded as the most time-consuming and difficult part of the technique. When queried about the challenges with gaari processing, the ladies who still grate the cassava by hand merely reveal their palms. Ozigbo *et al.* (2020) estimate that it takes 10 to 15 men days to traditionally grate 1 tonnage of fresh peeled roots.

Cassava roots are typically grated at least one hour after being cleaned to allow surplus water to draw off the peeled and washed roots; so that the roots will not be too difficult and slippery to handle while grating. A galvanized or stainless metal sheet or a flattened can or tin with a raised jagged flange on the bottom perforated with roughly 3mm diameter nails is commonly used as a hand grater. The peeled cassava roots are pressed against the jagged side of the metal as they get rubbed vigorously on this grating surface, which is mounted on a wooden frame, with strong downward movements (Oyesola, 1981). Accidents do happen, despite the fact that caution and certain expertise are required not to grate the fingers as well. When the grating surface is supported against the operators legs, the rubbing action can be improved by positioning it on a hardwood table at a sensible height rather than in a downward slant. Because thoroughly grating a cassava piece is impractical, cassava 3 to 5% must be left un-grated (Flach, 1990; Bencini, 1991). Only about 20 kg can be produced each hour by a qualified worker. In 1990, hand graters were offered for $2 to $3 each in the local market places of Cameroon's north-west province (Flach, 1990).

2. Mechanized Grating Method

A processors group may buy their own mechanically powered grating machine. Also, a private service provider may grate cassava for a fee within a group of villages. There are two varieties that are widely used: 1) hammer mills with abrasive discs; 2) graters with an abrasive disc. The surface of the abrasive disc is usually a galvanized or stainless metal sheet with nail-punched holes like in the hand type, and fastened to a wooden frame (Ozigbo *et al.,* 2020). The grating layer is supposed to wear out after six months of constant usage and must be repaired, otherwise the machine's production will be drastically reduced. Another problem of this basic grating layer is how difficult it is to clean after use. Debris are caught in the holes and torn flanges, providing a breeding ground for the growth of microbes and the potential for grated cassava contamination, which could disrupt the fermentation process. A machine for grating cassava was designed with two methods of operation. It can be manually or electrically powered (Ndaliman, 2006b; Adejumo, 1995).

Local institutions invented several of the simple graters currently in use., A cassava grater was built in the early 1970s in Nigeria by the Intermediate Technology Development Group's (ITDG) using inexpensive workshop spare components and hacksaw blades installed on a vertical disc. It happened while someone was peddling. The vertical disc grater was created, and it was peddled by humans. The "Wadwha" disc grater is made of a disc shaped hardwood block with a perforated metal sheet affixed to it, and it was invented in Ghana. With a stated throughput of one tonne of cassava, the disc was driven by a diesel engine of 5 hp capacity. Another vertical drum grater was developed by Sierra Leone's Tikonko Agricultural Extension Centre.

A sheet of perforated metal covered the drum's exterior surface, and a wooden block crushed the cassava against the grating surface as it revolved. A diesel engine or 4 horsepower electric motor powered the drum. The capacity ranges from 300 kg to 1000 kg/hr in general (Bencini, 1991). Majority of the cylindrical power graters used in communities in Cameroon are modeled on the CENEEMA design, which has certain distinctive design elements aimed at improving grating productivity and effectiveness without particularly increasing power consumption. However, there are several differences in design, voltage regulation, performance efficiency, power drive and structural systems (Plate 2.6a – 2.6c).

Plate 2.6a: New Modern Electrical Grating Machine

(Ozigbo *et al.*, 2020).

Plate 2.6b: Electrical Grating Machine

(Ozigbo *et al.*, 2020)

Plate 2.6c: Motorized Grating Machine

(Source: IITA Archives, 2005)

2.6.3 Fermentation and Dewatering Machine

1. Traditional Method

Fermentation and dewatering (pressing) can be performed in one operation in conventional processes. The grated mash is fermented for 1 to 4 days in perforated plastic sacks, jute bags, or baskets. The color, flavor, and texture of the gaari are affected by the length of the activity. Seeding the freshly grated mash with already fermented liquor as a starter can shorten this time if it can be completely blended. Okolie and Ugochukwu (1988) investigated the activity of proteolytic enzymes isolated in Citrobacter freundii in cassava fermentation. Fermentation occurs in 2 stages. Corynebacterium first hydrolyzes the starch in the roots to produce sugars. The sugars are converted to organic acids that hydrolyze the cassava's cyanogenic glucosides and produce HCN. When enough acid has been produced, the second stage, which is characterized by the growth of Geotrichum candida, begins. The mold develops the aldehydes and esters which then provide gaari its distinctive flavor from the sugars (Bruisma *et al*., 1983). Some organic acid and soluble cyanide are eliminated with the press fluid during dewatering. It also contains some forms of starch, and can be used as a basis for soups and stews or the starch can be extracted by letting the liquor to set and then decanting the liquid.

In most of the traditioanl fermentation, the jar is piled with big stones, the necks of the bags are forcefully twisted, and the sack is pressed between wooden poles tightened by ropes (see Plate 2.7a). It has also been discovered that microorganisms play a crucial role in cassava root fermentation in both procedures. The protein concentration of fungi-fermented CFs has been observed to be higher (Akindahunsi *et al.,* 1999; Oboh and Akindahunsi, 2003). However, rats fed Saccharomyces cerevisae fermented CF showed signs of hepatotoxicity and cardiotoxicity (Oboh and Akindahunsi, 2005).

2. Improved Commercial Methods

Pressing (De-watering) are done after fermentation in bigger scale facilities. In its container, the sample of mash is allowed to undergo fermentation for 1 to 4 days. Pressing is accomplished with one of several screw or hydraulic presses, each of which requires access to a simple workshop to create. A parallel board press was invented by Ghana's Technology Consultancy Centre, in which a

Plate 2.7a: Traditional Fermentation and Pressing Method

(Picture Accessed Online, 2018)

Pulp filled sack is inserted between 2 parallel boards that are screwed together to give pressure to the sack. This concept was expanded to include a screw press that could hold many sacks. However, its production necessitates the use of heavy metal components (Plate 2.7b–2.7d). Some experts believe it takes 20 to 30 mins for the mash to accomplish desired moisture content of 45 to 50 percent (Flach, 1990; Bencini, 1991), while others believe it takes longer in larger dewatering equipment (Flach, 1990; Bencini, 1991), but many researchers recommended that in the bigger dewatering equipment, it might take 3 – 4hrs (Bencini, 1991)

2.6.4 Sifting Machine

To accomplish a homogenous result, the dewatered cassava mash produces hard cake that must be pulverised and sifted to eliminate large volume of lumps formed and fiber (from the central vascular strands). It's vital to have homogeneous mixture in that it allows more even frying of individual mash particles throughout the frying process, with fine particles taking less energy and time to fry (Adetunji and Osunlana, 2011).

Sieving is traditionally done by hand with palm leaves, bamboo, or raffia cane sieves is a lobour intensive operation. In comparison to some of the other gaari processing activities, the sieving operation is not particularly complicated or time-consuming. However, mechanization, in all of its forms, guarantees that production is simple and quick. It makes cassava crop easier to process (lower drudgery in production), thereby promoting the hygienic state of cassava production with a short processing time (Ajao and Adegun, 2011; Adetunji and Quadri, 2011). Today, mechanical sieves are used in even small commercial enterprises to boost production process. Sifters are double screen trays or single that swings due to an eccentric cam driven by an electric motor or a power source from the petrol engine of small capacity. The machine's sieving efficiency ranged from 92.5 percent to 99.14 percent according to the results of the performance evaluation test (Adetunji *et al*., 2013). Plate 2.8a – 2.8b shows the mechanical and manual sieving methods.

Plate 2.7b: Hydraulic Jack Press Method

(Picture Taken in IITA, 2018)

Plate 2.7c: Hydraulic-Pneumatic Press Method

(Picture Taken in IITA, 2018)

Plate 2.7d: Electrical Hydraulic Press Method

(Picture Taken in IITA, 2018)

Plate 2.8a: Electrical Sieving Machine
(Ozigbo *et al.*, 2020)

Plate 2.8b: Traditional Sieving Method

(Ozigbo *et al.*, 2020)

2.6.5 Frying/Roasting Machine

Gaarification is the gaari frying process of cooking and drying gaari at the same time. The gaari is dehydrated after it has been cooked with liquid. The amount of heat used while frying has an impact on the product's output and quality. According to lgbeka, (1995) as described by Samuel and Adetifa (2012), the moisture level of pressed and sieved cassava mash is between 50 and 65 percent, which need to be decreased to about 12 percent during frying. To stop the creation of several seed lumps or caking in the classic frying method, the initial temperature during frying is kept low. When the temperature rises, the moisture content decreases, and the little lumps that formed could be eliminated by repeated agitation and pressing against the frying surface of the fryer. An increase in the amount of heat applied to the drying surface enables it to cook, dehydrating the product (Odigboh and Ahmed, 1984). The starch gelatinization of the particles and drying processes were noticed during the frying procedure. Igbeka (1995) also mentioned discomforts caused by heat and the operator's seating posture. He estimated the process's fuel efficiency to be less than 10%. The task subjects the operator to heat, smoke, and cyanide flumes.

In many African nations, gaari is the most carbohydrate dish. Gaari is progressively acquiring a footing in the international culinary market due to its convenience and versatility of application. The main producers, consumers, and exporters of gaari appear to be Ghana and Nigeria. Gaari exports in Ghana increased by 23.2 percent per year between 2001 and 2007. Gaari is made from nearly 75% of the cassava produced in Nigeria (Abass *et al.*, 2012)

Harvested tubers are peeled, rinsed, and crushed before being placed in coarsely knitted bags. To release part of the fluid, a hefty item is put on the jute sack. The components of the sack are allowed to ferment naturally for many days. Then the grated cassava is dewatered to around moisture content of 10%. The starch is presumably slightly dextrinized during gaarifying (the process of making gaari). Gaari is made by hand in the African continent, as previously stated (Osho and Dashiell, 2002).

2.6.5.1 Traditional Method

Cassava's post-harvest system has been proven to need more labor than most other main crops (IITA, 2012). Harvesting and processing of cassava of 1 hectare amounts to 10 – 15 tons of cassava roots in Africa. The operation takes about 721 man-hours: 353 for processing, 212 man-hours for harvesting, and 156 for handling. Traditional gaari processing is time-consuming and labor-intensive (Plate 2.9). Peeling the roots, grating, fermenting, dewatering, sifting, and frying are the six distinct activities required. Three huge stones hold the frying pan in a typical fireplace. The operators are very uncomfortable as a result of the smoke from the fire and heat as well as steam from the wet cassava mash (Plate 2.10). Simultaneously, the system is poor in terms of fuel use, with a high energy consumption per unit of dried gaari. Even surrounding the fire on 3 sides will cut down on fuel use and prevent smoke in the operator's face. The inadequacy of frying and the usage of firewood are the two most pressing challenges in ancient gaari processing that must be solved immediately (Ozigbo *et al.*, 2020).

According to Nweke (1994), females only processed cassava in 67 percent of cases, whereas male only processed cassava in 6% of cases. In another 19 percent of cases, females worked alongside children, and in 6% of situations, females collaborated with males. This equates to 92 percent women's involvement in cassava processing (Nweke, 1994). Nevertheless, as the potential for commercialization grows, so does the number of males employed in cassava processing (Ugwu and Ay, 1992). Though males are rarely engaged in cassava processing, they are more capable to complete heavy-duty farm work. Male's engagement in cassava processing continues to rise as automated processing equipment (such as grating machine and milling machine) is purchased, as they mostly control and run these machines. As cassava processing gets increasingly mechanical, it appears the gender role shifts.

For such a vast series of processing phases, the chances of food loss throughout the system increase considerably. Harvesting (13.6%), processing (23.2%), and handling (8.5%) account for the majority of losses (Table 2.3). Because digging is more challenging during the dry period, harvesting losses are substantial; roots fracture and stay in the soil. The production performance is affected by the size, structure, toughness, relative humidity, and type of technology employed. IITA recently put up a technological package for rural cassava processing (IITA, 2012). The equipment, which is shaped like a village processing center, includes a grating and chipping machine, mill, dewatering device, sifter and gaari fryer. Food losses during cassava processing were

Plate 2.9: Traditional Gaari Fryer (1st Generation)

(Ozigbo *et al.*, 2020)

Plate 2.10: Improved Gaari Fryer (2nd Generation)

(Experimental Pictures in IITA, 2019)

Table 2.3: Processing Operations of Gaari and the Losses during Production Process

Operation	Loss of material	Residual MC %
Peeling and washing	27 kg peel	70
Grating	3 kg	70
Pressing/Fermentation	30 kg	96
Sieving	1 kg	50
Frying/drying	17 kg	8
Residual Gaari	22 kg	

(Source: IITA, 2012)

reduced from 22.3 – 10.1 percent, and labor effort per 10 tons of cassava roots was lowered from 295.2 to 87.6 man-hours (Figure 2.8).

2.6.5.2 Improved Method

Many findings were carried out in recent years to mechanize some components of the gaari production process, such as root peeling of cassava and washing or cleaning the peeled roots, grating, fermenting, de-watering, sieving, frying, and cooling (Igbeka, 1995), as reported by Akinnuli *et al.* (2015). The frying activities are the most important operation in gaari production since they define the quality of the final product (Odigboh, 1985). Although gaari frying can be mechanized but because the technique and processes were likely not understood by many manufacturers and designers, or probably the technical expertises were invoked then, it was fairly difficult to automate the operation correctly and accurately. For example, an automated gaari fryer was built and tested by Ajayi *et al.* (2014). The machine had an optimal speed of 20 rpm and 21 minutes processing using a charcoal of 5 kg as a heat energy supply. The machine was not fit for an industrial operation and the output was very low.

The following scholars in Nigeria were responsible for the historic design of gaari frying equipment/machines.

1. UNIBADAN Fryer

Igbeka J. C. (1988) created the UNIBADAN enhanced gaari fryer, which consists of a frying pan, and a fire-place oven with a chimney (Plate 2.10). The trapezoidal shape of the frying pan, which measures 200cm x 60cm x 10cm, is designed with one side tilted at a 60^{o} degree to the horizontal level. The slant nature of the two two sides allows for a slow flow of gaari down the sides of the fryer due to gravity. It's fashioned out of a 4 mm thick black stainless-steel sheet that won't corrode and won't become black when heated. The final product is discharged into a receiving pan through an aperture or chute on one side of the frying trough. The frying trough is placed on a 60 cm high rectangular clay fire-place with an aperture on a side of the width through which firewood or coal is supplied to the oven, and the chimney on the other. On one side of the length, there are two small airflow apertures. The fireplace's wall thickness is 22.5 cm, and the fireplace's heating chamber has an effective volume of 0.72 m^3. It can heat

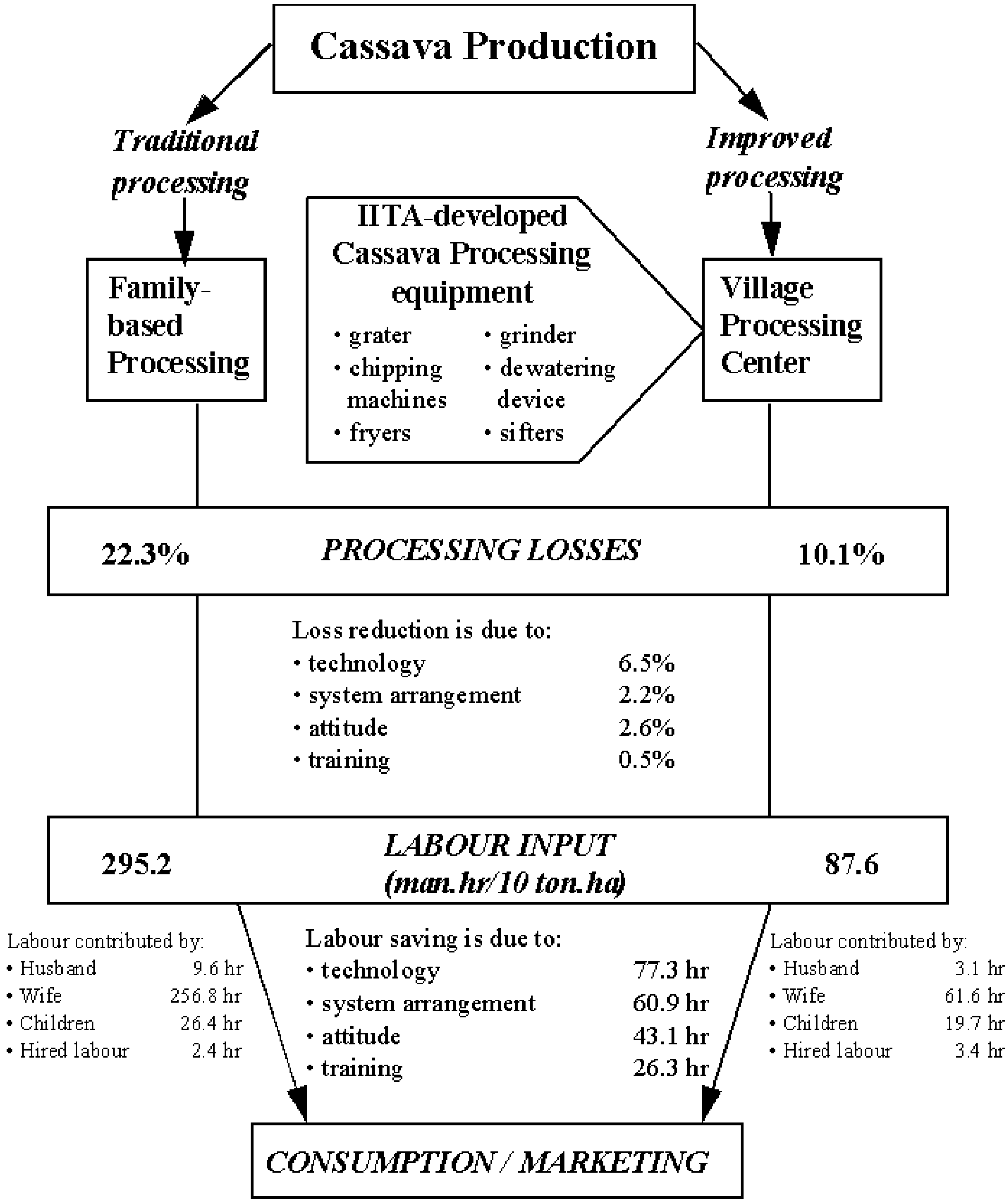

Fig. 2.8: Improved Cassava Processing Requirements and Postharvest Losses

(Source: IITA, 2005)

itself with up to 20 kilograms of wood. The structure is protected by a corrugated iron sheet shed. 2 persons sit on opposite ends of the fireplace and run the fryer without any airflow. In Egba (1987), one can get more information on the fryer development.

Testing results among gaari makers revealed that the modified models out performed the community fryer in the following ways:

a) The trouble of smoke was removed.

b) Because of the enhanced fireplace, the operator's sweating was considerably reduced.

c) Capacity and flight rates were raised. (For example, frying 5 kg de-watered and sieved mash took 20 mm instead of 1 hour).

2. IITA Fryer

The International Institute of Tropical Agriculture (IITA) model is a gaari fryer with a raised fireplace oven that can be handled by one person. The frying trough (pan) is a cast iron of a circular shape that is lower in diameter than a standard trough but with deeper depth. The trough rests on top of a circular oven with a chimney that may be filled with dense rice husk or wood shavings. The operator (s) are protected from heat and smoke by a modified version of the IITA model (Igbeka *et al.,* 1992). The operator's sitting position and comfort are improved owing to the elevated fireplace. Meanwhile, the fryer's throughput capacity is significantly higher than that of a regular fryer (Nwankpa, 2010).

3. RAIDS Fryer

The Nigerian Federal Department of Agriculture and Rural Development established the RAIDS (Rural Agro-Industrial Development Scheme) as an upgraded frying package for gaari rural processors. It's rectangular and looks like the UI model. The cast iron frying pan rests on top of an inclined oven fireplace with a chimney. It is operated by two people and contains outlet gates for releasing the end or dried products from the trough. The objective or RAIDS approach has been shown to boost production per unit time while also alleviating operator stress from smoke and heat. The model generates high-quality gaari (Nwankpa, 2010; Igbeka, 1995).

2.6.5.3 Mechanized Methods

1. Dunford Newell Model

The Dunford Newell Company, London and the Federal Institute of Industrial Research (FIIRO) in Oshodi in Nigeria collaborated on the first piece of equipment. It's a gaari-making facility, and the fryer is among the many components of the facility. In the process in the frying section, the heat from a gas fire is managed and regulated by thermostats at various points. The fryer is made of round stainless plate that is heated through the outside and has a linearly aligned internal curvature. Mash grains agitate on the surface edges of the fryer; thus, migrate along the pathways of the line curves when the fryer containing the sieved dewatered cassava mash rotates. Frying occurs due to the heat supply. Because the product created with this model lacked the core features of gaari, it was not well received by customers (Igbeka, 1995, Gbasouzor and Maduabum, 2012; Nwankpa, 2010).

2. *Brazilian Model*

The Brazilian model fryer is made up of a semi circular stainless steel plate that dries in batches. A big gear ring is attached to a vertical shaft with crossbar U-shaped stainless plates where the aluminum paddles are anchored. The circular movement of the paddles leads to production of a dried product at the application of heat to the sieved cassava mash dumped into the fryer. A discharge chute with a gate on side of the fryer is allowed to be at the end of the frying operation, so that the final products (dried) can roll into it by gravity. This variant, which was invented and built in Brazil, appears to be superior to the Dunford Newell model and the end product it produces is akin to gaari in Nigeria but not identical. Frying operation was not properly circulated in the batch in this model, and the outcome resembled dry mash of cassava rather than cooked and fried gaari (Igbeka, 1995, Gbasouzor and Maduabum, 2012; Nwankpa, 2010).

3. UNN Model

Odigboh and Ahmed (1982) devised the UNN model to accurately imitate community hand frying activities (Odigboh, 1985). A length of 1.7 m semi circular frying pan with a 57 cm diameter is positioned at a variable horizontal form at the inclination of 0 – 20 °C. The 16 spring loaded paddles are fastened to a length of 1.75 m shaft that is placed axially to keep the paddles aligned in the pan (trough) and in constant contact with it. To serve as a conveyor, the paddles overlied and are slanted in relation to the trough's axis. They are powered by an electric motor that is controlled by a series of speed reducers and linkages. Once in a cycle movement of *to* and *fro,* the group of paddles oscillates in 180 ^{o}C at a reversal of 40 per minute, metered mash of cassava is automatically entered into the pan. Swinging in one direction, the paddles push the mash against the heated trough surface while scraping, stirring, and moving it gradually close to the trough's exit point in the opposite direction. The fryer functions automatically by adjusting the pan tilt, mash quantity poured, and rate of heating to generate a continuous flow of well-fried gaari at the moisture content of 15%. This apparatus has been claimed to produce a 66 kg capacity throughput of gaari per hour (Obasouzor and Maduabum, 2012).

4. UNIBADAN Improved Model

The University of Ibadan designed and constructed the UNIBADAN model (Igbeka and Akinbolade, 1986). It is a continuous batch fryer that's an improved and modified version of UNN model, and thus a modified Fabbrico model. The feeding system, the heat source, and the placement of the paddles are the main distinctions. A frying plate, power transmission devices, feeding hopper, shaft with paddles, pulverizers, and oven where the fryer sits make up the UNIBADAN’s. The frying plate is a semicircular trough open at the top and both ends, just like the UNN type. It has a 2.44 m length and 0.67 m diameter which is slanted at an inclination of between 5 and 180 degrees. The hopper has a metering device, which is one of the most important design features, and the rate of pouring is critical to the quality obtained. Paddles are a different new feature in this generation. As in UNN type, rather than only paddles, it has a center metal rod containing pulverizers and 28 paddles positioned in such a way that they press scoop and agitate while also acting as a conveyor. The filtered mash of cassava is pressed on the surfacr of the heated pan by the pulverizers, while the paddles scrape and stir it. The oven is made of red bricks with vents for air passage at strategic locations, and it burns coal or firewood. Depending on the amount of heat required, the vent apertures can be decreased or enlarged. A petrol engine or wood can be used to operate the fryer. The final product was found to be satisfactory in tests conducted that use this design. The capacity was 80 kg/hr of completed items at 15 rpm (Gbasouzor and Maduabum, 2012; Nwankpa, 2010).

5. Niji Lukas Model

This is an improvement of Brazilian model whereby chimney is removed, and diesel burner is replaced which serves as the primary source of the heat. Just like the Brazilian model, the fryer was made up of a semi circular stainless steel plate that is used for batch drying. A big gear ring is attached to a vertical shaft with crossbar U-shaped stainless plates where the aluminum paddles are anchored. The circular movement of the paddles leads to production of a dried product at the application of heat to the sieved cassava mash dumped into the fryer. A discharge chute with a gate on side of the fryer is allowed to be at the end of the frying operation, so that the final products (dried) can roll into it by gravity. The design is acceptable by the public and several gaari production industries are adopting it. However, the problems associated the diesel burner as listed in the justification of this study are the major reasons for improving this model in order to manufacture an advantageous, reasonably priced, locally obtainable and good enough technology for farmers that will solve the gaari frying operational problem economically.

***Description of the machine*:** Just like the proposed automated gaari frying machine, Niji Lukas mechanized gaari fryer has the two major component parts; the mechanical, and electrical. Mechanically, it was built with 3 mm stainless plates, 2 mm of plates (mild steel), 32 mm of a shaft (mild steel), 205 pillow bearing, 243 cm x 122 cm x 8 mm U-channel, 30 cm and 10 cm sprockets and chain, 40 cm and 10 cm diameter; 35 cm and 10 cm aluminum pulleys, 30 cm and 10 cm diameter gear teeth. The overall dimension of the machine was 90 cm x 60 cm x 130 cm. The volume of the cylinder was 113,112 cm^3 while the surface area of the frying pan was 13,196.4 cm^2. The machine was powered electrically with a 2 hp, 3 phase, 220V, 50/60 hertz frequency, 1440 rpm electric motor. The normal speed of the electric-motor used was reduced to a standardized process 72 rpm as measured using circular speed measuring instrument called Tachometer on pulleys and chain-sprocket system method.

The Frying Pan: Unlike the automated gaari frying machine, the inner chamber is the compartment where gaari frying takes place and it was built with a 3 mm high stainless steel (HSS) plate. The choice of stainless plate was good because the area is in contact with food materials. However, the choice 3 mm thickness of HSS was not okay because according of material strength analysis 3 mm can deform under the application of high heat intensity and it was not braced underneath the base. From the material strength analysis, the recommended stainless plate is 4 – 6 mm. This is the reason behind the little hugging effect (deformation) that was noticed on the base of this frying pan. Therefore, to mitigate and accommodate any high heating effects of the electric filaments, 4 mm thickness of stainless plate was used although quite expensive than 3mm. In addition, 2 pieces of 55 cm length of angle iron dimension of 50 x 50 x 5 mm were employed to brace the inner chamber underneath to provide rigidity to base of the fryer. The outer chamber was built with 2 mm mild steel (MS) plate and a hole was created on a sectional part of this chamber which was directly opposite the discharge chute to pass in the mouth of the B14 diesel burner that was used as heat energy source. The heat resistant materials called fibre glass were then used to insulate the outer wall to avoid loss of heat to the environment, thereby, keeping the surrounding cool.

The diameter, perimeter, total surface area and volume of the Niji Lukas mechanized frying pan were 60 cm, 188.52cm, 13,196.4 cm^2 and 113,112 cm^3 respectively. These parameters results were seen to be lower than that of the automated gaari frying machine because in view to increase efficiency and capacity of the automated machine, the radius and height or depth of the frying pan were slightly increased from 30 to 32 cm and 40 to 52 cm respectively. High in the surface area, and volume of the frying of the automated fryer consequently gave a corresponding increase in efficiency and capacity of the fryer against that of the mechanized fryer.

The Frying Paddles/Mechanism: Just like the automated gaari frying machine, it is the system that is responsible for frying of the cassava mash. The materials selection and fabrication is the same but the difference in the two is the increment in dimension of the unit component parts in the case of the automated. For example, since the diameter and the radius of the Niji mechanized fryer were 60 cm and 30 cm respectively, the paddle frame dimension was 58 cm x 10 cm x 2.5 cm. Outside this, every other materials are the same. It was fabricated with 32 mm mild steel shaft, 15 x 15 cm base mild steel plate of 3 mm thickness, a cross sectional 10 cm x 2.5 cm (inches of 4 and 1) bended stainless plate of 1.5 mm thickness, 4 pieces of aluminum paddles, 2.5 cm x 2 mm thickness of flat bars, bolts and nuts. The 32 mm shaft was connected to the a small gear teeth which controls the speed of the paddles as the paddle frame was directly connected to it with the help of base plate and 4 pieces of 17 mm stainless bolts and nuts. The paddle frame was built by the bending of the stainless plate into the U-shaped form of 4 x 2.5 cm and welding operation using stainless electrodes on an arc welding machine. At the four corners of frame arms are U formed stainless flat bars that anchor the paddles to frame with 13 mm nuts and bolts.

The Driving or Gear System: Like the automated gaari frying machine, the gear system of the Niji Lukas mechanized fryer comprises of electric motor, pulleys, chain and sprocket system and the gear teeth. The same material types and makes but different dimensions. The Niji pulley system and sprockets and gear teeth are bigger in diameter than that of the automated fryer. The choice of smaller diameter of pulleys, sprockets and gear teeth was because during the performance of the mechanized fryer, it was observed that the paddle speed which was the operational speed of the fryer was a bit little slower than expected. Therefore, the idea of improving it came to mind as any improvement in the speed would possibly improve the frying efficiency and timeliness of operation. Thus, the same electric motor of 2 horse power and 1440 rpm was used but the 4 aluminum pulleys diameters were reduced from 10 to 7.5 cm, 12.5 to 10 cm, 35 to 30 cm and 40 to 35 cm and 2 sprockets were reduced from 35 to 30 cm and 12.5 to 10 cm. The belts and chain were reduced from B42 to B39, B45 to B43 and 106 to 102 respectively. However, the electric motor pulley remained the same 7.5 cm (3 inches). The same process of fabrication and the materials connections, fixing and coupling.

The Diesel Burner: The B14 common rail burner is the most frequent type of diesel burner used for burning mechanical gaari machines. With a large metal cylinder, it has a unique system. There are two kinds of burner systems: direct and conventional injection. The supply of fuel and the manner in which it is mixed with incoming air are the key differences between a direct and a standard injection. In combustion chamber, the gasoline is directly delivered with the direct injection system thereby, skipping the coming up phase in the air intake manifold. At time the combustion chamber is hottest, fuel is squirted directly in it which is controlled by the electronic unit, resulting in a good mix and thorough burn. Furthermore, with traditional diesel injection systems, each injection's fuel pressure must be generated separately. The common rail system, on the other hand, separates pressure generation and injection, ensuring that the fuel is always accessible at the proper injection pressure. The key benefits of the common rail direct fuel injection are reduced noise and exhaust pollution, enhanced overall engine performance and higher fuel efficiency .A rail, high pressure pump, injectors, filter, electrical igniters, combustion chamber, high-pressure pipes, capacitor, inlet and outlet pressure hoses, transformer, solenoid, plunger, cam, air flow meter regulator valve, suction blower, and an electronic control unit are all included in the system (module).

6. Fabrico Model

Spinning paddles in a semi circular staimless steel plate with makes up the Fabrico model, which is a plant continuous process that is simple. The paddles are eccentrically positioned so that the frying gaari grains are forced to migrate from one end of the plate to the other. During this time, the product dries out. Wood or gas-burning stoves (Plate 2.11a – 2.11b) provide heat. This type, which was invented and manufactured by the Nigerian company FABRICO, generates a gaari-like end product. The product was uncooked and resembled roasted gaari. The UNN and UI have improved on this approach (Ubasouzor and Maduabum, 2012; Nwankpa, 2010).

Plate 2.11a: Mechanical Gaari Fryer Back View (Using Fire Wood as Heat Source)

Plate 2.11b: Mechanical Gaari Fryer Front View

(Ozigbo *et al.*, 2020)

CHAPTER THREE

MATERIALS AND METHODS

The study was carried out in the Department of Agricultural and Environmental Engineering, University of Ibadan, Ibadan. The design and construction of the automated industrial gaari frying machine was done in IITA workshop at Ibadan Headquarters while coupling of the parts and installation were done in University of Ibadan, Ibadan. None of the component part of the machine was imported. All parts of the machine were locally sourced in Nigeria. The electrical/electronic components parts of the machine were purchased at Alaba International Market in Lagos State while the mechanical parts were purchased at Agodi-Gate Metal and Steel Market in Ibadan, Oyo State.

3.1 Comparative Study on the Existing Mechanical and Manual Gaari Processing Methods.

3.1.1 Determination of Diesel Fuel and Firewood Consumption

The essence of this evaluation was to determine the amount of diesel fuel and firewood consumed by the Niji Lukas mechanical and manual gaari fryer in a given quantity of cassava mash sample per batch frying operation or process. The distillation of crude oil produces diesel oil, which is a complex mixture. Diesel Fuel is a hydrocarbons mixture with carbon numbers varieting from C_9 to C_{20}. The boiling temperatures vary from 163 - 357 degrees Celsius (325 - 675 degrees Fahrenheit) (Shayne, 2005; 2014). The diesel and firewoods were purchased from Bovas filling station in Idi-ose, Oyo State, directly across from the IITA Ibadan Headquarters and Moniya market, respectively.

The Study Area:

The research was carried out in IITA, Ibadan Headquarters, Nigeria. In the forest-savannah agro-ecology, at a height of 248 meters above sea level, IITA is located at 7° 30 8 N latitude, and 3° 54 37 E longitude. It is situated at Idi-Ose Moniya, Oyo Road, Ibadan, Oyo State. The soil type is Alfisol clay loam, with a pH range of 5.0 to 6.5, and abundant in cassava, yam, beans, maize, plantains, and banana plantations.

Sample Collection Procedure:

625 kg sample of TME 419 cassava roots were freshly harvested from IITA Cassava Trial field, Phase 1. TME 419 variety was used due to its high starch and dry matter content. It was learnt that among all the cassava roots/tubers varieties, TME 419 is the best because it has higher yield tonnage abut 20 – 40 tonnes per hectare with high dry matter content good for gaari processing. The specie has low percentage of water 45 – 50% unlike other species with 50 – 60%.

Processing Procedure:

The fresh cassava roots was peeled using manual method (hand) by 3 casual staff, washed and grated using a platino grater in IITA (a Brazilian grating machine) cassava processing centre (CPC) by the factory machine operator. The grated pulp was collected and poured into 3 rubber containers of 250 litres each. The product was allowed to undergo fermentation for 2 days. After which, it was weighed using 50 kg bag into 18 different places. The bags were stacked in hydraulic press equipment with planks arranged on top and a manual hydraulic jack was used to dewater the product until it formed mashy cakes and lumps. These bags of caked products were then pulverized using the same grating machine that crushed the roots into pulpy substance. An electrical sieving machine was used to sieve out the stalks and ungrated particles of the cassava roots. Then, the friable fine texture of the mash sample of about 155 kg was gotten from the whole process. 30 kg sample was replicated 5 times. Each group sample was regulated to an initial MC of 30% wb a standard procedure for initial moisture content stated by Nnawdinobi *et al.* (2019), Olagoke *et al.* (2014), and by Adeniji *et al.* (2018).

Diesel Estimation procedure:

Before the frying operation started, 120 liters of the diesel fuel was poured the calibrated diesel tank of the mechanized gaari fryer. The machine was switched on and the temperature of burner was regulated to 220 ^{o}C. The frying time intervals of the sample of 5 replicates were recorded and the quantity of the fuel consumed by the machine for each sample were measured in liters.

3.1.2 Timeliness of Operation

This section helped to determine the time taken for mechanized garri fryer to fry to completion a given quantity of a fresh cassava mash sample in a single batch process. Time of operation is very important in machine design as it is a machine parameter. This is simply because it is a part of elements that determines the throughput capacity of the gaari fryer as well as its feeding rate. Therefore, during the evaluation the time it takes a machine to accomplish a given task or operation was considered and determined.

Processing Procedure:

600 kg of TME 419 fresh cassava roots variety was harvested, and processed into a friable mash quantity of 150 kg at initial moisture content of 30% wb. 30 kg sample of the mash was replicated 5 times. Each sample was allowed to fry to a final moisture content of 12.5% wb at a frying temperature of 220 ^{o}C. The starting and final quantity of each sample group was recorded.

3.1.3 Efficiency and Throughput Capacity Determination

***Processing Procedure*:**

300 kg of fresh cassava roots of was harvested, peeled using a manual peeling method, washed and grated or crushed using a cassava grating machine. The crushed pulpy sample was collected and permitted for a two days fermentation period using rubber containers. It was to reduce the cyanide effect of the roots which is toxic to human body. After fermentation process, the pulpy mash was bagged and dewatered using a manual hydraulic jack press system. The cake formed during this process was re-grated or pulverized to a friable mash sample. This sample was then sieved and a total of 71 kg of mash quantity was obtained. 60 kg was collected to run the experiment. The sample was divided into 3 different places of 10, 20 and 30 kg. At the 10 kg mash sample under a constant

30% wb of initial moisture content and frying temperature of 220 ^{o}C, the frying time, final moisture content and quantity out after frying results were recorded.

Then, the efficiency of the gaari fryers was estimated using a standard equation stated by Adeniji *et al.* (2018) that the mass of gaari obtained after frying a unit kg per mass of mash fed into the frying pan at each operation in a unit kg multiply by 100%.

The throughput of the mechanized fryer was determined from same mash sample prepared above for efficiency. This is to say that throughput capacity data was taken concurrently with that efficiency as estimated using an equation that stated in Adeniji *et al.* (2018) that mass of gaari obtained after frying in a unit kilogram (kg) over time of frying in an hour (hr).

A. Throughput Capacity of the Machine, C_T

This is to determine the mash quantity the fryer can fry at a given time interval under an optimum frying temperature, moisture content and mash quantity (Adeniji *et al.*, 2018).

$$C_T = \frac{Mass\ of\ gari\ obtained\ after\ frying,\ \ MG\ (kg)}{Time\ of\ frying,\ \ TF\ (hr)} \qquad \ldots\ldots\ldots\ldots(3.1)$$

B. Functional Efficiency of the Machine, F_E

$$F_E = \frac{Mass\ of\ gari\ obtained\ after\ frying,\ \ MG\ (kg)}{Mass\ of\ mash\ fed\ into\ the\ frying\ pan\ at\ each\ operation,\ \ MM\ (kg)} \times 100$$

…………………….(3.2)

C. Material or Water Loss, M_L

$$M_L = \frac{Mass\ of\ mash\ fed\ into\ the\ frying\ pan - Mass\ of\ gari\ obtained\ (kg)}{Mass\ of\ mash\ fed\ into\ the\ frying\ pan\ (kg)} \times 100$$

………………….(3.3)

3.1.4 Cost Analysis of the Mechanical and Manual Gaari Fryers

The fryers' manufacturing cost is referred to as fabrication or production cost here which included the cost of all materials used and workmanship/labour cost for the fabricators. The depreciation cost (cost of the machine over life spam of the machine) was estimated. The cost of materials was determined by pricing each unit of the material in the local market.

In estimation of the operating cost of the machine, following costs were considered: fuel, repair or maintenance, replacement of the machine component parts, maintenance or servicing cost, and causal labour.

3.2 Design and Construction of an Automated Gaari Frying Machine

3.2.1 Design Considerations

The design of different component parts of the automated gaari frying machine was made using computer aided design package, AutoCad, Creo-Ptc Solid Works Software and the detail engineering drawings of the components were generated during the design.

The development of any postharvest equipment or machine for storage processing, delivering, cleaning, conveying, harvesting, handling, or frying of any biomaterial under study requires a thorough understanding of the engineering properties (gravimetric, mechanical, frictional, aerodynamic, rheological, and physical) of the agricultural material under course of research study. Other important parameters that were considered before and during development of the machine include: materials' strength; material selection; materials' availability within the local market; materials' choice, fryer power drive's choice; capital, affordability of the materials; maintenance and operating, costs of the machine; selection of the electric motor, pulley belt size and type to be used; and machine capacity.

3.2.2 Design of the Mechanical Component Part of the Gaari Frying Machine

3.2.2.1 The Design Frame System

Shear Forces Determination and Bending Moment (Akinnuli *et al.*, 2015):

$$W = m \times g \quad \text{................ ......(3.4)}$$

Where,

$$\boldsymbol{m = w1 + w2 + w3} \qquad \text{.......................(3.5)}$$

m = mass of the shaft, pulley and bearings = $20.0\ kg$

$\boldsymbol{l}$ = the shaft length = 0.4 m

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

w_1 = shaft mass = 8.0 kg

w_2 = pulleys mass = 6.0 kg

w_3 = mass of the upper & lower bearings = 7.0 kg

$\boldsymbol{W = P =}$ mg = 21 x 9.81 = 206.01 = 206 N

To consider the shear force, V and the bending moment, M for the three forces of the shafts acting on the horizontal beam, the following equations below would be adopted;

For 0 < x < a,

$$V = R_A \ ; \qquad \text{.................................. (3.6)}$$

$$R_A = \frac{Pb_s}{L} \qquad \text{...................................(3.7)}$$

$$V_1 = R_A = \frac{206\ x\ 0.9 + 206\ x\ 0.6 + 206\ x\ 0.3}{1.2}$$

$$R_A = \frac{185.4 + 123.6 + 61.3}{1.2} = 308.58 = 309$$

$R_A = 309$ N

Σ Upward forces = Σ Downward forces

$$R_A + R_B = 618 \text{ N} \qquad \text{.................(3.8)}$$

R_B = 618 - R_A = 618 – 309

R_B = 309 N

BMA = U-channel metal bending moment about support reaction A (Nm),

BMB = U-channel metal bending moment about support reaction B (Nm)

$B_{MA} = B_{MB} = 0$

Taking moment about point C

$\therefore M = R_A$ x ……………………….(3.9)

$M_1 = R_A a_1$

$M_1 = 309 x 0.3 = 92.7$ Nm

For $a_1 < x < a_2$

$V = R_A - P_1$ ……………………….(3.10)

$\therefore V_2 = V_1 - P_1$ = 309 – 206 = 103 N

$V_2 = 103$ N

Similarly,

$\therefore V_2 \; to \; V_5$ ………… *can be calculated as follows*

$V_3 = V_2 - P_2$ = 103 – 206 = - 103 N …………………… (3.11)

$V_4 = V_3 - P_3$ = -103 – 206 = - 309 N ……………………..(3.12)

$V_5 = V_4 - R_B$ = - 309 + 309 = 0 ……………………..(3.13)

$V_5 = 0$

Taking moment about point D and E,

$M_2 = R_A L_A - P_1 a_1 - P_2 a_2$ ……………………..(3.14)

$\therefore M_2 = (309 x 1.2 - 206 x 0.3 - 206 x 0.3)$ Nm

$M_2 = 247.2 Nm$

$M_3 = R_A L_A - P_1 a_1 - P_2 a_2 - P_3 a_3$ ……………………(3.15)

$\therefore M_3 = (309 x 1.2 - 206 x 0.3 - 206 x 0.3 - 206 x 0.3)$ Nm

M_3 = 185.4 Nm

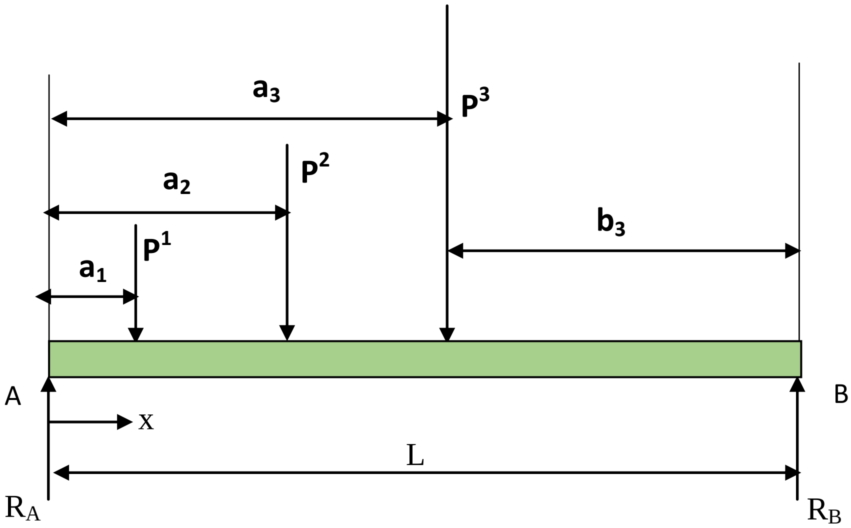

Fig. 3.1: Shear Force Diagram for the Concentrated Loads Acting on the Beam.

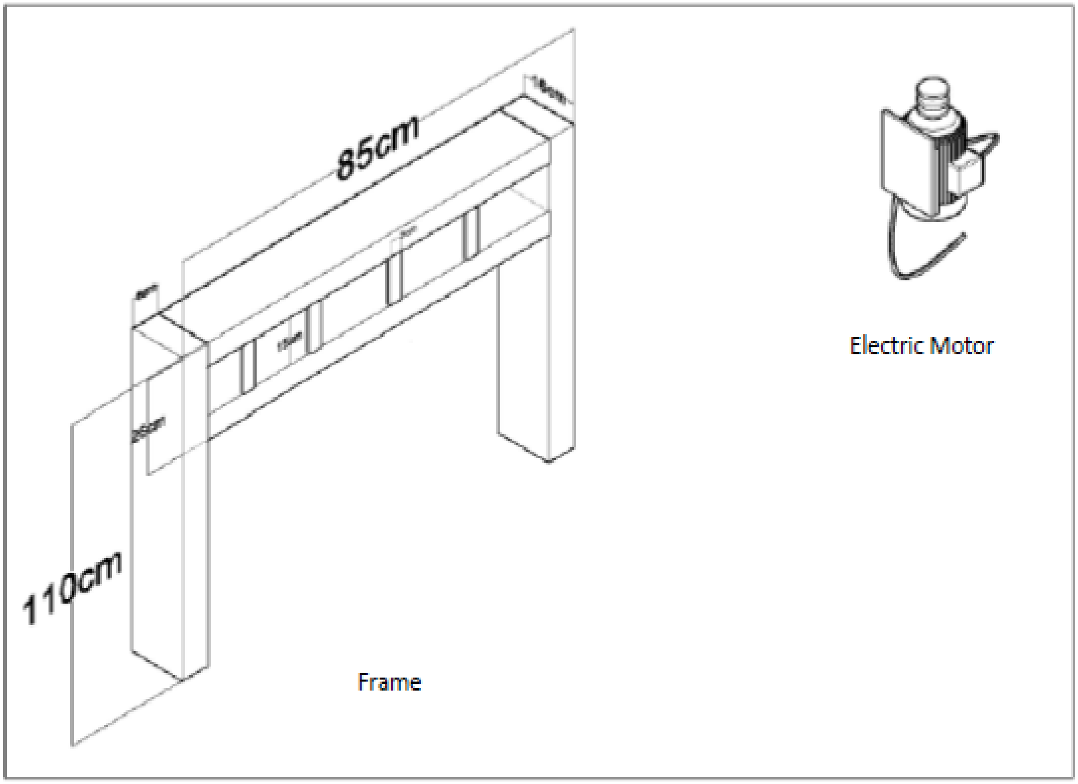

Fig. 3.2: The Frame and the Electric Motor

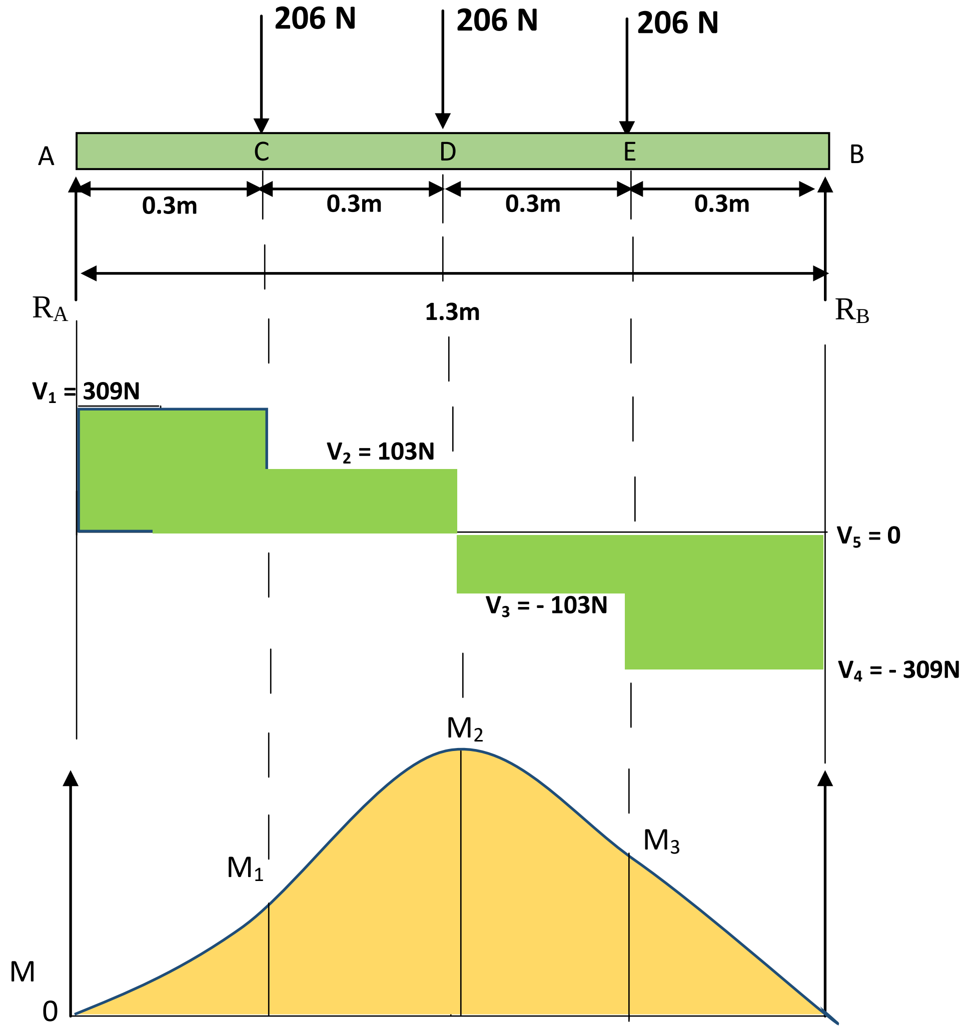

Fig. 3.3: Shear Force and Bending Diagram for the Concentrated Loads Acting on the Beam

Shaft Selection

According Ozigbo and Bamgboye (2020); Onyekachi and Anthiny (2018), the following equation could be adopted to estimate shaft diameter to be utilized:

$$\boldsymbol{d = [\frac{16}{\pi s}\sqrt{(K_b\ M_b)^2 + (K_t M_t)^2}]^{\frac{1}{3}}}$$ ……………………………(3.16)

Where,

M_b means maximum bending moment on shaft (Nm) = 17.19 N/m

M_t means maximum torsional moment on shaft (Nm) $\approx 2.35\ Nm$

K_b means dimensional combined and fatigue factor applied to bending moment = 1.5

K_t means dimensional combined and fatigue factor applied to torsional moment = 1.0

S_x means allowable shear stress for steel 40×10^6 N/m^2 (ASME code)

$$= [1.27307447 \times 10^{-7}\sqrt{664.87 + 5.52}]^{\frac{1}{3}}$$

$$= [1.27307447 \times 10^{-7}\sqrt{670.39}\ ]^{\frac{1}{3}}$$

$$= [1.27307447 \times 10^{-7} \times 25.89^{\frac{1}{3}} \quad = (3.2962 \times 10^{-6})^{\frac{1}{3}}$$

$$= \ 0.0149 \approx 0.0150\ m$$

$$d = 15\ mm + factor\ of\ safety$$

As described by Gbabo *et al* (2013), a 20 percent factor of safety for shaft diameter was applied, resulting in a 19 mm shaft.

3.2.2.2 The Design of the Frying Mechanism

Frying Chamber

The frying chamber is in cylindrical shape. This type of shape was considered because the circular movement of the paddle mechanism. Its space and size is the function of the size of the entire paddle mechanism (Akinnuli *et al.*, 2015); Shittu and Ndirika (2007).

$$V_c = \pi r^2 h$$ ………………………..(3.17)

r = frying chamber radius (m) $= 0.32\ m$,

h = frying chamber height (m) $= 0.52m$

$V_c = \pi \times 0.32^2\ m \times 0.52\ m$

$V_c = 3.142 \times 0.32^2\ m \times 0.52\ m$

$= 0.22417\ m^3$ …. …… *This is the frying chamber volume*

Therefore,

Assuming that the cassava mash volume in the cylinder is one-third that of the frying chamber, the cassava mash volume in the frying chamber will be;

$$\boldsymbol{V_m = \frac{1}{3} V_c} \quad \text{………………………(3.18)}$$

V_m = mash volume in the cylinder. V_c = cylinder volume

$$\boldsymbol{V_m = \frac{1}{3}\ x\ 0.22417\ m^3}$$

$$\boldsymbol{V_m = 0.074723\ \mathrm{m}^3}$$

Cassava mash mass in the cylinder

$$\boldsymbol{\rho = \frac{\mathrm{m}}{V_m}} \quad \text{………………(3.19)}$$

$\boldsymbol{\rho}$ = density of cassava mash = 1509 kg/m^3

$\boldsymbol{V_m}$ = cylinder volume = $\boldsymbol{0.074723\ m^3}$

$$\boldsymbol{\mathrm{m} = \rho\ x\ V_m = 1509\ \mathrm{kg}/m^3 x\ 0.074723\ m^3}$$

$\boldsymbol{m = 112.75\ kg}$ …………*This is the maximum capacity of the frying chamber*

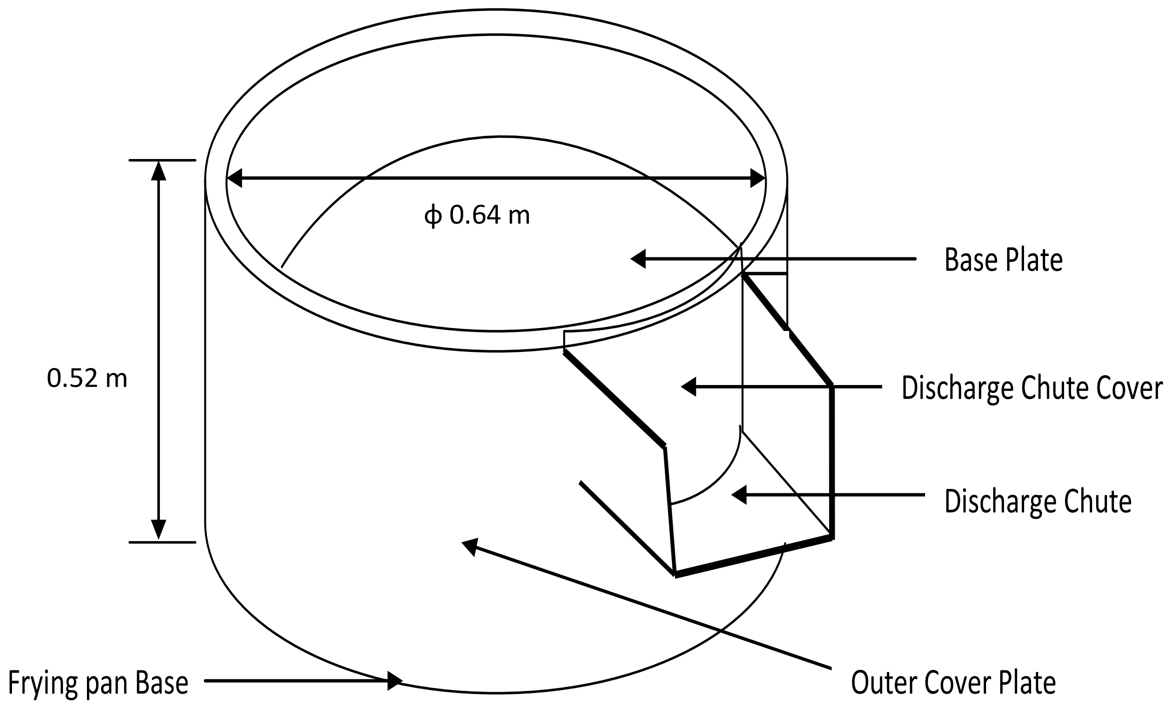

Fig. 3.4: The 2-Dimensional Diagram of the Frying Chamber

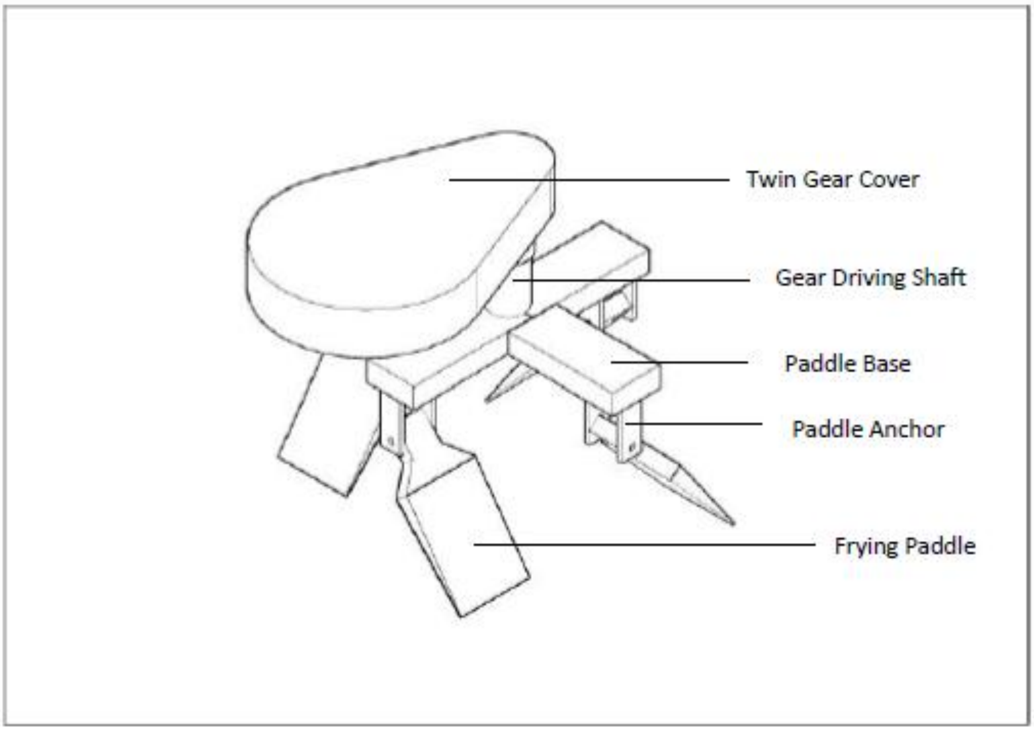

Fig. 3.5: The 2-Dimensional Diagram of the Frying Mechanism

3.2.2.3 Estimation of the Heat and Time Needed for the Drying Operation

$$\boldsymbol{Q = MC}\Delta T \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(3.20)$$

Q = the heat quantity required,

M_a = the cassava mash mass in the cylinder = 50 kg

C = the mash specific heat capacity = 1.59J/kg°C

T_1 = Initial temperature (Ambient temperature) = 30°C

T_2 = Final temperature (frying temperature) = 190°C

ΔT = temperature range = 160°C

$$\boldsymbol{Q = 50 \times 1.59 \times 160}$$

Q = 12,72 W = 12.7 kW ……….. *the quantity of heat required for drying*

Time required for the drying

$$\frac{\Delta Q}{\Delta t} = \frac{KA\,(T_2 - T_1)}{\Delta t} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(3.21)$$

$$\frac{\Delta Q}{\Delta t} = \textbf{Heat rate transfer} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(3.22)$$

Where,

K = the mash thermal conductivity = 0.2

A = the cylinder surface area

t = thickness of the cylinder = 40 mm

$$A = 2\pi rh + 2\pi r^2 \quad \ldots\ldots\ldots\ldots\ldots..(3.23)$$

$$A = (2\ x\ 3.142\ x\ 0.64\ x\ 0.52) + (2\ x\ 3.142\ x\ 0.52^2)$$

$$A = 2.0913 + 0.8836$$

$$= 2.9749\,m^2$$

$$\frac{\Delta Q}{\Delta t} = \frac{KA(T_2 - T_1)}{L} = \frac{0.2 \ x \ 2.9747x \ (160)}{40} =$$

$$= \frac{0.2 \ x \ 2.9747x \ (160)}{40} = 2.375 \text{ W/s}$$

Equating the transports heat rate to the cassava mash mass to be dried over a given time interval, Δt

$$\frac{\Delta Q}{\Delta t} = \frac{\Delta m}{\Delta t_m} L_h \qquad \text{.....................(3.24)}$$

Where,

L_h = Latent heat of transformation

Δt_m = time interval in minutes

Δm = mass of the cassava mash

$$\Delta t_m = \frac{\Delta m \, L_h}{\frac{\Delta Q}{\Delta t}} \qquad \text{.....................(3.25)}$$

$$\Delta t_m = \frac{12700 \ W}{2{,}375 \text{ W/s}} = 5{,}347 \text{ s}$$

$$\Delta t_m = 5{,}347 \text{ secs} \qquad = 89.11 \text{ minutes}$$

Δt_m = 89 minutes .... *the time required to dry the mash*

3.2.2.4 Determination of the Power Usage of the Frying Machine

The electrical power usage to drive this type of machine without a blower is divided into three parts. According to Gbabo *et al* (2013), Akinnuli *et al* (2015), the following equations can be used to express the power requirement:

Power needed to move or drive the Pulley

$$P_p = W_p \times R_p \qquad \text{.....................(3.26)}$$

Where;

W_p = weight of the pulley (N),

R_p = radius of the pulley = $0.25\ m$

Mass of the pulley = 2.2 kg

$W_p = mg$

$W_p = mg = 2.2\ kg \times 9.81\ m/s^2 = 21.58\ N$

$P_p = 21.58 \times 0.25 = 5.395\ W = 0.005395\ kW$

Power required to drive Shaft

$$P_s = W_s \times r_s \qquad \text{.....................(3.27)}$$

Where;

n = number of the shaft used = 3

W_s = weight of the shaft (N)

r_s = radius of shaft (m)

$$W_s = mass \times force\ of\ gravity \qquad \text{...............(3.28)}$$

total mass of the shaft = $n\ 6.00\ kg\ = 3\ x\ 6 = 18kg$

$W_s = 18.0 \times 9.81 = 176.58\ N$

$$r_s = \frac{D}{2} \qquad \text{...............(3.29)}$$

$r_s = \frac{D}{2} = \frac{0.08}{2} = 0.04\ m\ x\ 3 = 0.12\ m$

$P_s = 176.58 \times 0.12 = 21.19\ W \approx\ 0.02119\ kW$

Power Required to Drive Frying Paddle Shaft

$$P_d = \tau \times \omega \qquad \text{.................(3.30)}$$

$\tau =$ shaft Torque (Nm)

$\omega =$ shaft Angular speed (m)

f = overall load on the paddle = 78.48 N

r_s = radius of paddle shaft (m) = 0.1 m

Number of revolution of the electric motor = 1725 (after when it has been stepped down to lowest). Here, it is assumed that the revolution of 3450 has replaced with 1725 by doubling the diameter of the pulley or with the use of reduction gear mechanism.

Note: The shaft on a typical motor will rotate at either 1725 or 3450 RPM (revolution per minute). The speed of the driven machine will be determined by the size of the pulley used.

$\tau = f \times r_s$ ……………………(3.31)

$\omega = \frac{2\pi N}{60}$ …………………..(3.32)

$\tau = f \times r_s = 78.48 \: x \: 0.1 = 7.848 \: Nm$

$\omega = \frac{2 \: x \: 3.142 \: x \: 1725}{60} = 180.67 \: rad/sec$

$P_d = 7.848 \times 180.67$ = 1417.90 W = 1.41790 kW

Therefore, the total electrical power needed to move the entire frying machine is evaluated as follows;

$Total \: Power, \: P_T = P_p + P_s + P_d$ …………………(3.33)

$P_T = 0.005395 \: kW + 0.02119 \: kW + 1.41790 \: \text{kW} = 1.44449 \: kW$

$P_T = 1.44449 \: kW = 1.937 \: hp \approx 2.0 \: hp$

Consequently, 2.0 hp or 2.5 hp of electric-motor can be used to drive the mechanical system of the machine.

3.2.2.5 Estimation of the Pulley Size

As described by Aaron (1975), the pulley size used could be determined as follows;

$$N_1 D_1 = N_2 D_2 \qquad \text{........................(3.34)}$$

N_1 = means driving unit speed (rpm) = 1440 rpm (speed directly from the motor without reduction yet)

N_2 = means driven pulley speed (rpm) = 350 rpm

D_2 = means driven pulley diameter (mm) = 7.5 cm

D_1 = means driving pulley diameter (mm) =?

$$1440 \text{ x } 7.5 = 350 \text{ x } D_1$$

$D_1 = \frac{(1440 \ x \ 7.5)}{350} = 30 \text{ cm}$ ....*This diameter will be used*

3.2.2.6 Belt Selection

The length of the belt was computed as follows using Khurmi and Gupta's equation (2004):

$$L = 2C + 1.57(D_2 + D_1) + \frac{(D_2 - D_1)^2}{4C} \qquad \text{........................(3.35)}$$

L= belt length, mm

C = the distance between the drive center and the pulleys = 40 cm

D_1 = cm

D_2 = 30 cm

$$L = 2 \times 40 + 1.57(7.5 + 30) + \frac{(7.5 - 30)^2}{4 \times 40}$$

$$L = 80 + 58.88 + \frac{((-22.5)^2)}{160} = 138.88 + 3.164 = 142 \ cm$$

$$L = 142 \ cm$$

As a result, a B – 48 V-belt will be used, which is the equivalent of the predicted size. However, engine seat allowance will be made to accommodate over size belts of 46 – 48.

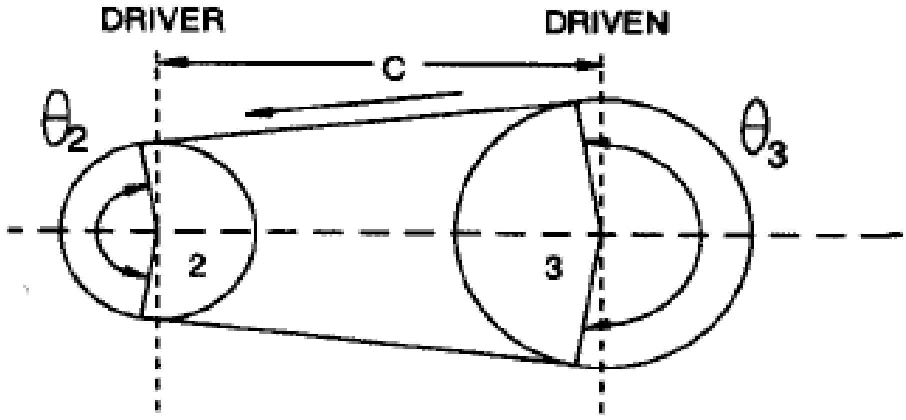

Fig. 3.6: Geometry of V-Belt Drives (Source: Srivastava *et al.*, 2006)

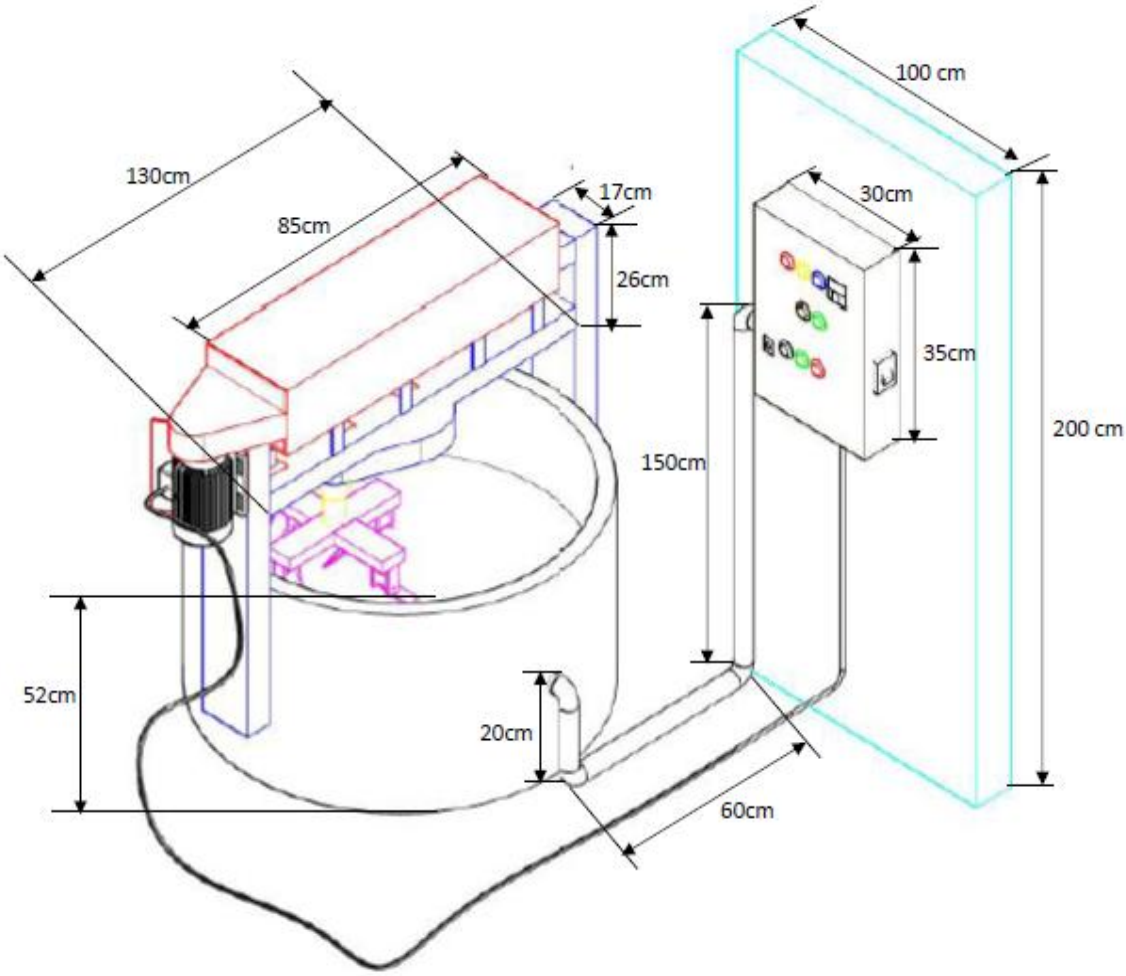

Fig. 3.7: The Schematic Diagram of the Machine

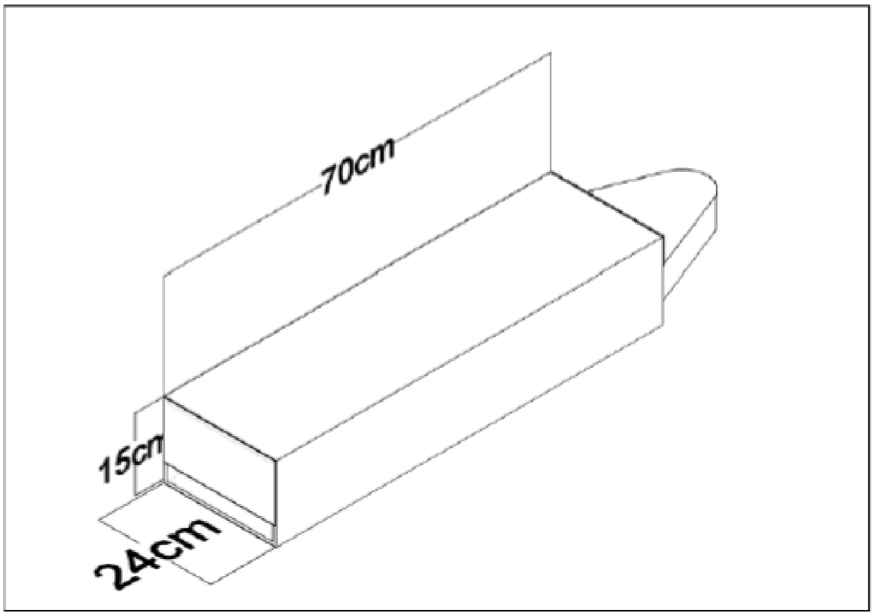

Fig. 3.8: 2-D of the Belt and Chain Cover of the Machine

3.2.3 The Design of the Electrical/Electronic Component Parts of the Gaari Frying Machine

3.2.3.1 Microcontroller PIC16F877A

PIC16F877A was the model of the microcontroller used on the Arduino software and it is classified of 8-bit microcontrollers of RISC (Reduced Instruction Set computer) design. The microcontroller is a 40 pins chip with two in-line packages. The PIC is a little computer with a lot of power. It is equipped with a processor (CPU), PROM (Program Memory), 2 input/output ports and RAM (Random Access Memory). It processes the information inputted in it and stores. The microchip is erasable and reprogrammable which means the stored data can be cleaned up and reused. Figure 3.9 and Plate 3.1 show the pin orientation of the microcontroller and the picture of the LCD used. While Figure 3.10 presents the design circuit of the automated gaari frying machine.

Design parameters programmed on the Arduino microcontroller were as follows: frying time (0 – 90 minutes), frying temperature (0 – 250 ^{o}C), heating filament capacity (0 – 15 kW), initial moisture content (0 – 55% wb), and final moisture content (0 –50% wb) (Appendix One).

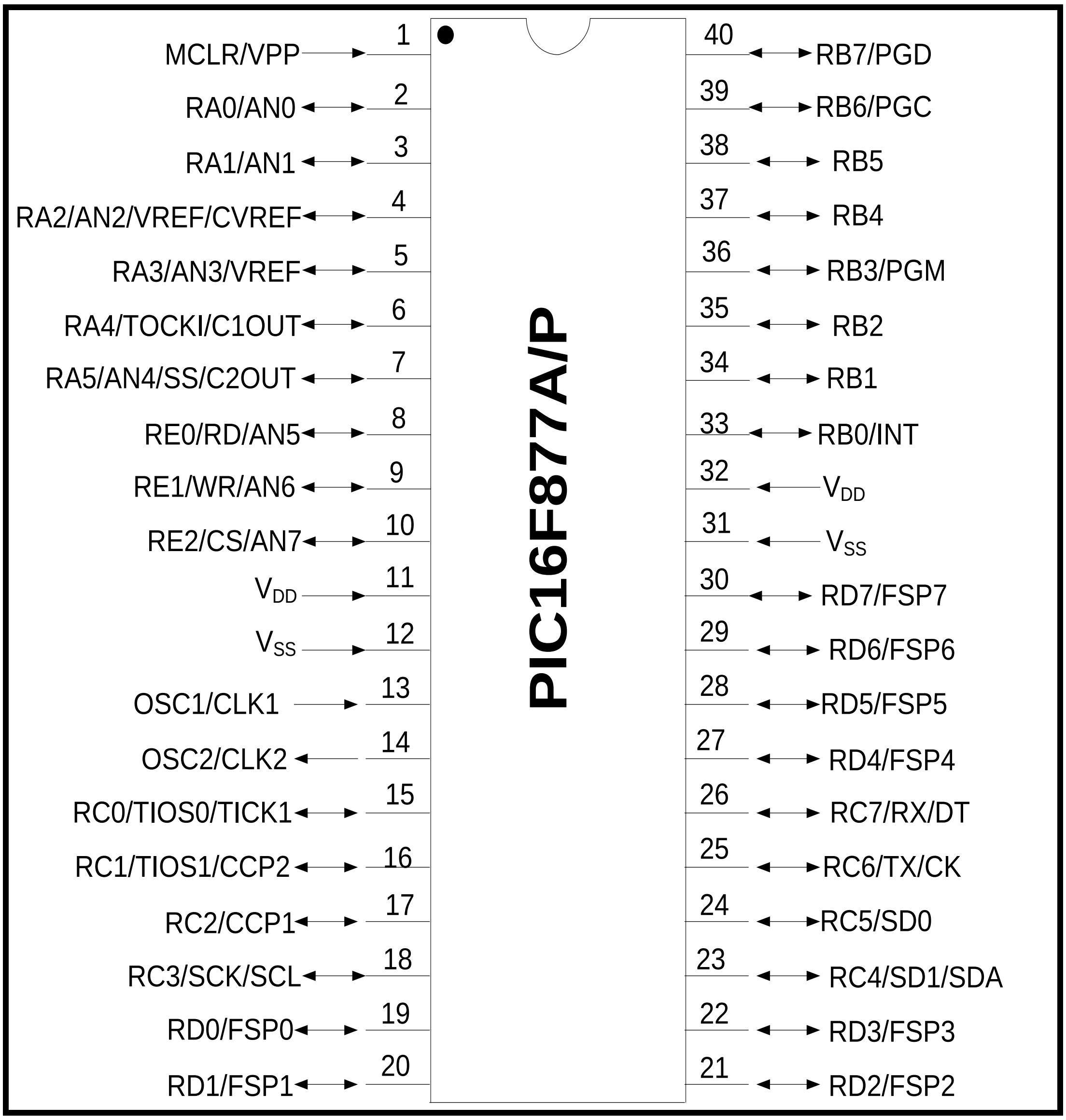

Fig. 3.9: Pin Orientation on P1C16F877A Microcontroller.

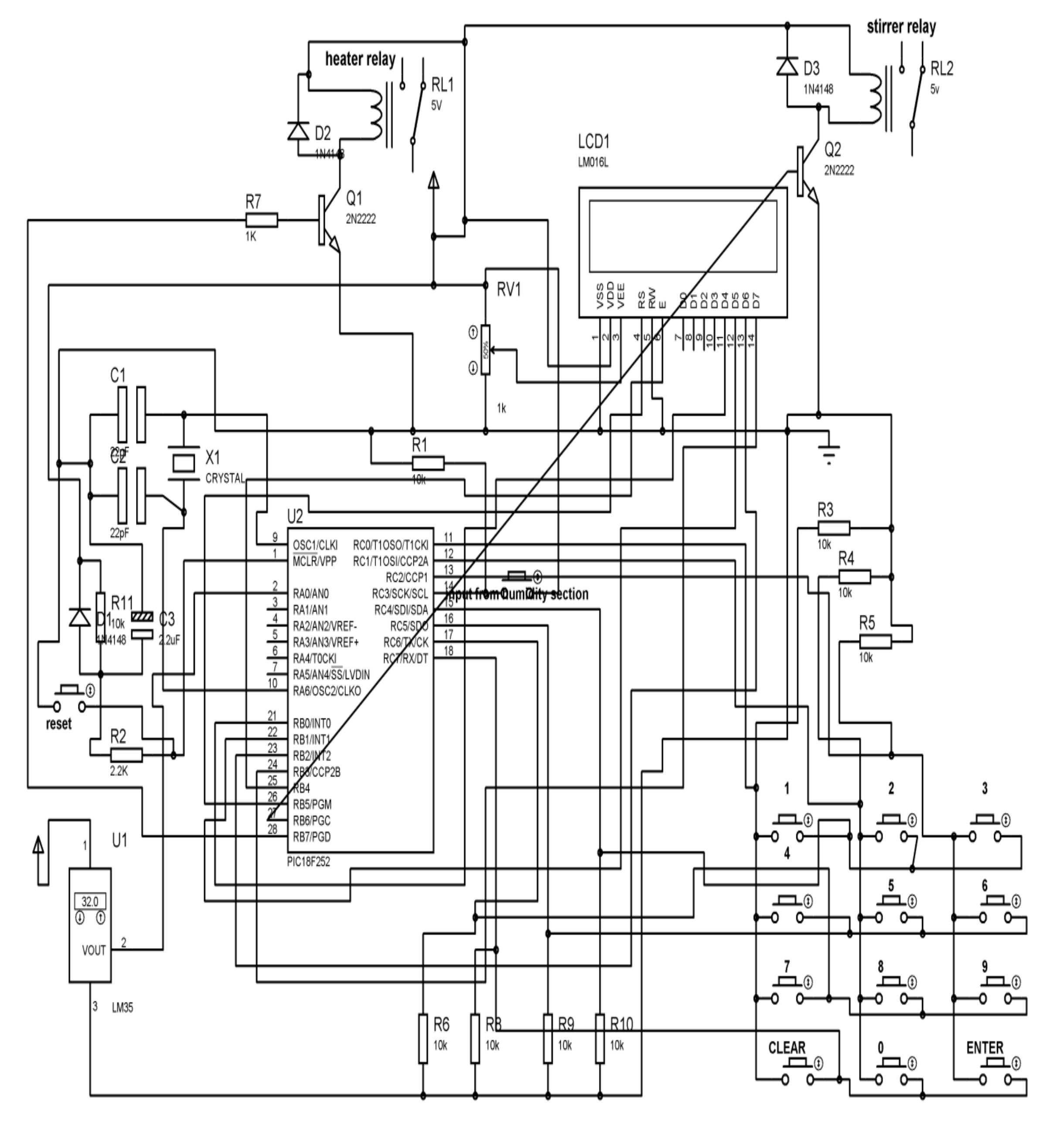

Fig. 3.10: Circuit Diagram of the Automated System

Plate 3.1: Picture of the LCD and Its Pin Orientation.

(Source: Everyday Practical Electronics, 1997)

3.2.3.2 The Design of the Power Supply Circuit

All stages of power supply in the project uses a fixed regulated +5Vdc supply except the relays that uses 12Vdc. The power supply stage is a linear power supply type which involves a voltage regulator, filter capacitor and step down transformer to give the various voltage levels needed. The fig. 3.11 presents the power supply circuit diagram.

The rectifier is designed with four diodes to form a full wave bridge network. C_1 is the filter capacitor (Plate 3.2) and C_1 is inversely proportional to the ripple gradient of the power supply, using a 240V transformer on a 50Hz supply and transformer secondary *r.m.s* voltage output is 12V.

$$Peak\ voltage, V_p = V_{rms} \times \sqrt{2} \qquad \text{.......................................(3.36)}$$

$$V_p = 12\sqrt{2} = 16.97V \qquad \text{..(3.37)}$$

$$Supply\ frequency, f = \frac{1}{period(T)} = 50Hz \qquad \text{........................(3.38)}$$

$$Period, T = \frac{1}{f} = \frac{1}{50} = 0.02s = 20ms$$

The total voltage drop, V_d, for the two diodes involved in the rectification process in either of positive or negative cycles,

$$V_d = 2V_{BE}\ [V_{BE} = 0.7V\ for\ a\ silicon\ diode] \qquad \text{……………..(3.39)}$$

$$V_d = 2 \times 0.7V = 1.4V$$

Actual peak voltage value,

$$V_{LM} = (V_m - 2V_{BE})V \qquad \text{…………………………….(3.40)}$$

$$V_{LM} = (16.97 - 1.4)V$$

$$V_{LM} = 15.57V$$

Change in peak voltage value over the discharge period,

$$\delta V = V_{LM} - V_{dc} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.41)$$

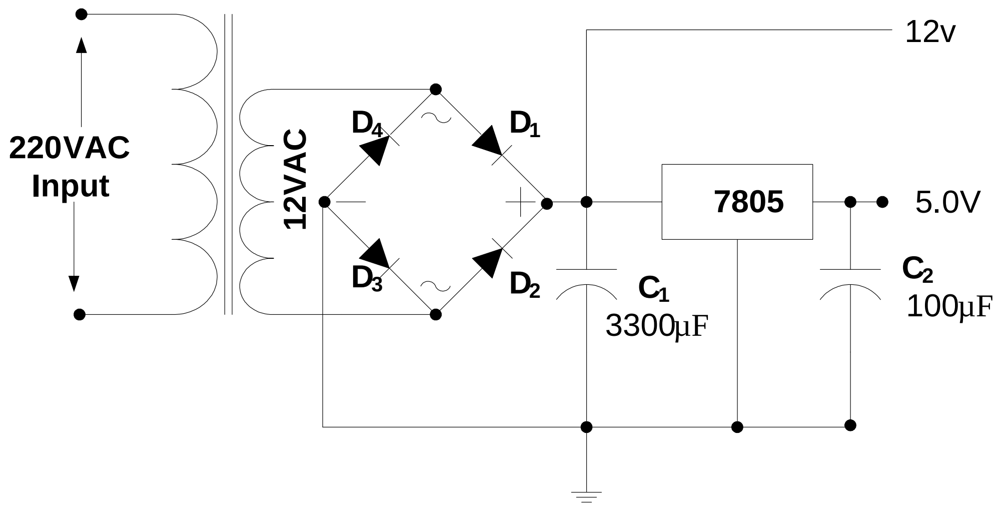

Fig. 3.11: Power Supply Circuit of the Automated System

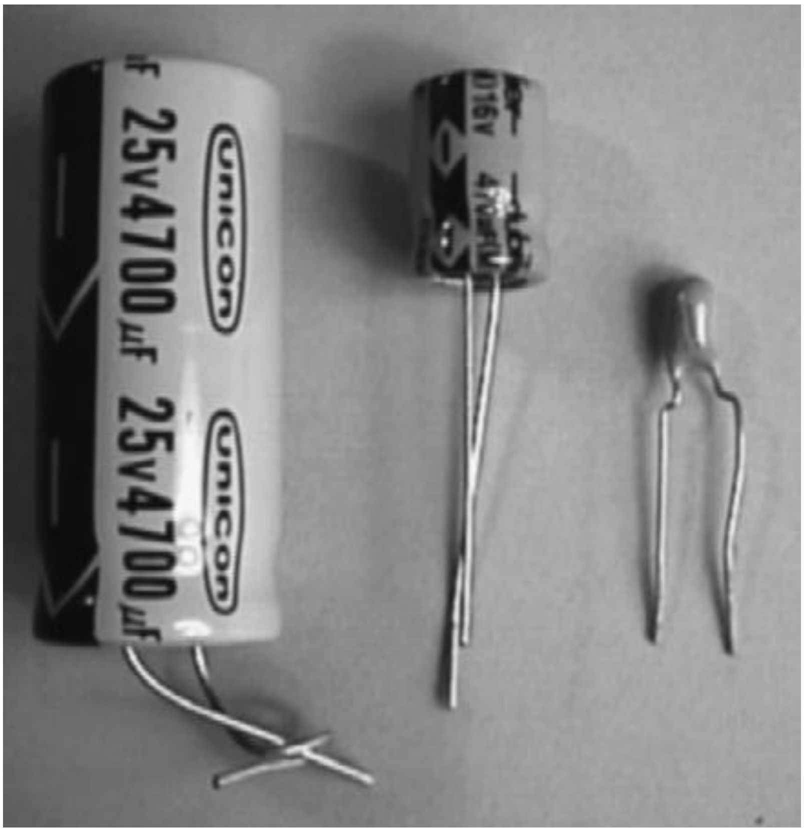

Plate 3.2: Filter Capacitors

$V_{dc} = 10V$

The filter capacitor should not discharge down to 6V in accordance with the input voltage specification of the voltage regulator.

$\delta V = (15.57 - 10.0) = 5.57V$

Change in time over the discharge period, $\delta t = 10ms$

Total current consumption for this design is not expected to exceed 600mA

Hence the value of the filter capacitor is obtained thus:

$$C = \frac{600mA \times 10ms}{5.57V} = 1077.20\mu F$$

To provide a safety margin, the capacitor value chosen is twice the calculated value which implies a value 2154.4µF.

The nearest available capacitor value of 3,300µF is used as the filter capacitor.

3.2.3.3 Transistor Switching Stage

The transistor as a switch operates in class A mode. The relay is switched on when the microcontroller gives a high output. A base resistor is required to ensure perfect switching of the transistor in saturation. The diode protects the transistor from back emf that might be generated since the relay coil presents an inductive load (Plate 3.3 and Figure 3.12).

In this case R, which is the collector resistance, is the resistance of the relay coil, which is 400Ω for the relay type used in this project.

Hence, given that Rc = 400Ω (Relay coil resistance)

V^+ = 5V (regulated voltage from the power supply stage).

Vbe = 0.6V (sillicon), Vce = 0V (when transistor is switched)

G Vin = 4.0V (from microcontroller), Hfe = 300 (from data sheet for BC547)

since,

$$V^+ = I_C R_C + V_{CE} \qquad \text{...(3.42)}$$

Plate 3.3: Picture of the Switching Transistor

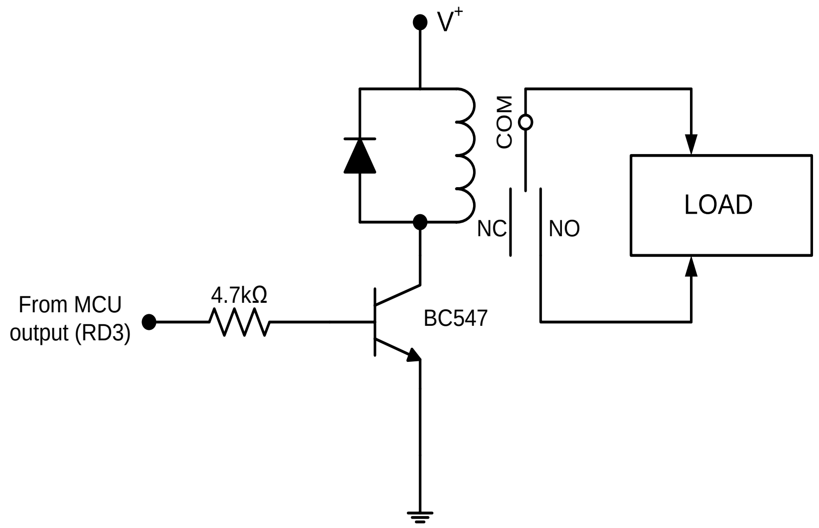

Fig. 3.12: Circuit Symbol of the Transistor.

$$V_{in} = I_B R_B + V_{BE} \quad \text{...(3.43)}$$

$$\frac{I_C}{I_B} = h_{fe} \quad \text{………...(3.44)}$$

$$R_B = \frac{V_{in} - V_{BE}}{I_B} \quad \text{...(3.45)}$$

Where,

I_C = collector current

I_B = base current

V_{in} = input voltage

V_t = supply voltage

V_{CE} = collector-emitter voltage

H_{fe} = current gain.

From equation i,

$$5 = I_C R_C + V_{CE}$$

$$5 = I_C(400\Omega) + 0$$

$$I_C = 12.5mA$$

From equation iii,

$$I_B = \frac{12.5mA}{300} = 0.417\mu A$$

$$5 = 0.417\mu A \ R_B + 0.6$$

$$R_B = \frac{4.4V}{0.417\mu A} = 10{,}000\Omega$$

3.2.3.4 Transformer

Transformers efficiently convert alternating current (AC) from one voltage to another. Transformers can only work with alternating current, which is why mains electricity is alternating current as well. The step-down transformer lowers the voltage input. Most power supplies in Nigeria require a step-down transformer to decrease the high mains voltage (220V) to a safer low voltage. The input coil is the primary coil, while the output coil is the secondary coil. An alternating magnetic field created in the soft-iron core of the transformer connects the two coils rather than an electrical connection (Plate 3.4). Figure 3.13 shows the isometric view of the automated gaari fryer.

The two lines in the middle of the circuit symbol symbolize the core. Because transformers waste very little energy, the output is nearly equal to the input. It's worth noticing that the current increases as the voltage is dropped. The voltage ratio is influenced by the 'turns ratio,' or the ratio of the number of turns on each coil. The primary (input) coil of a step-down transformer has a large number of turns and is connected to the high voltage mains supply, while the secondary (output) coil has a small number of turns and produces a low output voltage.

Turns ratio = $\frac{Vp}{Vs} = \frac{Np}{Ns}$ ……………………….(3.46)

Power out = power in

$Vs \times Is = Vp \times Ip$ ………………………..(3.47)

Where:

Vp denotes the principal (input) voltage.
Np denotes the number of turns on the primary coil.
Ip denotes the primary (input) current.
Vs is the voltage in the secondary (output) circuit.
Ns denotes the number of turns on the secondary coil.
Is indicates secondary current (output)

Plate 3.4: Picture of the Step-down Transformer

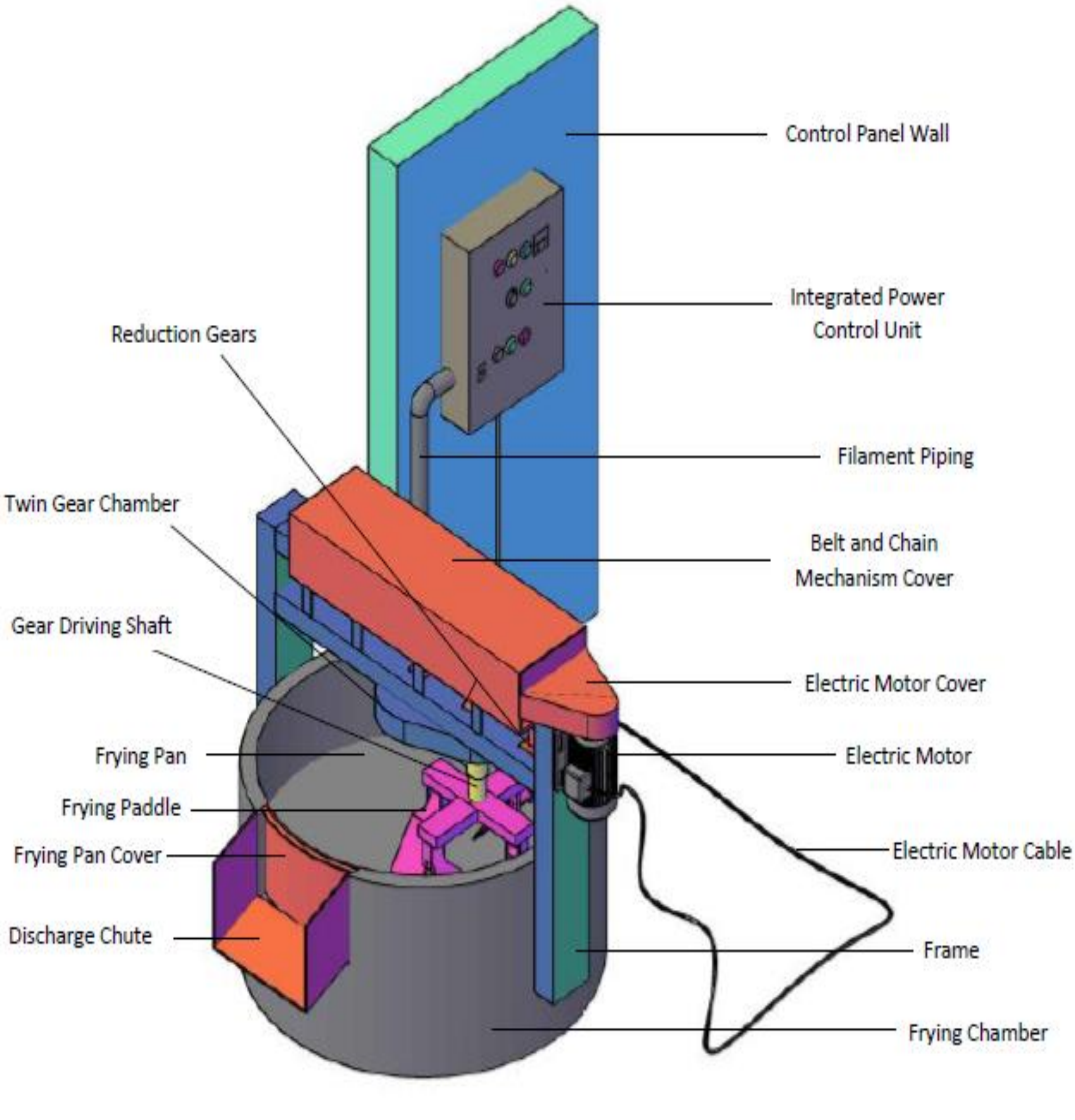

Fig. 3.13: The 3-Dimensional View of the Machine

3.2.4. Materials

3.2.4.1 Mechanical Component Parts

The automated industrial gaari frying machine has two major component parts; the mechanical and the electrical/electronic part. The former gives the machine its shape and size, while the later is the centre for control and operation of the entire system which consists of the automated parts. The mechanical components used include the following: 4 mm stainless sheet, 2 mm mild steel sheet, metal-steel rod of 32 mm, mild-steel rod of 2 mm, 205 pillow bearings, and 2.0 hp electric motor, reduction gears in form of chain and sprockets, fan belts, cast pulleys, bolts and nuts, electrical filaments, u-channel mild steel, heat resisting fibres, etc. All these materials contributed to the machine aesthetic appearance and framework.

3.2.4.2 Electrical/Electronic Component Parts

The electrical/electronic components include: Microcontroller. Transformer, Capacitor, Temperature Control Modules, 3-phase Control Switch, Electrical Sockets and Switches, 4MHz – Crystals, 12V Contactors, Relays, Capacitors, Vero-board, Resistors, Transistors, Regulators, Integrated Circuit; Light Emitting Diodes (LED), Leads, Connecting Wires, Plugs Insulating Sleeves, Board Casing, LCD Display sensors, Solenoids Push Switches, 7 segment displays, Rectifying Diodes, crystals, 4 x 4 Keypad Module, etc.

3.3 Performance Evaluation of the Automated Machine

The effects of the temperature variations, heating filaments on the final moisture content of the dried gaari product were determined using regression and variance analysis. Also, effects of the final moisture content (MCf) on the frying and mash quantity on the final moisture content were determined suing regression analysis. The energy consumption and thermal efficiency of the developed machine was estimated using standard methods. Meanwhile the functional efficiency, throughput capacity, and material loss of the automated gaari frying system were determined using equations below:

3.3.1: Processing Procedure for Evaluating Effect of the Temeperature Variation on Final MC of the Gaari Product.

250 kg of wet mash sample was processed from the TME 419 fresh cassava roots of 1000 kg. The sample was divided into 5 different places each containing 50 kg. The initial moisture content was kept at 30% wb, frying time interval was 60 minutes and the normal speed of the machine was 84 rpm. The sample was fried at the various temperature degrees level, 140, 160, 180, 200, and 220 ^{o}C. The choice this temperature range was chosen based on the report of Nwankpa (2010) which stated in his article titled “analysis of heat and mass transfer of a gaari frying machine” that the temperature range for gaari was between 120 – 200 ^{o}C. This selection is in close result with that of Okorun *et al* (2017) who reported that frying temperature for gaari varies from 180 – 200 ^{o}C in their work. The results of the final moisture content of the dried product were recorded.

3.3.2: Processing Procedures for Evaluating Effect of the Electrical Filaments Variation on Final MC of the Gaari Product.

500 kg of fresh cassava roots TME 419 was harvested, and processed to a friable mash sample with an MCi of 30%, and then the cake was pulverized and sieved using a grating machine and sifter respectively. Total mash sample gotten from the 500 kg of the fresh roots was 284 kg. Thus, 250 kg of wet sample was used for the test running process. The mash was divided into 5 different samples and fried using 2.5, 5.0, 7.5 10.0 and 12.5 kW. The results of the moisture content of the final products obtained were recorded.

3.3.3: Processing Procedure for Evaluating Effect of the Mash Quantity, Time Intervals and Initial MC on Final MC of the Gaari Products

Initial moisture content of the mash: 30, 35, 40, 45, and 50%; time of frying of the mash: 15, 30, 45, 60, and 75 mins: mash quantity: 10, 20, 30, 40 and 50 kg at the frying temperature of 200 ^{o}C were the parameters used. In Day 1, 1000 kg of fresh cassava roots (TME 419) was harvested, peeled using manual peeling method, grated using a grating machine, dewatered with a manual press equipment, pulverized with a help of a pulverizer and sieved with an electrical gaari sieving machine to a fine cassava mash. A mash quantity of 250 kg was gotten from the given cassava root quantity. The sample was divided into 5 different groups at 50 kg per group. Each group (50 kg) was shared into 5 different samples at 10 kg per sample. Each sample was adjusted to an initial moisture content of 30, 35, 40, 45 and 50% wb and fried for a given time interval of 15 minutes. The second to the fifth groups of sample were also adjusted to the same initial moisture content but fried at 30, 45, 60 and 75 minutes frying time intervals.

The same processing procedures were repeated in Day 2 but with a total quantity of mash of 500 kg shared into 20 kg and adjusted to an initial moisture content of 30, 35, 40, 45 and 50% wb and fried at 15, 30, 45, 60 and 75 minutes frying time interval. In Day 3, 750 kg of cassava mash was processed from 3,000 kg of cassava roots, shared into 30 kg per sample, adjusted to the same initial moisture contents above and fried at the time same time intervals in day 1 and 2. Similarly, in Day 4 and 5, 4,000 kg and 5,000 kg of cassava roots were processed and 1000 and 1,250 kg of mash was gotten and shared into 40 and 50 kg per sample respectively. The samples were adjusted to initial moisture contents; 30, 35, 40, 45 and 50% wb and fried at 15, 30, 45, 60, and 75 minutes frying time intervals. All the results of data got were subjected analysis using ANOVA at $\alpha = 0.05$.

3.3.4: Experimental Procedure for Energy Consumption and Thermal Efficiency

The energy consumption and thermal efficiency was determined using the equation stated by Choi and Okos (1986).

$$Q_u = W_c C_c (T_f - T_i) + W_d h_{fg} (M_i - M_f) \quad \text{.........(3.48)}$$

W_c means mass of wet cassava mash added to the fryer (50 kg),

C_c means the wet cassava mash specific heat capacity (3.29 kJ/kg°C) calculated using Choi and Okos' model (1986),

T_f means the cassava meal's final frying temperaturel = optimum temperature = (183 °C)

T_i means the temperature of the cassava mash when it was first made which was 25°C,

W_d means the dry matter content of cassava garri mass (43.5 kg),

h_{fg} means the vaporization heat of water at the frying temperature (2.2834kJ/kg),

M_i means the cassava mash's initial moisture content (MCi) (30% wet basis)

M_f denotes the cassava mash's final moisture content (MCf) (12.6% wet basis).

$$Q_a = (2.92 + 0.162t) \times 10^3 \quad \text{for experiments using } 0.0075\ m^3/s \qquad (3.49)$$

$$Q_a = (1.30 + 0.292t) \times 10^3 \quad \text{for experiments using } 0.03\ m^3/s \qquad (3.50)$$

Where,

Q_a is the true heat dissipated by the heating components (kJ), while *t* is the frying time (minutes) required to achieve the specified final moisture content for the cassava. η_t (%) is the thermal efficiency and t is the frying time (minutes) needed to acomplish the specified MCf for the cassava.

$$\eta_t = \frac{Q_U}{Q_a} \qquad (3.51)$$

3.4 Optimisation of the Machine Parameters

Optimization analysis was carried out using Response Surface Methodology (RSM) in Design Expert 10 Application Software. In the optimization process, Response Surface Methodology (RSM) at 4-factors and 5-levels (Initial Moisture Content 30, 35, 40, 45, and 50%; Frying Temperature 140, 160, 180, 200, and 220 ^{o}C; Frying Time 15, 30, 45, 60, 75 minutes; and Mash Quantity 10, 20, 30, 40, 50 kg) was used to carry out the simultaneous testing of the effects between and within parameters in the optimum experiment. The raw data of the independent variables (Initial MC, temperature, time, and mash quantity) were inputted into the research software. The design of the experiment and data used in the software is presented in Table 3.1. The software generated 25 runs experimental design at two responses (Final MC and Throughput Capacity).

Table 3.1: Experimental Design and Data Used in RSM

	Factor 1	Factor 2	Factor 3	Factor 4	Response 1	Response 2	Response 3	Response 4
Run	A:Mash Quantity	B:Frying Time	C:Initial MC	D:Temperature	Throughput Capacity	Functional Efficiency	Heat Energy	Thermal Efficiency
	kg	Mins	%	Degree Celcius	kg/hr	%	J	%
1	10	15	50	220	27.2	68	3477.62	61.23
2	40	15	30	140	146.8	91.75	5255.85	92.5
3	30	30	40	160	49	81.67	5896.11	58.61
4	50	75	30	220	33.12	82.8	16751	72.2
5	10	75	40	220	4.4	55	3400.37	14.66
6	50	15	40	220	184.4	92.2	5630.19	99.12
7	50	45	40	160	62.13	93.2	10672.5	73.9
8	50	75	50	220	35.2	88	18793.2	81
9	20	30	50	140	30.4	76	3900.72	38.77
10	30	30	40	160	49.6	82.67	7039.32	69.97
11	10	15	40	140	32.8	82	1794.51	31.59
12	30	15	50	180	102.4	85.33	5595.99	98.52
13	50	30	50	140	90.6	90.6	9748.61	96.9
14	10	60	35	180	6	60	2698.82	11.85
15	20	30	30	180	29.6	74	4851.13	48.22
16	10	15	30	220	26	65	3252.6	57.26
17	10	75	30	140	4.64	58	1968.9	8.49
18	10	60	35	180	6.2	62	2703.62	14.37
19	50	75	40	140	36.08	90.2	11402.6	49.15
20	10	75	50	140	4.8	60	2220.42	9.57
21	30	45	40	220	31.73	79.33	10367.6	71.8
22	50	75	40	140	60.27	90.4	17706.6	76.32
23	50	45	30	180	59.87	89.8	13617.1	94.3
24	30	15	50	180	100.8	84	5578.12	98.21
25	30	45	40	220	31.47	78.67	10674.7	73.92

Further results analysis generated model equations (Appendix Two) for both initial moisture content and throughput capacity in coded and actual factors. Four distinct models were tested using multiple linear regression with a 95% confidence level. The R^2 and probability of prediction F ratio tests were used to determine the models' legitimacy. The model of best fit was chosen based on the highest polynomial order with considerable additional terms and no aliasing, insignificant lack of fit, maximizing of the "Adjusted R^2 value and the Predicted R^2 value.".

By comparing experimental and calculated data, the models were found to be valid. The significance and fitness of each equation, as well as the interactions of responses and variables, were determined using analysis of variance. Optimal parameters were validated by conducting experiments and comparing experimental values to predicted values during the demonstration of the optimization process. The models were evaluated with the help of the Chi-square goodness of fit test.

3.5 Statistical Analysis

The experimental data obtained were collected and analyzed using the following statistical tools: descriptive analysis, inferential analysis, statistical quality control and Research Surface Methodology (RSM). The descriptive analysis such as mean, standards deviation and charts were used for the explanation of the parameters in the study. The ANOVA was used as one of the major statistical research for the separation of means under various experimental samples. The comparison between samples means was carried out using Duncan Multiple Range Test (DMRT). The DMRT was used to carried out the Least Significant Difference test for the separation of means that were significant different from each other at $P < 0.05$. RSM in Design Expert software (Version 11.0 Stat-Ease, Inc., Minneapolis, USA) was used to determine the most optimum processing parameters for the automated gaari fryer. The desirability surface response method was employed by tracing the profile generated to predict optimum dependent processing parameters of the fryer. Then correlation of determination of relationship between experimental and predicted dependent processing parameters was established.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Comparative Study of the Existing Mechanical and Manual Gaari Processing Methods

4.1.1 Energy Consumption of Mechanical and Manual Fryer

Table 4.1 shows the diesel consumption of the existing mechanized gaari frying machine (Niji Lukas Model). The overall average quantity of the diesel fuel consumed at 30 kg mash sample with initial moisture content (30%) was 19.36 litres. In other words, 1 kg of cassava mash sample takes approximately 0.65 liter of diesel to be fried as shown in Table 4.2. Since a litre of diesel was purchased at ₦285, it could be found that the total amount spent on diesel in processing 30 kg mash sample was ₦5,517.6 (Table 4.2). This was the major reason behind the high operating cost of the mechanical fryer. However, with manual fryer, the total amount spent on 30 kg mash sample was ₦300 using 30 kg of firewood. It can be concluded that mechanical fryer consumes more energy than the manual fryer. It was found that the manual fryer was economical and less expensive but stressful and drudgery. The processors underwent heat stress and the whole frying operation was time consuming. The two fryers were allowed to reach a drying state with final moisture content (MCf) of 12.5% wb in accordance with results of MCf of 12.6% wb by Olagoke *et al.* (2014), 13% wb by Rufus and Odo (2018), and 12.14% wb by Nwadinobi *et al.* (2019). Thus, it was the same research problem with much diesel consumption that led to the use of electrical filaments in modification and upgrading of the mechanized fryer.

4.1.2. Timeliness of Operation

Table 4.3 shows the comparison in time taken for both the mechanical and manual fryers to process a given quantity of gaari sample.

Table 4.1: Determination of the Diesel Consumption of the Mechanical Fryer

Group	Mash Quantity (Kg)	Starting Diesel (L)	Ending Diesel (L)	Consumption Rate (L/Min)	Frying Temperature (^oC)	Frying Time (Min)	Final MC (% wb)
A	30	120	100.6	19.4	220	54.48	12.5
B	30	100.6	81	19.6	220	54.59	12.5
C	30	81	61.7	19.3	220	54.45	12.5
D	30	61.7	42.6	19.1	220	54.47	12.5
E	30	42.6	23.2	19.4	220	54.52	12.5
Average	**30**			**19.36**			**12.5**

Table 4.2: Determination of Unit Price and Energy Consumed by Mechanical and Manual Fryer

Fryer Type	Energy Type Diesel (Litres)	Firewood (kg)	Qty Used	Mash Qty (kg)	Unit Price (₦)	Amount (₦)
Mechanical	1	-	19.36	30	285	5,517.6
Manual	-	1	30	30	10	300

Table 4.3: Timeliness of Operation Comparison for Mechanical and Manual Fryer

Mechanical				Manual	
Qty In (kg)	**Time (mins)**	**Qty out (kg)**	**Initial MC (%)**	**Time (mins)**	**Qty out (kg)**
10	26.0	5.00	30	32.0	4.00
20	42.0	11.0	30	49.0	8.50
30	55.0	20.20	30	62.0	13.20

In a constant moisture content of 30% wb, the mash samples of 10, 20 and 30 kg took both mechanical and manual fryers 26; 42; 55 minutes and 32; 49; 62 minutes to process respectively. As the loading (mash) quantity increases, the final quantity of the product increases with a progressive increase in time. The finding is in concordance with that of Mohammed *et al.* (2021) who stated that additional increment of product during frying increases time while the frying temperature decreases. Onyekachi and Anthony (2018) reported frying time of 25 – 40 minutes with mash quantity of 5 – 10 kg sample, depending on the operator. This is in a close confirmation with the findings found in this study during the assessment of the manual frying equipment when 32 minutes time interval was obtained at the frying operation using 10 kg mash sample. Thus, the mechanical fryer has better processing time than the manual fryer.

One of the challenges observed with the mechanical fryer that was usually increasing its frying time was the unexpected shutting down of its burner (heat source) in between the operation (Appendix seven, Plate 7.3). This usually happen when bad diesel is used or the burner filter is dirty. Another deficiency observed was linked to its frying mechanism (gear system, driving system and paddles). The gear speed was slow. The slow movement of the machine was the reason for the modification of the gear system of the machine which improved the frying performance of the proposed equipment under study with regards to time and speed of operation. Had it been that the mechanical fryer was without these issues, the result would have been much better than what was obtained.

4.1.3. Efficiency and Throughput Capacity Determination

Table 4.4 shows the efficiency and throughput comparison of mechanical and manual gaari fryers. At the constant moisture content of 30% wb, the efficiencies of the mechanical and manual fryers at 10, 20, 30 kg mash sample were 50, 55, 57% and 40, 42.5, 44%, respectively. This shows that mechanical fryers performed better than the manual fryer. Also, across the table, it was observed that as mash quantity of the sample increases, the efficiency of both mechanical and manual fryers increases. This implies that efficiency is a function of mash quantity i. e. efficiency is largely dependent on mash or loading quantity which resulted in the direct relationship of the two parameters. This result is similar with that reported by Ajav and Akogun (2015) which stated that

Table 4.4: The Efficiencies and Throughput Capacities Comparison of Mechanical and Manual Fryers

Mash Sample (kg)		**Efficiencies (%)**		**Throughput Capacity (Kg/hr)**	
	Initial MC	**Mechanical**	**Manual**	**Mechanical**	**Manual**
10	30	50.0	40.0	8.00	7.50
20	30	55.0	42.5	13.21	9.44
30	30	57.0	44.0	18.70	14.66

the sifting efficiency increases with the mash quantity and decreases with moisture content. Similarly, the throughput capacity of the mechanical and manual fryers at the same 10, 20 and 30 kg of the mash sample were 8,0, 13.2, 18.70 kg/hr and 7.50, 9.44, 14.66 kg/hr under a constant 30% wb of MCi. It was found that as the mash quantity increases from 10 – 50 kg, the throughput capacity of mechanical and manual fryer increases from 8 – 18.70 kg/hr and 7.5 – 14.66 kg/hr, respectively. Thus, this is in similar with the result of Adeniji *et al.* (2018) which stated that increase in mash quantity lead to increase in throughput capacity. It was observed that the mechanical fryers had higher throughput capacities than the manual fryer because throughput is inversely proportional to frying time. Mechanical fryer has lower frying time when compared with the manual fryer, thus, high throughput was obtained by the mechanical fryer.

4.1.4. Cost Analysis of the Mechanical and Manual Fryer

The overall estimated production cost of the mechanical fryer was ₦700, 000, while that of the manual fryer was ₦185, 400. These production costs are only the cost of materials used in fabricating the fryers plus cost of labour (workmanship) as presented in Tables 4.5 and 4.6. However, according to IITA cassava processing factory manager, the fryers under review (Niji mechanical and manual fryers) at the factory were purchased at ₦1,500,000 and ₦350,000, respectively together with their delivery and installation costs. The mechanical fryer required a total operating cost of ₦699,936 to produce 3,630 kg of gaari product for 22 working days as shown in Table 4.7. The diesel consumption (₦607,636) accounted for 86.71% of the total running cost. However, the manual fryer required ₦61,000 operating cost to produce the same quantity of gaari sample (3,630 kg) at approximately 36 days depending on the expert person frying, nevertheless, it took 3 women to complete the task at 22 days. Although, the manual fryer is highly economical and less expensive to acquire but there are a lots of drudgery and health risks (Appendix seven, Plate 7.4) associated with it which makes it not the best option for processors.

Table 4.5: BEM for Mechanical Gaari Frying Machine

S/NO	MATERIALS USED	SPECIFICATIONS	Qty	UNIT PRICE(₦)	AMOUNT (₦)
1.	Angle Iron	50 x 50 x 5 mm	1 ½ lgths	6, 500	13, 000
2.	Stainless Plate	3 mm	1	90, 000	90, 000
3.	Pulley Double Groove	14’’ diameter	1	15, 000	15, 000
4.	Pulley Double Groove	12’’ cm diameter	1	10, 000	10, 000
5.	Stainless Electrode	2.5 Gauge	1pack	13,000	13, 000
6.	Electric motor	2hp	1	25, 000	25, 000
7.	Pillow Bearing	205	6 pcs	3, 000	18,000
8.	Diesel Burner	T14	1	16000	160,000
9.	Bolts and Nuts14, 19	2’’ inch	24 pcs	100	2, 400
13.	Belts	B45	2	1, 000	2, 000
14.	Shaft	32 mm	4 feet	12, 000	12,000
15.	Flat Beam	4’’ x 4’’ x 8mm	1 length	25,000	25,000
16.	Body filler + Hardener	Abro	4 litre	6, 000	6, 000
17.	Chain and Sprocket	4 and 12’’	1	20,000	20,000
18.	Steel Hinges	½’’ rod grove	2	500	1, 000
19	Mild Steel plate	2 mm thick	2	20, 000	40, 000
20.	Paint (Aluminum)		4 Litre	3, 500	3, 500
21.	Mild Steel Electrodes	Gauge 12	1 pack	2, 500	2, 500
22.	Filing and Cutting Discs	9 inches	7 pcs	900	6, 300
23.	5/8 Rod	½ inch	1 length	1, 500	1, 500
24.	Aluminum Paddles	-	4	3, 000	12,000
25	Operating Board	Electrical	1	35, 000	35,000
26.	Rolling				7,000
27.	Bending				5, 000
28.	Turning				5, 000
29.	Depreciation				48,200
30.	Workmanship Cost				100,000
				TOTAL	**700, 000**

Table 4.6: BEM for Manual Garri Frying Machine

S/NO	MATERIALS	SPECIFICATIONS	Qty	UNIT PRICE (₦)	AMOUNT (₦)
1.	Angle Irons	60 x 60 x 5mm	1 length	8, 500	8, 500
2.	Stainless Plate	3 mm	1	90, 000	90, 000
3.	Mild Steel Plate	1.5 mm	1 and 1/2	9, 000	14, 500
4.	Stainless Electrode	2.5 Gauge	½ pack	6,500	6, 500
5.	Mild Steel Electrode	2.5 Gauge	½ pack	1, 500	1, 500
6.	Chimney – Abestor pipe	6 inches diam	1 length	12, 000	12, 000
7.	Filling and Cutting Discs	9inches	6 pcs	900	5, 400
8.	Body filler + Hardener	Abro	1 litres	3, 000	3, 000
9.	Paint	Black	1 lites	3, 500	3, 500
10.	Depreciation				10,500
11.	Labour				30,000
				TOTAL	**185, 400**

Table 4.7: The Operating Cost Determination for Mechanical and Manual

Parameters	**Mechanical Fryer**	**Manual Fryer**
Average Production/Day (kg)	165	165
Production for a Month (22 Working Days in kg)	3,630	3,630
Cost of Energy Consumed For 22 Working Days (₦)	607,636	36,300
Repair/Servicing Cost for 22 Working Days (₦)	45,000	Nil
Replacement of Damage Parts for 22 Working Days (₦)	11,300	Nil
Casual Labour for 22 Working Days (₦) @18,000	36,000	54,700
Total Operating Cost for 22 Working Days (₦)	**699,936**	**61,000**

High diesel consumption rate of this mechanized fryer was what makes the fryer uneconomical to industrial processors and therefore, required a modification. According to the factory manager, at a point in the factory, the choice of a gas burner was being considered as a substitute to its heat source which is still not okay for commercial production.

4.2 Machine Description

The automated gaari frying machine was developed (Plate 4.1). It has three (3) major component parts; the mechanical, electronic and electrical. The mechanical component part is the unit that carries out the frying operation of the machine. The component parts in contact with food materials are were produced with food grade materials (stainless) while the parts that are not in contact with the food materials were made of mild steel materials as recommended by Akinnuli *et al.* (2015) and Shittu and Ndirika (2007). The electronic part is the unit that receives the data inputted into the machine, processes it and stores the information in the memory of the machine. The electrical component part is the unit that controls the electrical system of the machine. The overall dimension of the machine was 100 cm x 64 cm x 140 cm. The volume of the cylinder was 167,305.22 cm^3, while the surface of the frying pan was 16,891.39 cm^2. The machine was powered electrically using a 2 hp, 3 phase, 220V, 60 hertz frequency, 1440 rpm electric motor.

The automated gaari fryer is gender friendly and can be operated by only one operator. Under prevailing standards of engineering design, the machine was considered to have the following design parameters: high efficiency and throughput; beauty of line and proportion; safety of operation and convenience or comfort in use; ease of maintenance and serviceability; functionality and durability.

Plate 4.1: The Automated Gaari Frying Machine

4.2.1 The Frame System

The frame (Plate 4.2) has 4 major parts; the upper, lower base, right and left arms. The upper part housed a set of driving unit such as the pulleys, the chain and sprockets system. It further anchored the 3 driving shafts to the lower base part. The lower base braced the upper, right and left arm of the frame, thereby creating rigidity to the entire frame. It anchored the gear system (twin set of teeth) that controls the movement of the mechanical frying paddles and helped to hold the 3 driving shafts in upright position through the help of 3 set of 205 pillow bearings. While the left and right arms were responsible for fixing the entire frame to the frying chamber of the machine to make it a complete machine. The frame is an important part of the machine as it helped to give the machine its rigid support and esthetic look. It also supported the electric motor that drives the entire system of the machine. The dimension of the upper part was 85 cm x 25 cm, lower base was 76 cm x 25 cm, left and right arms are the same and was 110 cm x 25 cm. In the formation of the frame that controls gear system, and frying mechanism of the machine, 25 cm x 10 cm x 8 mm thickness of a U-channel metal and 2.5 cm x 3 mm of a flat bar were used. The materials selection was as recommended by Akinnuli *et al*. (2015).

4.2.2 The Frying Pan

This is the cylindrical form-like chamber made with two major compartments: the inner and outer. The inner chamber is the compartment where gaari frying takes place. The frying pan (Plate 4.3) was built with a 4 mm high stainless steel (HSS) plate because it is the area in contact with food materials (Dalipi *et al.*, 2015). 4 mm thickness of HSS was used to accommodate the high heating effects of the electric filaments so as to prevent materials hugging or sagging or permanent deformation under the application of heat. Two pieces of 50 cm x 50 cm x 5 mm angle iron of 55 cm length each were used to brace the inner chamber underneath to provide rigidity to base of the fryer. The choice of the stainless plate was to prevent corrosion effect of materials which might set in because of diffused moisture and oxygen inherent in the food materials to be fried. However, if mild steel materials or plates were used corrosion would occur and enter into the food substance. The outer chamber was built with 2 mm mild steel plate where there is no any health implication. This compartment housed

Plate 4.2: The Frame of the Machine

Plate 4.3: The Frying Pan of the Machine

the electrical heating filaments and the heat resistant fibres and cables of the fryer to enable the outermost chamber of the fryer remain cool during the frying process. The diameter, perimeter and total surface area of the frying pan were 64 cm, 201 cm and 16,891.39 cm^2 respectively.

4.2.3 The Driving System (Mechanism)

This comprises of Electric motor, pulleys, chain and sprocket system and the gear system. The 4 aluminum pulleys (7.5, 10, 30 and 35 cm) and 2 sprockets (30 and 10 cm) were used to drive 39 and 43 sizes of B-fan belts and chain 102 size of chain, respectively. The 7.5 cm (3 inches) aluminum pulley from the electric motor was connected to the 30 cm (12 inches) aluminum pulley on the first driving shaft of the machine using an A39 fan belt. Beneath the base of this same shaft was a 10 cm (4 inches) aluminum pulley which was connected to the 35 cm (14 inches) aluminum pulley on the second driving shaft of the machine. Also, under this second shaft was a 10 cm (4 inches) sprocket that was connected to 30 cm sprocket on the third driving shaft with a chain system. This third shaft transmits the motion to the gear system that carries the frying paddles of the machine known as "mechanical hands". It was the strategy that was used to decrease the operation speed of the 3-phase electric-motor used from 1440 rpm to 84 rpm which was later used as the operational speed of the machine throughout the operations.

The gear system (Plate 4.4) is made up of two gear teeth (big and small) and shaft. The big gear teeth with diameter 22.5 cm (9 inches) was fixed on the lower base of the frame while the small gear teeth with diameter 8.75 cm (3.5 inches) was used by welding it on a shaft that bears the paddles frame and it was also connected to the third driving shaft of the machine. So that when this shaft rotates, the small gear teeth moves on the circular motion along the walls of the big gear teeth that is fixed, thereby transmitting the motion to paddles frame. In so doing, the gaari was being turned and fried at the application of heat.

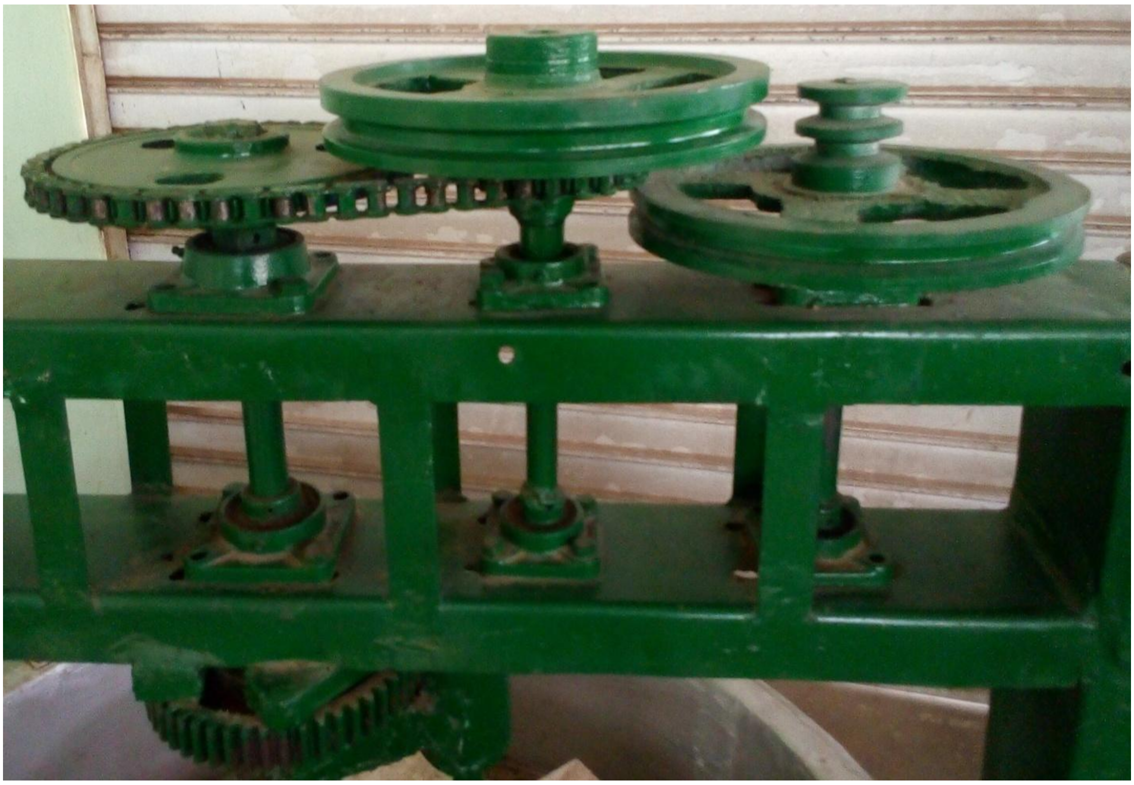

Plate 4.4**:** The Driving System (Mechanism) of the Machine

4.2.4 The Frying Mechanism

This is the mechanical hand or paddles. It is the system that is responsible for frying of the gaari. The frying mechanism (Plate 4.5) was made with 32 mm mild steel shaft, 15 x 15 cm mild steel base plate of 3 mm thickness, a cross sectional 2.5 x 10 cm (4 and 1 inch) bended stainless plate of 1.5 mm thickness, 4 pieces of aluminum paddles, 2.5 cm x 2 mm thickness of flat bars, bolts and nuts. The paddle frame dimension was 58 cm by 10 cm by 2.5 cm. Shaft of 32 mm from the small gear teeth was anchored to the paddle frame with the help of base plate and 4 pieces of 17 mm stainless nuts and bolts. The paddle frame was built with 1.5 mm thickness of a stainless plate which was formed into U-shaped 4 x 2.5 cm. At the four corners of frame arms were U-formed stainless flat bars that anchored the paddles to frame with 13 mm bolts & nuts. This section of the machine is part that it is usually turned off last after any given operation. As soon as frying operation is over, the discharge chute is let open and the continuous movement of the frying paddles pushes the dried products out of the machine. Most times, the products are also allowed to cool inside the frying pan but the frying mechanism must be on and in continuous stirring to prevent the products from burning.

When the product is ready to be evacuated, there is a gate plate at the outlet discharge chute area where the products can come out from. If the mechanical paddles are still working and the gate plate is opened, the product can easily come out without the help of an external force. The discharge chute was built in a tilted form in such a way that the product can easily flow out into a collection chamber and it was made with a stainless plate since its surface area is always in contact with consumable food materials.

4.2.5 The Electronic System of the Machine

The automated unit (Plate 4.6) of the gaari frying machine with a PIC16f877A microcontroller has a high performance, low power consumption, and supports software and hardware tools such as debuggers and compliers. This microcontroller is simple to operate, and its coding or programming is equally straightforward. One of the primary advantages of using FLASH memory technology (the microcontroller) is that it may be write-erase as many times as

Plate 4.5: Frying Mechanism of the Fryer

Plate 4.6: The Electronic Component Part of the Machine

needed. It has a total of 40 pins, where 33 of them are used as output and input pins. It has a frequency range of up to 20 MHz. The operating voltage is in the range of 4.2 and 5.5 volts.

The main voltage from power supply unit was reduced from 240V AC to 18V AC using a 9V-0V-9V transformer. Four (4) rectifiers were used to rectify 18 AC. The rectifiers' output was filtered by a 2000 F capacitor, which ensured that the system's DC supply was ripple free. The 7812 IC was used to control the DC supply output to 12V and the 7805 IC to 5V with a 12 V relay. The microcontroller was given 5 volts. The microcontrollers then process and control the set of instructions that have been programmed into them. The main distribution board furnished a distribution cabinet for both mechanical and electronic systems (DB). A push button and a resistor are attached to the first pin, known as the master clear (MCLR) pin, to reset the microcontroller as when due. The pin is already powered by a steady 5V supply. The IC is reset by pressing the push button, which resets the controller by bringing the MCLR pin to 0 potential.

4.2.6 The Electrical System of the Machine

The electrical system of the machine was built in a single unit called the distribution cabinet which comprises of circuit breaker, contactor, intermediate relays, push buttons switch, thermal relays, indicators, limit switches and cam switches. These 8 major components were what made up the electrical control loop. There are high and low voltage circuit breakers depending on the scope of use. However, the low circuit breaker was used for this system of automation. It was a combination of an overheating relay and a fuse switch. Its functions here were to distribute electrical energy to the machine, start the electric motor, protect the power lines and the motor when there is a power a serious surge, short-circuit, overload or and under-voltage faults. When this happens, the circuit breaker automatically cut off the circuit without damage to the system and a reset is then necessary without replacement of any component part. AC contactor was used which it has main and auxiliary contact. The auxiliary contact was used to control the circuit while the main contact was used to terminate the main circuit..

Thermal relay was used to control the heating effects resulting from high voltage. When the current flowing into the circuit is higher than the required, the heat element produces heat which makes the bimetallic strip with various coefficients of expansion to bend. When this bending reaches a particular distance, it causes the contactor to open the control circuit and then the power is dissipated. Then, the main circuit is disconnected to realize the overload protection of the motor. The intermediate relay was used to amplify the signal i.e increases the capacity of the contact relay. It helps the voltage relay more especially when its number of contact pairs is not enough to expand its contact pairs. To control the on and off electrical coil currents involving relays, contactors and electromagnetic starters, the push button is used which starts or stops instruction in the circuit.

4.3 Performance Evaluation of the Automated Gaari Frying Machine

The automated gaari frying machine was evaluated based on the effect of temperature variation on final moisture content, heating filaments on final moisture content, mash quantity and frying time on final moisture content. The performance efficiency was based on functional efficiency, throughput, energy consumption and thermal efficiency.

4.3.1 The Effect of Temperature Variations on the Final Moisture Content

Table 4.8 shows the temperature variation on the final moisture content. At the constant mash sample (50 kg), initial moisture content (30% wb) and frying time (60 mins), the frying temperature increases from 140 to 220 ^{o}C, the final moisture content decreases from 23.4 to 9.8% wb. At 23.4 % wb moisture content, the product was still having much quantity of moisture content and gaari sample was not properly formed. Thus, more energy is needed for drying at that stage. At 160 ^{o}C, with the corresponding final moisture content of 19.8% wb, the product texture obtained was not good enough as it was powdery and not well gelatinized as a result of the low heat (see sample B). The product at this stage was prone to spoilage during storage. Although, Duduyemi *et al.* (2016) stated that 160 ^{o}C gave them best drying product but at 5 kg wet sample and 25 – 22 min time intervals. This is small quantity when compared with the 50 kg of sample used here. At 180 ^{o}C, it was observed that the product was okay, but not within the acceptable limit of drying.

This result of the frying temperature of 180 ^{o}C produced a good product with final moisture content of 13.3 % wb in terms of texture, and colour but the sample was not well dried. This final moisture content is in a close range with 13 % wb result of Rufus and Odo (2018) that a dry gaari product could actually be stored at 13 % moisture content. However, at 200 ^{o}C frying temperature, a better result in terms of texture, colour and dryness was obtained which was in conformity with results stated by Olagoke *et al.* (2014) with 12.6% for storage (Sample C). The finding is in concordance with that of Nwadinobi *et al.* (2019) and Ikechukwu and Maduabum (2012) with final moisture content of 12.14% and 12% wb, respectively. However, at frying temperature of 220 ^{o}C, final moisture content was 9.8% with a negative impact on the products (Sample A). It formed much burnt lumps and was not visually acceptable as it was looking burnt. The result of the gaari sample produced at 220 ^{o}C frying temperature was not acceptable during the visual inspection of the sample.

4.3.2 Effect of the Heating Filaments on the Final Moisture Content

From Table 4.9, an increase in filament capacity from 2.5 to 12.5 kW reduces the MCf from 26.4 to 9.2 % wb at a constant mash quantity (50 kg),initial moisture content (30% wb) and frying time (60 minutes). This implied that there was an inverse relationship between the filament capacity and final moisture content. That is, the moisture content was largely dependent on the heating filament capacity from. This result was concomitance with that of Adeniyi *et al.* (2018) i. e. increase in heat filament leads to the corresponding decrease in moisture content of the mash. This statement agreed with the report published by Sanni *et al.* (2016) who showed that increase in the heating element of 1,800 W capacity from 1 to 6 in the dryer, generated and raised sufficient heat energy with drying temperature of 140^{o}C to 200^{o}C that was used to achieve the drying operation of the sample.

At 2.5 kW heating filament, when mash quantity, initial moisture content and frying time were held constant, the final moisture content of sample was 26.4% wb. At this time, it was observed that the heat intensity was very low and the product was not dried. However, at 5.0 and 7.5 kW heat obtained was not sufficient, and their final moisture contents were 21.5 and 14.1% wb, respectively. Thus, the products obtained were not well dried. But at 10.0 kW,

Table 4.8: Temperature Variation vs Final Moisture Content

Sample (kg)	**Temp (^oC)**	**Frying Time (mins)**	**Initial MC (%)**	**Final MC (%)**
50	140	60	30	23.4
50	160	60	30	19.8
50	180	60	30	13.3
50	200	60	30	12.6
50	220	60	30	9.8

Table 4.9: Electrical Filament Capacity Determination

Sample (kg)	**Filament Capacity (kW)**	**Time of Frying**	**Final MC (%)**
50	2.5	60	26.4
50	5.0	60	21.5
50	7.5	60	14.1
50	10.0	60	12.3
50	12.5	60	9.2

an adequate heat intensity was obtained which was capable of frying the product to a good storable moisture content of the product required within the range of 12 – 12.7% as stated by Duduyemi *et al.* (2016) and Igbeka, (1995). The product had a fine texture, quality colour and well dried with moisture content of 12.3% wb. Also, at 12.5 kW, a very high intensity occurred which led to burning of product sample in the fryer. It was also noticed that the gaari obtained from 5 kW electrical filaments was not really gelatinized while that obtained from 12.5 kW formed much big seeds and started burning at about 60 minutes of frying.

4.3.3 The Effect of the Mash Quantity and Frying Time on the Final Moisture Content of Gaari.

Table 4.10 explains the effect of time intervals on the final moisture content (MCf) of gaari. The results obtained depicted the direct relationship that existed between the moisture content and the rate of frying. It was observed that as the frying time increased from 15 – 75 minutes time interval, the MCf of the sample decreased from 25.5 to 10.23% db with an average Mean of 16.49 (±7.38) at $p \leq 0.05$. However, statistically, there was a significant difference only from the interval 15 – 60 minutes with the mean values from 25.5 – 15.07%. Meanwhile, there was no significant difference between 60 and 75 minutes in time interval of the sample of the final product with final moisture content mean values 11.72 and 10.23% wb, respectively. This result is similar to that of Onyekachi and Anthony (2018) who in their report noted that an increase in frying time leads to fall in the MCf of the product. Also, Abasi *et al* (2009) and Correia *et al* (2015) illustrated the significant effect of moisture content on increasing rate of drying time and temperature. They further concluded that rise in these drying parameters (time and temperature) results in reduction of the MCf of the final garri products.

In Table 4.11, the overall results showed that as mash quantity of the cassava sample increased from 10 – 50 kg, the final moisture content increases from 11.71 – 20.9% wb. This showed that there was a direct positive relationship, therefore, increase in any of the parameter leads to corresponding increase in the other. There was a significant difference between 10 – 30 kg (with mean value of 11.71 – 17.02%) while there was no significant different between 30 – 40 kg mash sample. Another significant difference was observed between 40 – 50 kg

Table 4.10: ANOVA of the Effect of Time on the Final Moisture Content of the Dried Sample

Frying Time	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
15	25	25.508[a]	7.0295	1.4059	22.606	28.410	13.6	39.0
30	25	20.008[b]	6.1872	1.2374	17.454	22.562	10.2	32.9
45	25	15.072[c]	4.5636	.9127	13.188	16.956	8.3	24.2
60	25	11.672[d]	1.9705	.3941	10.859	12.485	7.7	15.4
75	25	10.236[d]	2.0824	.4165	9.376	11.096	5.2	13.1
Total	125	16.499	7.3795	.6600	15.193	17.806	5.2	39.0

Table 4.11: ANOVA Effect of the Mash Quantity on the Final Moisture Content of the Product

Final MC

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
10	25	11.712^{c}	3.6324	.7265	10.213	13.211	5.2	20.6
20	25	14.528^{bc}	5.6552	1.1310	12.194	16.862	6.7	27.5
30	25	17.024^{ab}	6.5307	1.3061	14.328	19.720	8.1	30.4
40	25	18.316^{ab}	7.9178	1.5836	15.048	21.584	9.8	35.8
50	25	20.916^{a}	8.8813	1.7763	17.250	24.582	9.1	39.0
Total	125	16.499	7.3795	.6600	15.193	17.806	5.2	39.0

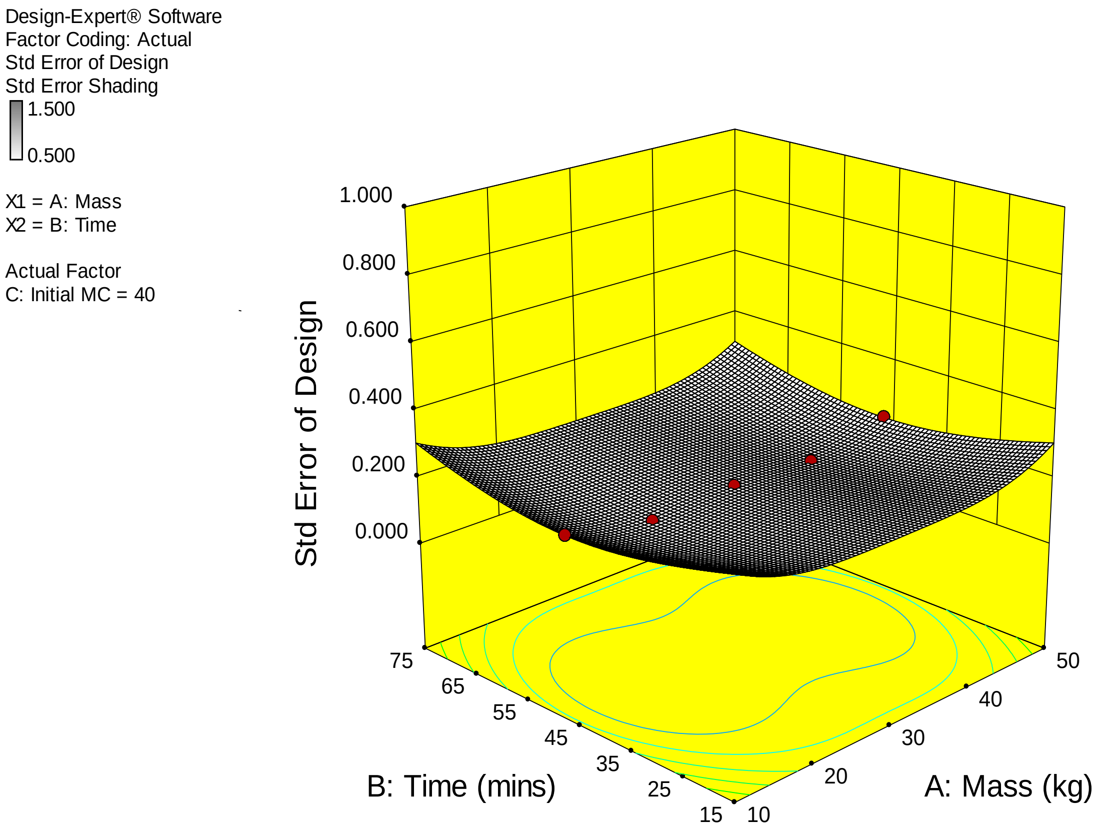

Fig. 4.1: Standard Error Graph of the Samples Used

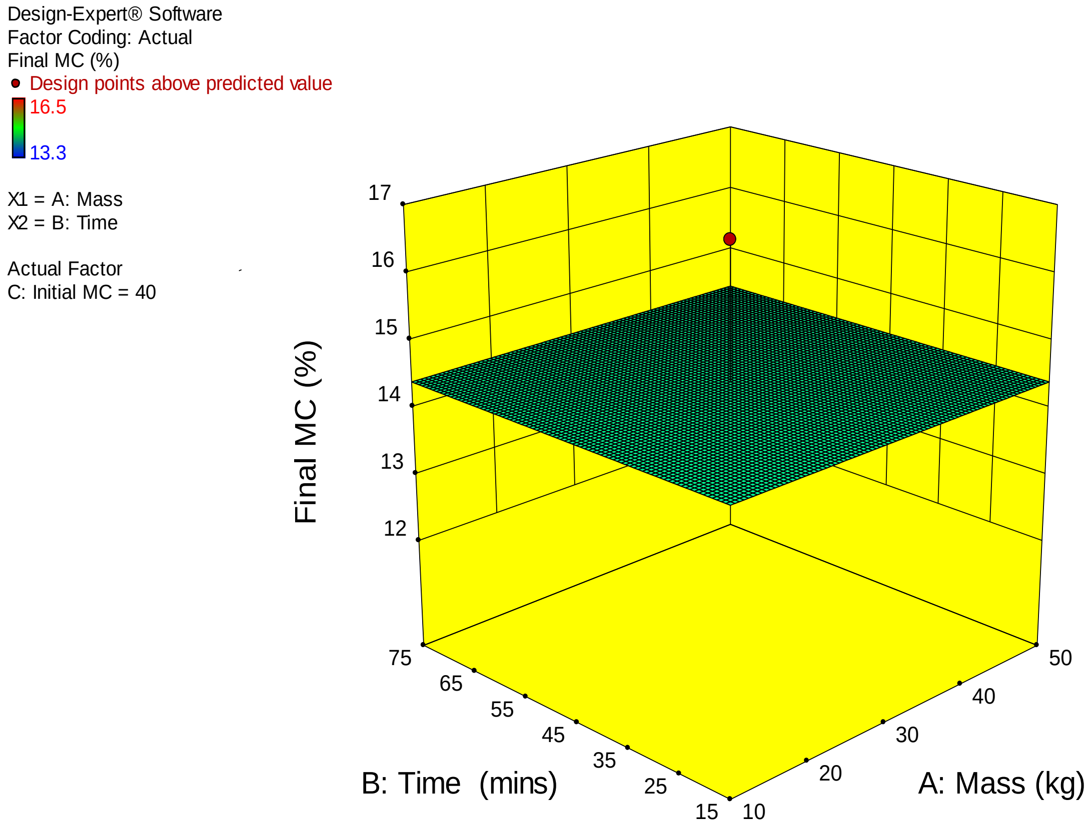

Fig. 4.2: Effect of Mash Quantity and Frying Time on Final Moisture Content

with a mean value interval of 18.3 – 20.9%. Figure 4.1, shows the standard error value of the sample used. The result obtained signified that since the standard error of 0.4 value was achieved, therefore, the mean values of the samples used were adequate (accurate). While Figure 4.2 shows the surface 3D interaction of the frying time, mash quantity and final moisture quantity at initial moisture content variation from 30 – 50% wb. From the result analysis, it was found that the frying time increases with decrease in the final moisture content of the product as mash quantity increases. Surprisingly, as the frying time increased to 75 minutes at a mash quantity of 10 kg and initial moisture content of 30%, the final decreased to 5.2% (Appendix Eight, Table 8.1 – 8.5). While at 20 kg and 30 minutes at initial moisture content of 35%, the final moisture content was observed to have increased to 14.4%. Also, at 30 kg and 45 minutes at initial moisture content of 40%, the final moisture content increased to 16.5%. This result is in close agreement with that of Nwadionobi *et al.* (2019) who described how he achieved 23 minutes frying time with 12 kg of mash sample at initial moisture content of 42% wb, 20 rpm and 8 kg charcoal. However, at 40 kg and 60 minutes at initial moisture content of 45%, the final moisture content was observed to have reduced to 14.2. Also, at 50 kg and 75 minutes at initial moisture content of 50%, the final moisture content decreased to a minimum value of 13.3%. The result complied with that of Duduyemi *et al.* (2016), Olagoke *et al.* (2014) and Adeniyi *et al.* (2016) who agreed that the final moisture content normal range varies from 12.5 – 13.5% for good storage of gaari product. The different samples of the gaari produced by the automated garri frying machine are presented in Plate 4.7a – 4.7b.

4.3.4 Heat Energy and Thermal Efficiency of the Automated Fryer

The useful heat energy (Q_u) consumed in the frying process was 7.91978 x 10^3 kJ. It was the energy needed to increase the cassava mash temperature and the energy needed in drying and vaporization. While the actual heat dissipated by the heating filament was 12.528 kJ. The thermal efficiency of the fryer was 42.74%. The conductive dryer's performance is within the range of 25 to 70% recommended for rotary dryers, as stated by Sanni *et al.* (2016), which is still within the range of the thermal efficiency recommended by

Plate 4.7a: The Different Products of 10 kg Mash obtained at Different Time Intervals

Plate 4.7b: Inside of the Products Showing Different Product Quality at Different Time Intervals

Table 4.12: Determination of Unit Price and Energy Consumed by Automated, Mechanical and Manual Fryer

Fryer Type	**Energy Type**						
	Electricity (kW)	**Diesel (Litres)**	**Firewood (kg)**	**Qty Used**	**Mash Qty (kg)**	**Unit Price (₦)**	**Amount (₦)**
Automated	1	-	-	12.5	30	50.9	636.25
Mechanical	-	1	-	19.36	30	285	5,517.6
Manual	-	-	1	30	30	10	300

Taylor and Francis (2006). The fryer's heat energy was provided by five 2,500 W electrical heating components, as shown in Table 4.12. The actual heat dissipated during each frying process was divided into two parts: the time it took to heat up the stainless drum or cylinder from room temperature to the desired temperature level, and the time it took to dry the mash from its initial moisture content to its final moisture content. By tracking the time portion of each heat transfer interval during which the heating elements were powered, the actual heat dissipated was calculated. The drum reached 140 °C and 220 °C in 2.2 and 5 minutes, respectively, according to the experiment. This is similar to Sanni (2014), who found that the drum reached 200 °C and 140 °C in 4.5 minutes and 2 minutes, respectively. The conductive gaari fryer's thermal efficiency (t) was estimated using the ratio of usable energy used to real energy dissipated by the heat source of the fryer as stated by Moreno *et al.*, (2007).

4.3.5 Comparative Analysis on the Automated, Mechanized and Manual Fryers

This examined the differences that exist between the improved automated fryer, Niji Lukas mechanical fryer and IITA manual fryer available within the scope of this work in relation to their efficiency, timeliness, throughput capacity and production cost.

4.3.5.1 Efficiency Comparative Analysis

Table 4.13 shows that the improved automated fryer had the overall efficiency of 87%, the highest efficiency followed by the Niji Luksa mechanized garrri fryer (57%), while the manual gaari fryer had the least result of the efficiency (44%). As the mash samples increases from 10 – 50 kg, the efficiencies increased from 59.0 – 87.0% as shown in Table 4.12. Similar situation occurred with the mechanized and IITA manual gaari fryers, as the mash quantity increases, the efficiencies increased from 50.0 – 57% and 40.0 – 44.0%, respectively. There was no efficiency results for 40 and 50 kg mash sample for both mechanized and manual gaari fryers because their maximum friable capacities were 35 kg for the mechanized fryer and 30 kg for the manual fryer. It was observed during the evaluation that any loading above 35 kg on the mechanized gaari fryer, the paddle speed tends to slow, thereby, causing the product to burn. This is one of the deficiencies in design with the mechanized fryer that was corrected in this automated gaari frying machine. The automated fryer can take as much as 60 kg of wet cassava mash sample per frying batch which helps to achieve quick production process. While on the manual gaari fryer, any loading above 30 kg of cassava mash sample makes it difficult to turn by the operator and pouring out of the frying pan.

The vertical paddle semi-automated fryer reported by Nwadinobi *et al.* (2019) with 66% functional efficiency does not use of heating elements as heat source but charcoal. Also, the improved gaari fryer by Adeniji *et al.* (2018) only has an efficiency of 75% which is higher than the mechanized but less than the automated. However, Gbabo *et al*. (2020) claimed that they achieved a functional efficiency of 90% with horizontal gaari fryer from 45 – 73 rpm processing speed. They further argued that the equipment can process 50 kg/hr at a batch process. But the equipment was not automated and the heat sources are firewood and charcoal.

4.3.5.2 Throughput Capacity Comparison

Table 4.13 also shows that the throughput capacity result got during the performance evaluation. The throughput capacity of theautomated gaari frying machine was 45.0 kg/hr while the Niji Lukas mechanized fryer type was 18.70 kg/hr. The IITA manual gaari fryer had the lowest throughput capacity of 14.66 kg. The throughput capacities of the automated gaari fryer at 10, 20, 30, 40 and 50 kg weight by mass of cassva mash were 17.1, 25.82, 34.85, 40.10, and 45.0 kg/hr respectively. Meanwhile, the throughput capacities for the mechanized and manual gaari fryers with the cassava mash of 10, 20, and 30 kg were 8.0, 13.21, 18.70 and 7.50, 9.44, 14.66 kg/hr respectively. It could be observed that there were no throughput capacities for both mechanized and manual gaari fryers. This simply was due to the lack of mash quantity carrying capacity as explained earlier. At the 30 kg mash sample which was applicable to all the three fryers, it was discovered that there was a significant and distinctive difference across the three fryers.

Outside the Horizontal gaari fryer by Gbabo *et al.* (2020) with a throughput capacity of 50 kg/hr which is higher than the automated (45 kg/hr) in

Table 4.13: The Efficiencies and Throughput Capacities Comparison

Mash Sample (kg)	Efficiencies (%)			Throughput Capacity (Kg/hr)		
	Automated	**Mechanical**	**Manual**	**Automated**	**Mechanical**	**Manual**
10	59.0	50.0	40.0	17.71	8.00	7.50
20	71.0	55.0	42.5	25.82	13.21	9.44
30	79.3	57.0	44.0	34.85	18.70	14.66
40	83.5	-		40.10	-	-
50	87.0	-		45.00	-	-

this report, most of the available gaari frying equipment or machine have little or poor throughput capacity. Onyekachi and Anthony (2018) automated batch process garification machine (17.30 kg/hr), Nwadionobi *et al.* (2019) vertical paddle semi-automated gaari frying machine (30.66 kg/hr), and Adeniji *et al.* (2018) improved garri fryer (6.6 kg/hr).

4.3.5.3 Timeliness of Operation Comparison

Table 4.14 showed that as the gaari quantity across the column increases from 10 – 50 kg in a unit difference of 10 kg, the time taken for the all the gaari fryers to complete their frying operation increases. Also, it was observed that as the quantity inputted increases from 10 – 50 kg, the output quantity increases with increase in processing time from 20 – 59 minutes for the automated gaari fryer. However, for the mechanized and manual gaari frying equipments which had no sample at 40 and 50 kg, the results of the time of operation were 26, 42, 55 minutes and 32, 49, 62 minutes at 10, 20, and 30 kg gaari product respectively. Using 30 kg gaari product as benchmark for the three fryers, the automated fryer had better processing of 41 minutes than the mechanical fryer with 55 minutes processing time interval. While the least processing time was observed with the manual gaari fryer at 62 minutes.

Also, at the sample of 40 and 50 kg, it could be noted that both the mechanized and manual fryers had no result owing to lack of their capacities to further contain the gaari product, however, in Fig. 40, a projection result was presented to give a processor an idea how the time result would look like at 40 and 50 kg gaari product: mechanized fryer (74 and 98 minutes) and manual fryer (87 and 114 minutes). These results showed that both mechanized and manual gaari fryers are time consuming with the manual having much time lost.

4.3.5.4 Cost Comparison of the Automated, Mechanized and Manual Fryers

The total costs for fabrication or production of the automated, mechanical and manual gaari frying machines evaluated are as follows: ₦609,200, ₦700,000 and ₦185,400. The material cost of all the component parts of the automated was presented in Table 4.15 while that of the mechanized and manual fryer was

Table 4.14: Timeline of Operation Comparison

	Automated		Mechanical		Manual	
Qty In (kg)	**Time (mins)**	**Qty out (kg)**	**Time (mins)**	**Qty out (kg)**	**Time (mins)**	**Qty out (kg)**
10	20.0	5.9	26.0	5.00	32.0	4.00
20	33.0	14.2	42.0	11.0	49.0	8.50
30	41.0	23.80	55.0	20.20	62.0	13.20
40	50.0	33.40	-	-	-	-
50	59.0	43.50	-	-	-	-

Table 4.15: BEM for Automated Gaari Frying Machine

S/NO	MATERIALS USED	SPECIFICATIONS	Qty	UNIT PRICE(₦)	AMOUNT (₦)
1.	Electric motor	2hp	1	25, 000	25, 000
2.	Stainless Plate	3 mm	1	90, 000	90, 000
3.	Electrical Filaments	2.5kW	5	3,000	50,000
4.	Pulley Double Groove	12’’ cm diameter	1	10, 000	10, 000
5.	Angle Iron	50 x 50 x 5 mm	1 ½ lngths	6, 500	13, 000
6.	Pulley Double Groove	14’’ diameter	1	15, 000	15, 000
7.	Pillow Bearing	205	6 pcs	3, 000	18,000
8.	Stainless Electrode	2.5 Gauge	1pack	13,000	13, 000
9.	Bolts and Nuts 14, 19,	2’’ inch	24 pcs	100	2, 400
10.	Belts	B45	2	1, 000	2, 000
12.	Shaft	32 mm	4 feet	12, 000	12,000
13.	Flat Beam	4’’ x 4’’ x 8mm	1 length	25,000	25,000
14.	Body filler + Hardener	Abro	4 litre	6, 000	6, 000
15.	Chain and Sprocket	4 and 12’’	1	20,000	20,000
16.	Electronic Board	Electronics	1	40, 000	40, 000
17	Mild Steel plate	2 mm thick	2	20, 000	40, 000
18.	Paint (Aluminum)		4 Litre	3, 600	3, 600
19.	Mild Steel Electrodes	Gauge 12	1 pack	2, 500	2, 500
20.	Filing and Cutting Discs	9 inches	6 pcs	900	5,400
21.	5/8 Rod	½ inch	1 length	1, 500	1, 500
22.	Aluminium Paddles	-	4	3, 000	12,000
23	Steel Hinges	½’’ rod grove	2	500	1, 000
24.	Rolling				7,000
25.	Bending				5, 000
26.	Turning				5, 000
27.	Programming Cost				15, 000
28.	Depreciation				48, 200
29.	Labour				100,000
				TOTAL	**609, 200**

presented in Table 4.5 and 4.6 above under the sub-topic titled cost analysis of the mechanical and manual fryer. The automated and mechanical frying machines were industrial equipments and were more sophisticated than the manual equipment. The automated and mechanical fryers had a close comparison in terms of costs and work principles. The two machines adopted a similar structural form with little differences. The major difference was the replacement of diesel burner system in mechanical type to electrical filament system in automated and the change of manual off and on switch system in mechanical to automated programmable circuit system (electrical-electronic system) in automated machine.

For a month (22 working days), the operating cost of the automated fryer for 8 hours of operation per day was summed to ₦138,000 which includes: a monthly NEPA bill (₦76, 986) for a factory NEPA bill estimate; serving/maintenance cost (₦43, 000); and labour (₦18,000). Meanwhile, the mechanical fryer was ₦699,936 (fuel consumption ₦607,636; servicing ₦45,0 00; replacement of parts ₦11, 300 and labour ₦33,000). The manual gaari fryer under 8 hours of operation per day was estimated at ₦93,300 (fire-woods, ₦36, 300 and labour cost, ₦54, 000) as presented in Table 4.16. The evaluation results indicated that the mechanized fryer was seen to have the highest operating cost because of the high rate of diesel fuel consumption during the working process of the machine. The production and operation costs of the mechanical gaari fryer were both higher than that of automated and manual fryer which implies that the equipment is not economically viable.

The automated fryer requires only an operator to fry at any given batch of gaari sample from beginning till the end while mechanical fryers requires may require the services of 2 operators for frequent monitoring of the product and the burner which can trip off at any time, thereby, causing a loss of production time (operational down time). For manual fryer, it has always being 3 operators with a long frying pan system of 8 x 4” as shown in Table 4.16 while 2 operators could be used for a short frying pan system of 4 x 4” dimension. Meanwhile, the manual type is less expensive, simple in construction and maintained least operating cost. However, the problem associated with it includes: poor throughput, efficiency, time wasted, heat stress and drudgery associated with its operation.

Table 4.16: The Operating Cost Determination for Automated, Mechanical and Manual Fryer

Parameters	Mechanical Fryer	Manual Fryer	Automated Fryer
Average Production/Day (kg)	165	165	165
Production for a Month (22 Working Days in kg)	3,630	3,630	3,630
Cost of Energy Consumed for 22 Working Days (₦)	667,629	36,300	76,986
Repair/Servicing Cost for 22 Working Days (₦)	45,000	Nil	43,000
Replacement of Damage Parts for 22 Working Days (₦)	11,300	Nil	Nil
Casual Labour for 22 Working Days (₦)@18,000	36,000	54,000	18,000
Number of Operators	2	3	1
Total Operating Cost for 22 Working Days (₦)	**699,936**	**61,000**	**138,000**

4.4 Optimization Analysis of the Automated Garri Frying Machine

The Gaari quantity that can be fried per batch in the automated fryer ranged within 55 – 65 kg of wet sample, with an average value of 57 kg (± 3.0), this was obtained at a moisture content of 30% wet basis. Optimum responses (throughput capacity, functional efficiency, heat energy and thermal efficiency) were 43.64 kg/hr, 87%, 7,919.8 and 42.7%, respectively at processing condition of gaari quantity 49.997 kg, frying time 57.80 minutes, Initial Moisture content 30.0%, frying temperature 183 ^{o}C and measured final moisture content of 12.422 at a desirability of 0.975. The responses results obtained at 4 factors and 5 levels were presented in Table 4.17. The factors ranges were gaari quantity (10 – 50 kg), frying time (15 – 75 minutes), initial moisture content (30 – 50% wb) and frying temperature (140 – 220 ^{o}C) while the responses were throughput capacity (4.4 – 184.4 kg/min), functional efficiency (55 – 93.2%), heat enery (1794.51 – 18793.2 J) and thermal efficiency (8.49 – 99.12). The former parameters are the independent variables generated based on the preliminary investigations of the related worked. The later parameters are dependent obtained from the experiment. Oti *et al.* (2017) have closed agreement with optimum values of the final moisture content obtained (12.04%) and the desirability (0.92).

However, their optimum temperatures (91 ^{o}C) were far different from the 183 ^{o}C obtained in the automated fryer. The reason behind it could because the gaari quantity used was small (25 kg) compared to the approximately 50 kg for the automated fryer. RSM results were confirmed to be very effective in modeling and optimization processes by Tripathi *et al.* (2010), Boulifi *et al.* (2010), and Ozgen *et al.* (2009) reported in Armin *et al.* (2013).

4.4.1 The Effect of Mash Quantity, Frying Time, Initial MC, Temperature on the Throughput Capacity of the Machine

The throughput capacity of the automated gaari frying machine is based on the mash quantity, frying time, initial moisture content, and temperature. As presented in Table 4.17, the machine’s throughput was in the range from 4.4 to 184.4 kg/hr, with the maximum fraction to minimum of 41.91. A fraction greater than 10 usually means that a change is needed and a fraction a fraction smaller than 3 indicates a small effect.

Table 4.17: The Responses Results of the Parameters Used in the Experiment.

Run	Throughput Capacity kg/hr	Functional Efficiency %	Heat Energy J	Thermal Efficiency %
1	27.2	68	3477.62	61.23
2	146.8	91.75	5255.85	92.5
3	49	81.67	5896.11	58.61
4	33.12	82.8	16751	72.2
5	4.4	55	3400.37	14.66
6	184.4	92.2	5630.19	99.12
7	62.13	93.2	10672.5	73.9
8	35.2	88	18793.2	81
9	30.4	76	3900.72	38.77
10	49.6	82.67	7039.32	69.97
11	32.8	82	1794.51	31.59
12	102.4	85.33	5595.99	98.52
13	90.6	90.6	9748.61	96.9
14	6	60	2698.82	11.85
15	29.6	74	4851.13	48.22
16	26	65	3252.6	57.26
17	4.64	58	1968.9	8.49
18	6.2	62	2703.62	14.37
19	36.08	90.2	11402.6	49.15
20	4.8	60	2220.42	9.57
21	31.73	79.33	10367.6	71.8
22	60.27	90.4	17706.6	76.32
23	59.87	89.8	13617.1	94.3
24	100.8	84	5578.12	98.21
25	31.47	78.67	10674.7	73.92

The main impact of the interaction determined for each factor on the throughput capacity is given in Table 4.18. The quadratic regression models derived from the D-optimal employed in the optimization of throughput capacity are presented in Table 4.18. The statistical significance of the second order equation was observed from the Table, showing that the model was significant at (P < 0.0001). Nevertheless, the lack of fit is not statistically significant at 99% confidence level. The ANOVA and regression coefficients significance for the regression model were also found in the table. The results showed that the response equation proved to be suitable for the D-optimal experiment (Demirel and Kayan, 2012; Oduntan and Bamgboye, 2015). The model's F -value of 77.23 obtained in the table shows that the model is significant for the throughput capacity of the automated gaari frying machine. Adequate precision measure of the signal to noise ratio is required and a ratio value greater than 4 is desirable. Hence, in the quadratic model of the throughput capacity of the automated gaari fryer, an adequate of precision of 34.80 depicts an adequate signal for throughput capacity process.

The value of R^2 (92.61%) and Adj-R^2 (95.01) are close to 1.0 which is very high indicating that there was a high correlation between the observed values and predicted values. According to the Demirel and Kayan (2012) and Mason *et al*. (2003), an excellent explanation of the interaction between the independent variables and the response is provided by the regression model. P-value for the interaction for between gaari quantity and frying time was significant. The 3-dimensional surface curve for variation in the throughput capacity was shown in Figure 4.3. This figure shows the throughput capacity in respect to frying time and gaari quantity. It was also found from Figure 4.3 that increase in gaari quantity resulted in quadratic increase in throughput capacity in the frying operation up to 50 kg. Onyekachi *et al.* (2017) and Adeniyi *et al.* (2018), obtained a similar result that proved that as a unit of gaari quantity increases, the throughput capacity increases in the production.

However, as the frying time decreases up to 15.42 minutes, and the gaari quantity increases to 44.0 kg, the optimum throughput capacity of 154.26 kg was obtained in the production process. The contour graph in Figure 4.4 below shows the points where all parameters simultaneously meet the desirable throughput capacity. Figure 4.5 presents the graph of the predicted values vs actual values.

Table 4.18: ANOVA Response for Quadratic Model Predicting the Throughput Capacity of the Automated Gaari Frying Machine.

Source	**Sum of Squares**	**df**	**Mean Square**	**F Value**	**p-value Prob > F**	
Model	46551.78	6	7758.63	77.23	< 0.0001	Significant
x_1	*25722.87*	*1*	*25722.87*	*256.06*	*< 0.0001*	
x_2	*22003.29*	*1*	*22003.29*	*219.03*	*< 0.0001*	
x_3	*77.01*	*1*	*77.01*	*0.77*	*0.3928*	
x_1x_2	*8627.03*	*1*	*8627.03*	*85.88*	*< 0.0001*	
x_2^2	*6136.52*	*1*	*6136.52*	*61.09*	*< 0.0001*	
x_3^2	*305.97*	*1*	*305.97*	*3.05*	*0.0980*	
Residual	1808.22	18	100.46			
Lack of Fit	*1514.13*	*13*	*116.47*	*1.98*	*0.2324*	*not significant*
Pure Error	*294.09*	*5*	*58.82*			
Cor Total	48360.00	24				

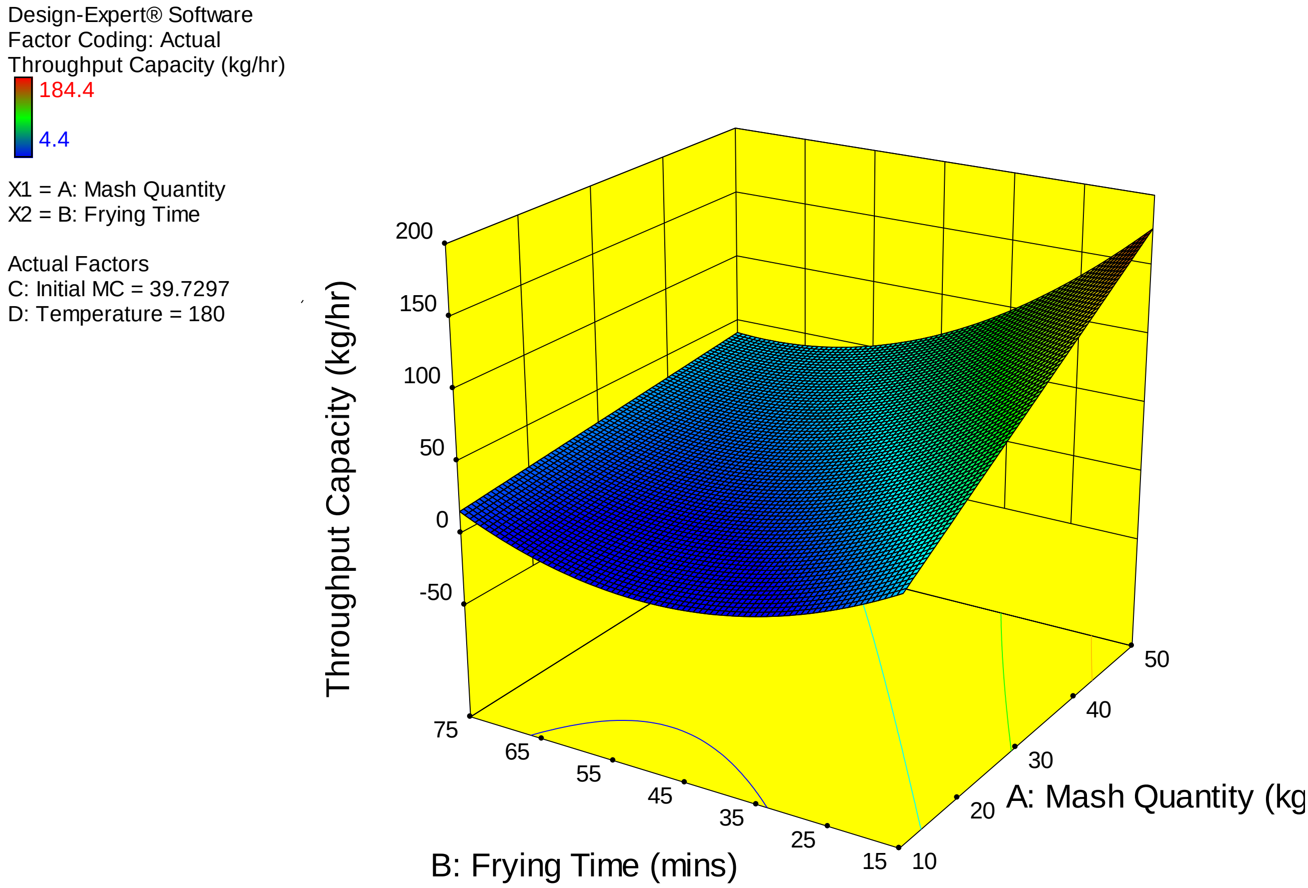

Fig. 4.3: The 3-Dimensional Surface Curve for Variation in the Throughput Capacity at the Initial Moisture Content of 39.73% and Frying Temperature 180^{o}C

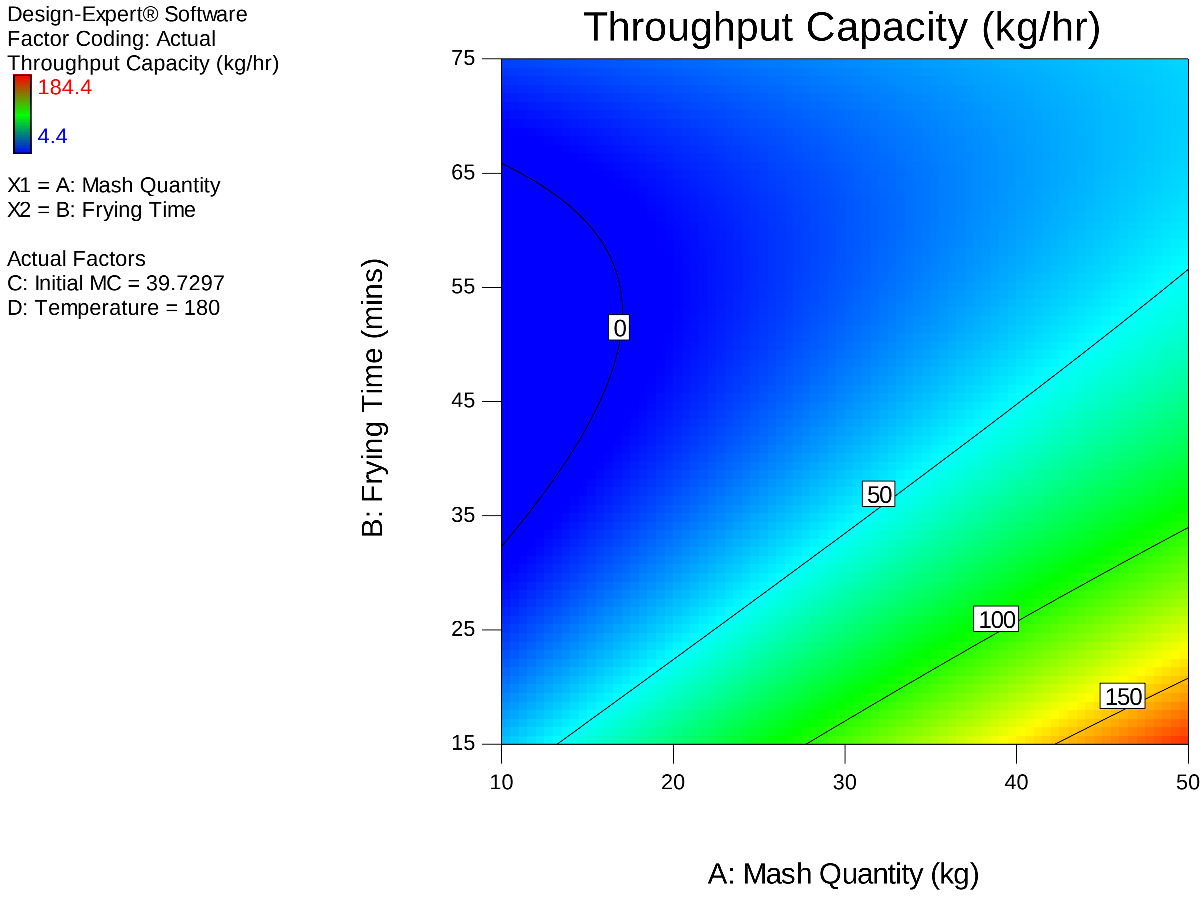

Fig. 4.4: The Contour Graph for the Variation in the Throughput Capacity at the Initial Moisture Content of 39.73% and Frying Temperature 180^{o}C

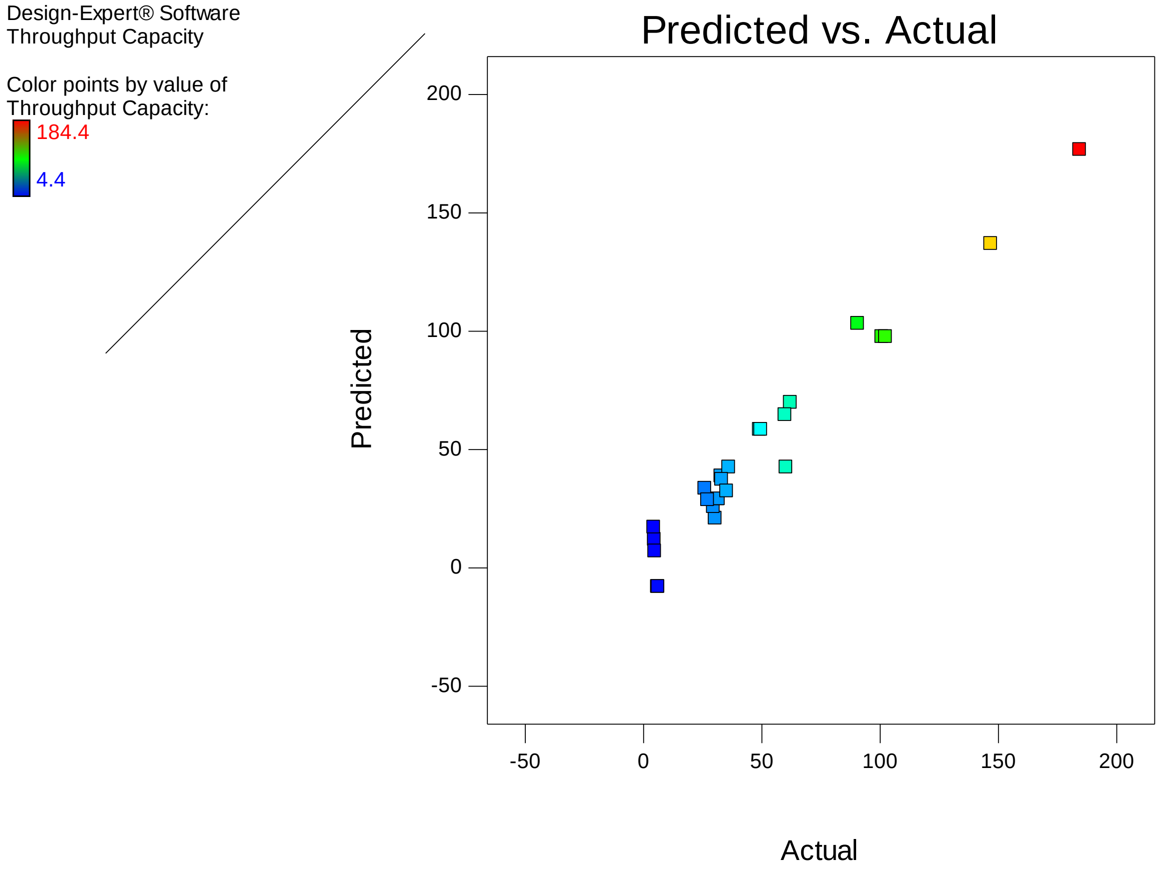

Fig.4.5: The Graph of the Predicted Values versus Actual Values

and the closeness of the data along the curve line is the indication that the result better fit the model. The actual of the throughput is the result of the given run and the estimated value is evaluated based on the independent variable of the model (Zhang and Zheng, 2009; Kayan and Gozmen, 2012). While the Figure 4.6 shows the perturbation plot of the throughput capacity and the independent variables used indicating the silhouette view of the response surface. The plots provides how response change as each factor moves from a chosen reference point with all other factors held constant at the reference point. The following coded response equation was obtained for variation of Throughput Capacity, y_{TC}

$$y_{TC} = 29.09 + 40.82x_1 - 38.94x_2 - 2.44x_3 - 28.12x_1x_2 + 39.72x_2^2 - 7.64x_3^2$$
……………(4.1)

It was observed from the model equation (4.1) above that the coefficients of x_2 and x_3 are negative while that of x_1 is positive. Therefore, a unit increase in the mash quantity (x_1) of the operation increased the throughput capacity (y_{TC}) by 40.82 kg/hr. However, an increase in the frying time (x_2) led to a decrease in the throughput capacity by 38.94 kg/hr. Also, a corresponding increase in a unit mass of initial moisture content (x_3) brought about a decrease in the throughput capacity with an appreciable value of 2.44 kg/hr.

The interaction between mass of the cassava mash quantity and the frying time gives a decrease value of 28.12 kg/hr when there is a unit change in the process. The quadratic form of frying time (x_2) has a positive effect on the throughput capacity while the quadratic form of the initial moisture content (x_3) has a negative impact on the throughput. Since the coefficient of x_2^2 is positive, a minimum throughput capacity will occur in the range of frying time selected for the experimentation while as the coefficient of x_3^2 is negative, a maximum throughput capacity will occur in the range of the initial moisture content measured in percentage wet basis.

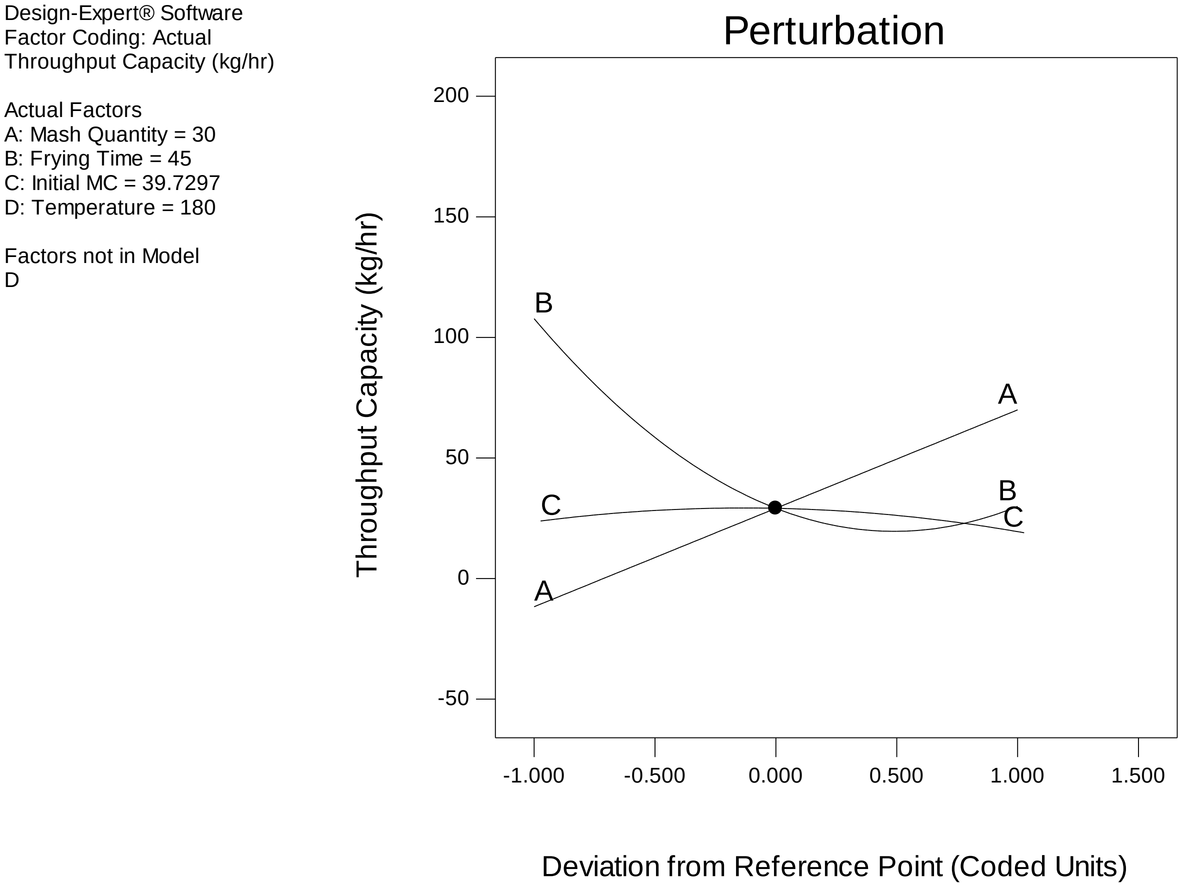

Fig. 4.6: The Perturbation Plot for Throughput Capacity

4.4.2 The Effect of Mash Quantity, Frying Time, Initial MC, Temperature on the Functional Efficiency of the Machine

The functional efficiency of the automated gaari frying machine is based on the mash quantity, frying time, initial moisture content, and temperature. As presented in Table 4.17, the machine's functional efficiency was in the range of 55 to 93.2%, with the maximum fraction to minimum of 1.70. A fraction greater than 10 usually means that a change is needed and a fraction smaller than 3 indicates a small effect. The main impact of the interaction determined for each factor on the functional efficiency is given in Table 4.19. The variance analysis for quadratic model predicting the functional efficiency of the automated gaari frying machine was presented in Table 4.19. The F-value of 136.37 for the quadratic model shows that the model is significant. It was found from Table 4.19 and Eq. 4.2 below that F-values for mash quantity (x_1), frying time (x_2), and frying temperature (x_4): 789.47, 151.30 and 35.06, respectively and p-values of less than 0.05 each are significant, indicating that there is direct relationship between these independent variable with the functional efficiency of the machine.

The F-value for initial moisture content (x_3) of 2.68 and p-value of 0.1208 greater than 0.05, indicated that there was no direct significance effect on the machine functional efficiency. The Lack of fit F-value of 6.09 indicates that the Lack of Fit is significant. There is only a 2.94% chance that a Lack of Fit F-value this large could occur due to noise. R^2 and adjusted R^2 values for the model are 0.9510 and 0.9783, respectively. This shows that the pred R-squared is in a close agreement with adj R-squared since the difference between them is less than 0.2. Adequate Precision measures the signal to noise ratio. A ratio greater than 4 is desirable as reported by Montgomery (2001). Thus, adequate precision ratio of 37.66 implies an adequate signal. The modified quadratic model was presented in Eq. (4.2) where y_{FE} is denoted as functional efficiency in the experiment.

$$y_{FE} = 79.75 + 12.84x_1 - 5.83x_2 + 0.82x_3 - 2.66x_4 + 2.86x_1x_2 + 1.73x_1x_4 + 1.36x_3x_4 - 3.07x_3^2 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4.2)$$

Table 4.19: ANOVA Response for Quadratic Model Predicting the Functional Efficiency of the Automated Gaari Frying Machine

Source		Sum of Squares	Df	Mean Square	F Value	p-value Prob > F	
Model		3553.97	8	444.25	136.37	< 0.0001	Significant
x_1		*2571.86*	*1*	*2571.86*	*789.47*	*< 0.0001*	
x_2		*492.90*	*1*	*492.90*	*151.30*	*< 0.0001*	
x_3		*8.75*	*1*	*8.75*	*2.68*	*0.1208*	
x_4		*114.23*	*1*	*114.23*	*35.06*	*< 0.0001*	
x_1x_2		*88.46*	*1*	*88.46*	*27.15*	*< 0.0001*	
x_1x_4		*35.24*	*1*	*35.24*	*10.82*	*0.0046*	
x_3x_4		*16.25*	*1*	*16.25*	*4.99*	*0.0402*	
x_3^2		*51.33*	*1*	*51.33*	*15.76*	*0.0011*	
Residual		52.12	16	3.26			
	Lack of Fit	*48.50*	*11*	*4.41*	*6.09*	*0.0294*	*Significant*
	Pure Error	*3.62*	*5*	*0.72*			
Cor Total		3606.10	24				

It is evident from Eq. 4.2 that the coefficient of x_1, and x_3 are positive while x_2 and x_4 are negative. Therefore, a unit increase in mass of mash quantity and initial moisture content will result in the increase of the functional efficiency by 12.84% and 0.82%, respectively. However, a unit increase in the frying time and frying temperature will lead to a decrease in the functional efficiency of the machine by 5.83% and 2.66%, respectively. A similar result was obtained in optimization of a clay-slate fluid bed dryer for production of fish feed by Oduntan and Oluwayemi (2021). Since the coefficient of x_3^2 is negative, a maximum efficiency will occur in the range of initial moisture content selected for the study. The interaction between mass of the cassava mash and the frying time gives an increased value of 2.86% for functional efficiency. Also, the interaction between the mash quantity and frying temperature gave a positive increment of 1.73% functional efficiency while the interaction between the initial moisture content and frying temperature produced an increment of 1.36% functional efficiency.

The 3-D surface plot in Figure 4.7 below shows the effect of frying time (15 – 75 minutes) and mash quantity (10 – 50 kg). The curve shows that there was a resultant increase in the functional efficiency as the mash quantity increases while there was a decrease in functional efficiency as the frying time increases. The contour graph in figure 4.8 below shows points where all processing parameters met. At the minimum range, 60% of functional efficiency was observed at the mash quantity and frying time of 10.95 kg and 70.28 minutes, respectively. Whereas, at the maximum range, 90% of functional efficiency, the mash quantity and frying time were 45.32 kg and 41.40 minutes, respectively both at a constant temperature and initial moisture content of 180 ^{o}C and 40%, repectively. Figure 4.9 shows the graph of the predicted values versus actual values and the closeness of the data along the curve line is the indication that the result better fit the model. While the Figure 4.10 shows the perturbation plot of the functional efficiency and the independent variables used indicating the line view of the response surface. The plots provides how response change as each factor moves from a chosen reference point with all other factors held constant at the reference point.

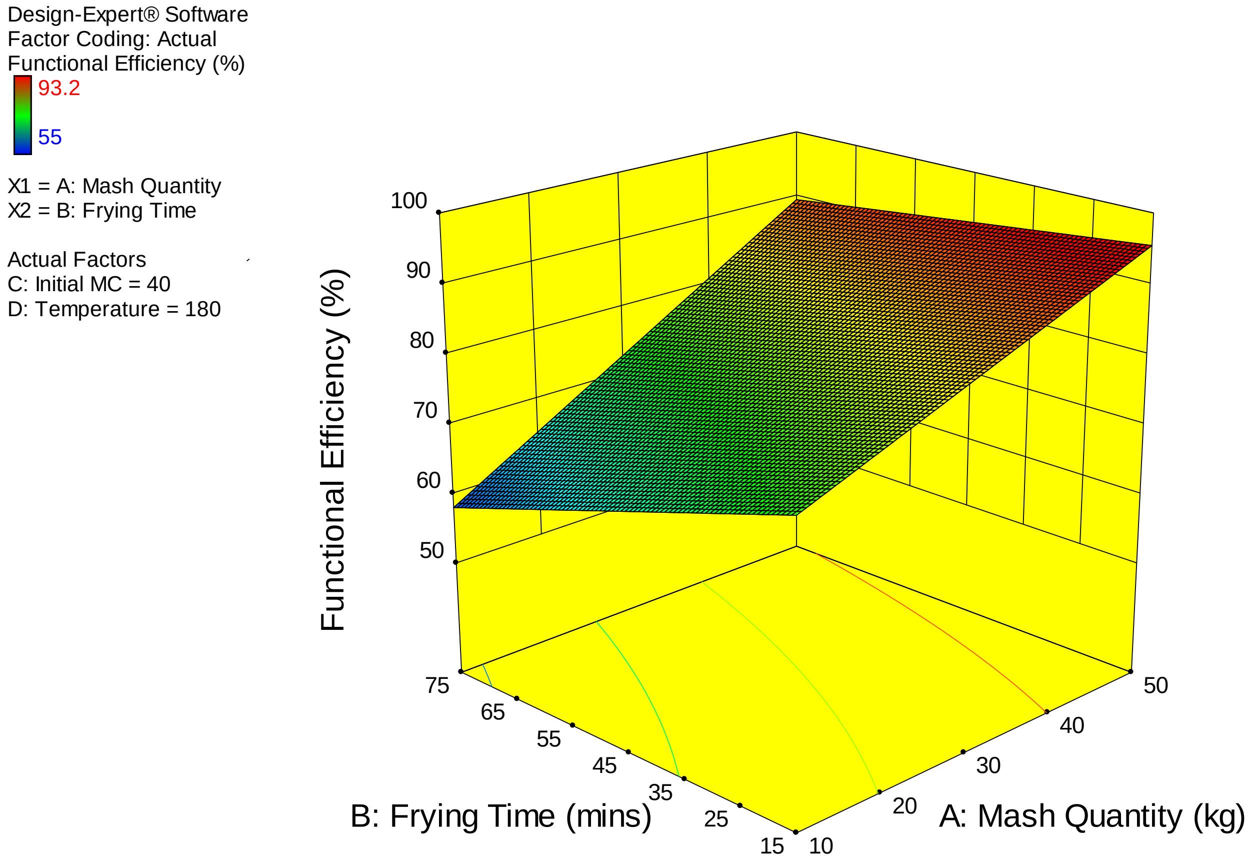

Fig. 4.7: The 3-Dimensional Surface Curve for Variation in the Functional Efficiency at the Initial Moisture Content of 40% and Frying Temperature 180°C

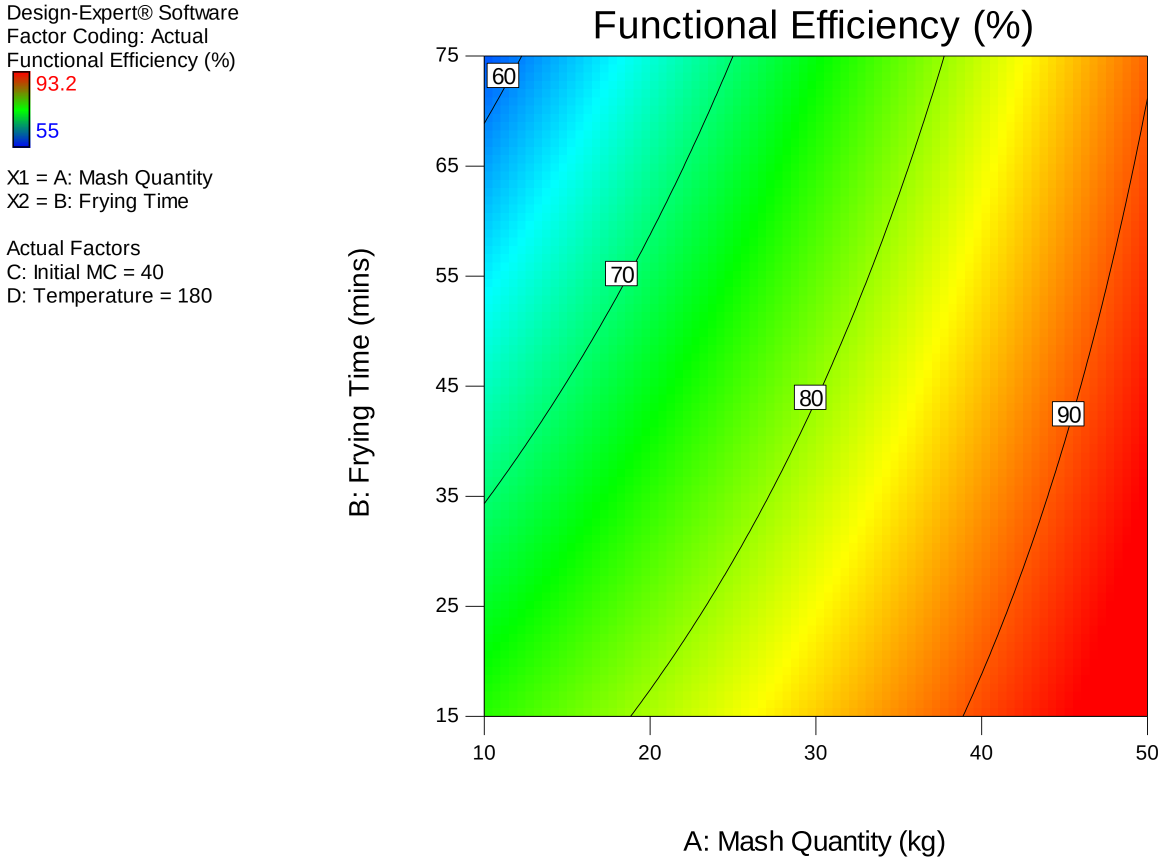

Fig. 4.8: The Contour Graph for the Variation in the Functional Efficiency at the Initial Moisture Content of 40% and Frying Temperature 180^{o}C

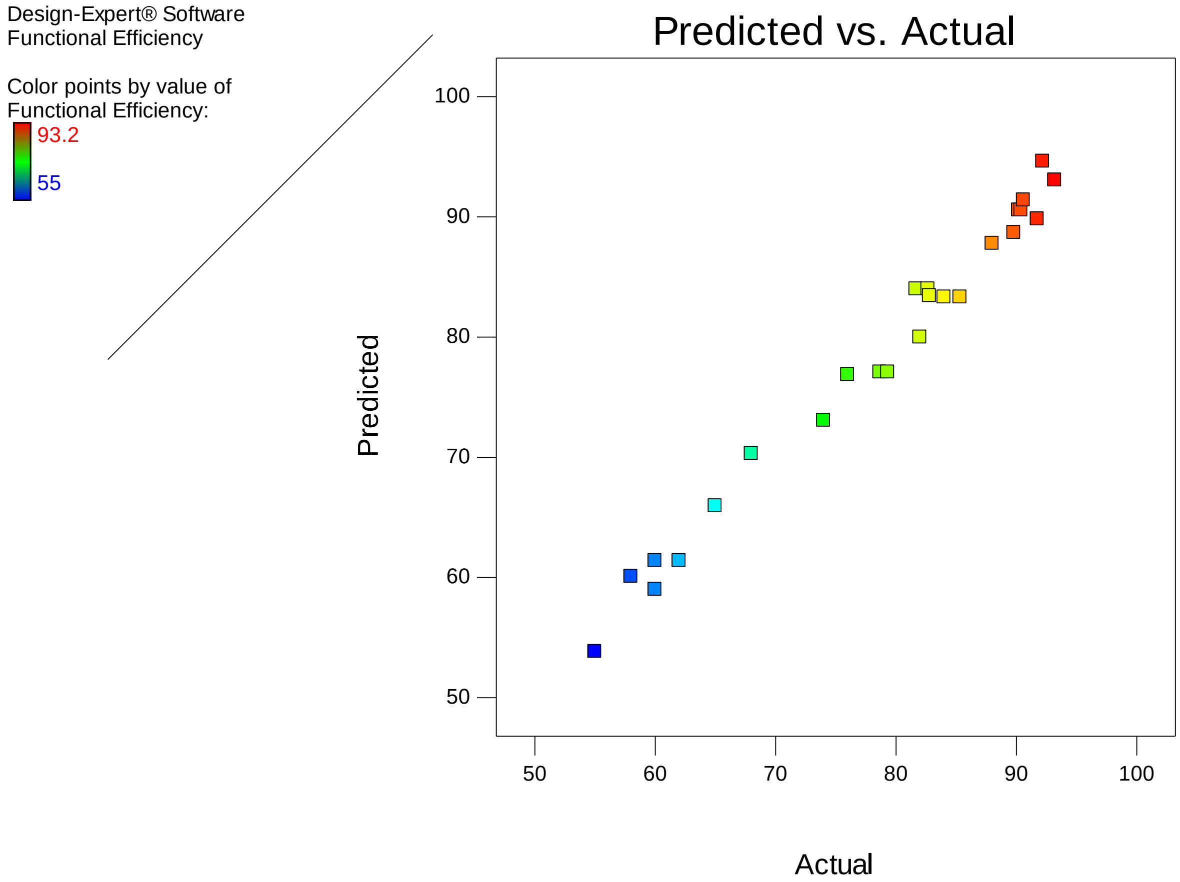

Fig.4.9: The Graph of the Predicted Values versus Actual Values for Functional Efficiency

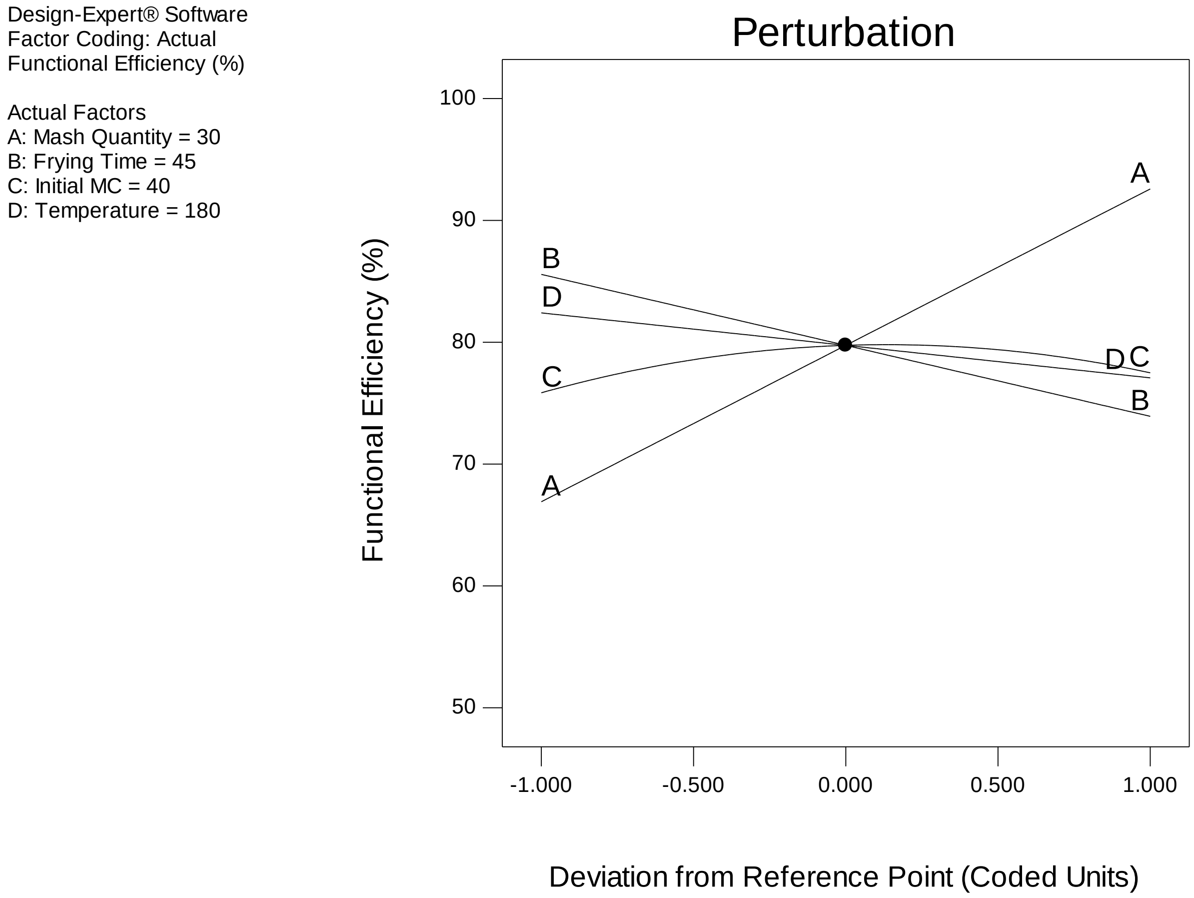

Fig. 10: The Perturbation Plot for Functional Efficiency

4.4.3 The Effect of Mash Quantity, Frying Time, Initial MC, Temperature on the Heat Energy of the Machine

The heat energy of the automated gaari frying machine is based on the mash quantity, initial moisture content (MCi), frying time, and temperature. As shown in Table 4.17, the heat energy of the machine was in the range of 1794.51 to 18793.2 J, with the maximum fraction to minimum of 10.47. A fraction greater than 10 usually means that a change is needed and a fraction smaller than 3 indicates a small effect. The main impact of the interaction determined for each factor on the heat energy is given in Table 4.20. The Table depicts the analysis of the variance result generated with average heat energy at different processing conditions (mash quantity, initial moisture content, frying time, and frying temperature). The Table also showed the design of experiment (DOE) matrix generated through the use of RSM; having actual and coded values of the input variables along with one output response effects (terms in x_1, x_2, and x_4) and one interaction effect ($x_1 x_2$) as shown in equation 4.3. A reduced linear model in terms of coded factors was observed and the model was significant at $p < 0.05$. The following coded response equation was found for variation of Heat Energy, Y_{HE}

$$Y_{HE} = 7551.88 + 4482.01x_1 + 2288.41x_2 + 1030.86x_4 + 2280.69x_1 x_2 \quad \text{……...............(4.3)}$$

It was observed from the model equation (3) above that the coefficients of x_1, x_2 and x_4 are all positive. This indicates that a unit increase in the mass quantity (x_1), frying time (x_2) and frying temperature (x_4) will leading a significant increase in the heat energy of the automated gaari fryer by 4482.01 J, 2288.41 J, and 1030.86 J, respectively. The interaction between the cassava mash mass and the frying time gives a progressive increase value of 2280.69 J when there is a unit change in the production process. However, it was observed that the initial MCi (x_3) has no considerable impact on the sample of the experiment used.

Table 4.20: Analysis of the Model Data for the Heat Energy Response Variable for the Automated Gaari Fryer

Source		**Sum of Squares**	**df**	**Mean Square**	**F Value**	**p-value Prob > F**	
Model		5.822E+008	4	1.455E+008	61.08	< 0.0001	significant
x_1		*3.161E+008*	*1*	*3.161E+008*	*132.67*	*< 0.0001*	
x_2		*8.066E+007*	*1*	*8.066E+007*	*33.85*	*< 0.0001*	
x_4		*1.733E+007*	*1*	*1.733E+007*	*7.27*	*0.0139*	
$x_1 x_2$		*5.816E+007*	*1*	*5.816E+007*	*24.41*	*< 0.0001*	
Residual		4.766E+007	20	2.383E+006			
	Lack of Fit	*2.709E+007*	*15*	*1.806E+006*	*0.44*	*0.9006*	*not significant*
	Pure Error	*2.057E+007*	*5*	*4.114E+006*			
Cor Total		6.298E+008	24				

The F-value (61.08) shows that model is significant. The value of R^2 (0.8526) and Adj-R^2 (0.9092) are in a close agreement since the difference between them is less than 0.2. Thus, indicating that there was a high correlation between the observed values and predicted values. According to the Demirel and Kayan (2012), a good explanation of the relationship the independent variables and the response is provided by the regression model. P-value for the interaction between mash quantity (x_1) and frying time (x_2) was significant. The 3-dimensional surface curve for variation in the heat energy of the automated gaari fryer was shown in Figure 4.11. This figure shows the heat energy in respect to frying time and mash quantity. It was observed from figure 3a that as mash quantity and frying time increase in the production process, the heat energy of the fryer increases progressively. A similar result was reported by Sanni (2014) on studies of conductive rotary drying for industrial cassava processing.

The contour graph in figure 4.12 below shows the points where all processing parameters used in the experiment meet the desirable heat energy. The minimum heat energy (4,000 J) was observed at the processing conditions of mash quantity (45.12 kg), frying time (14.16 mins), initial moisture content (40% wb) and frying temperature (180 ^{o}C) while the maximum heat energy range seen at 14,000 J at mash quantity (45.33 kg), frying time (67.37 mins), initial moisture content (40% wb) and frying temperature (180 ^{o}C). The Figure 4.13 presents the graph of the predicted values against actual values and the closeness of the data along the curve line is the indication that the result better fit the model. While the Figure 4.14 presents the perturbation plot of the heat energy and the independent variables used indicating the silhouette view of the response surface.

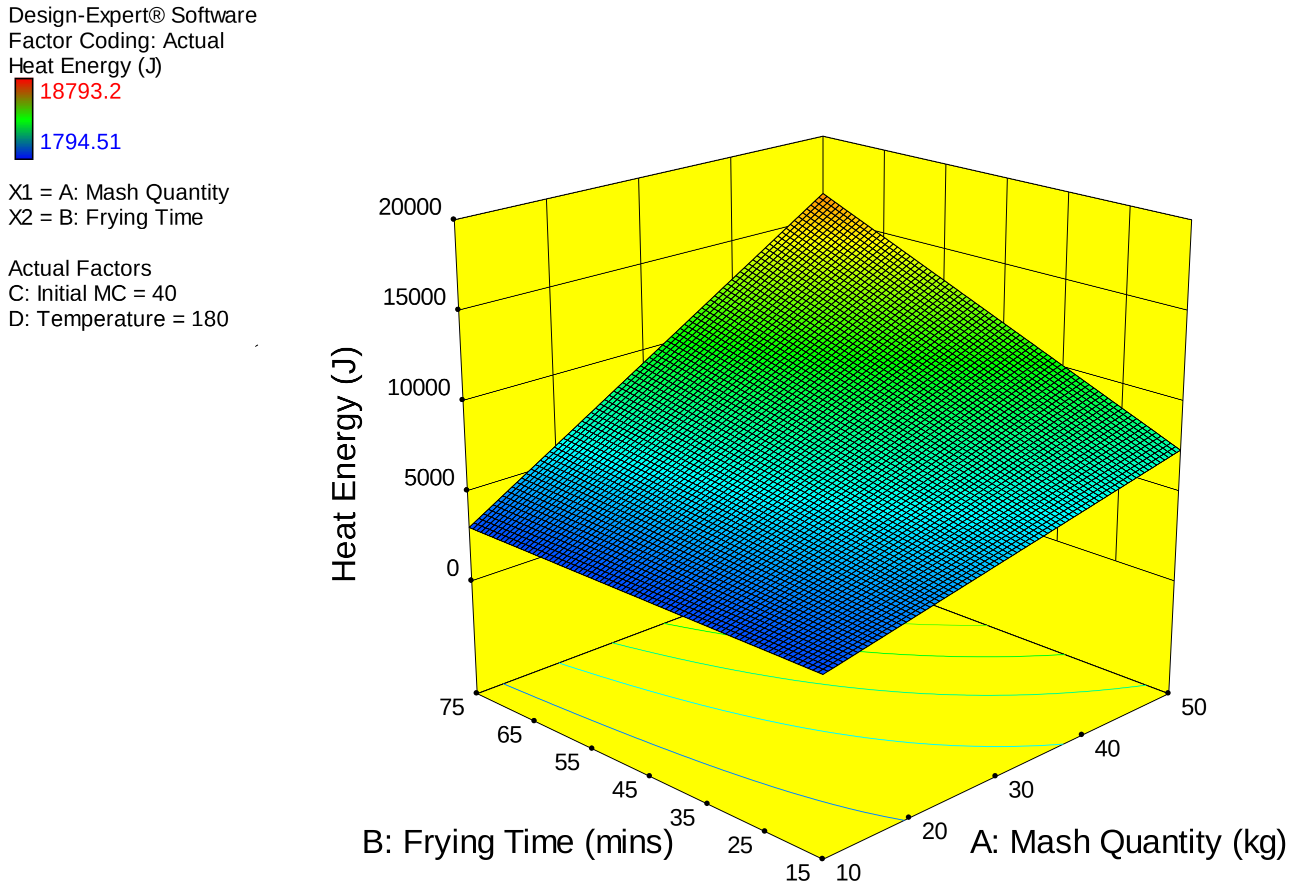

Fig. 4.11: The 3-Dimensional Surface Curve for Variation in the Heat Energy at the Initial Moisture Content of 40% and Frying Temperature 180°C

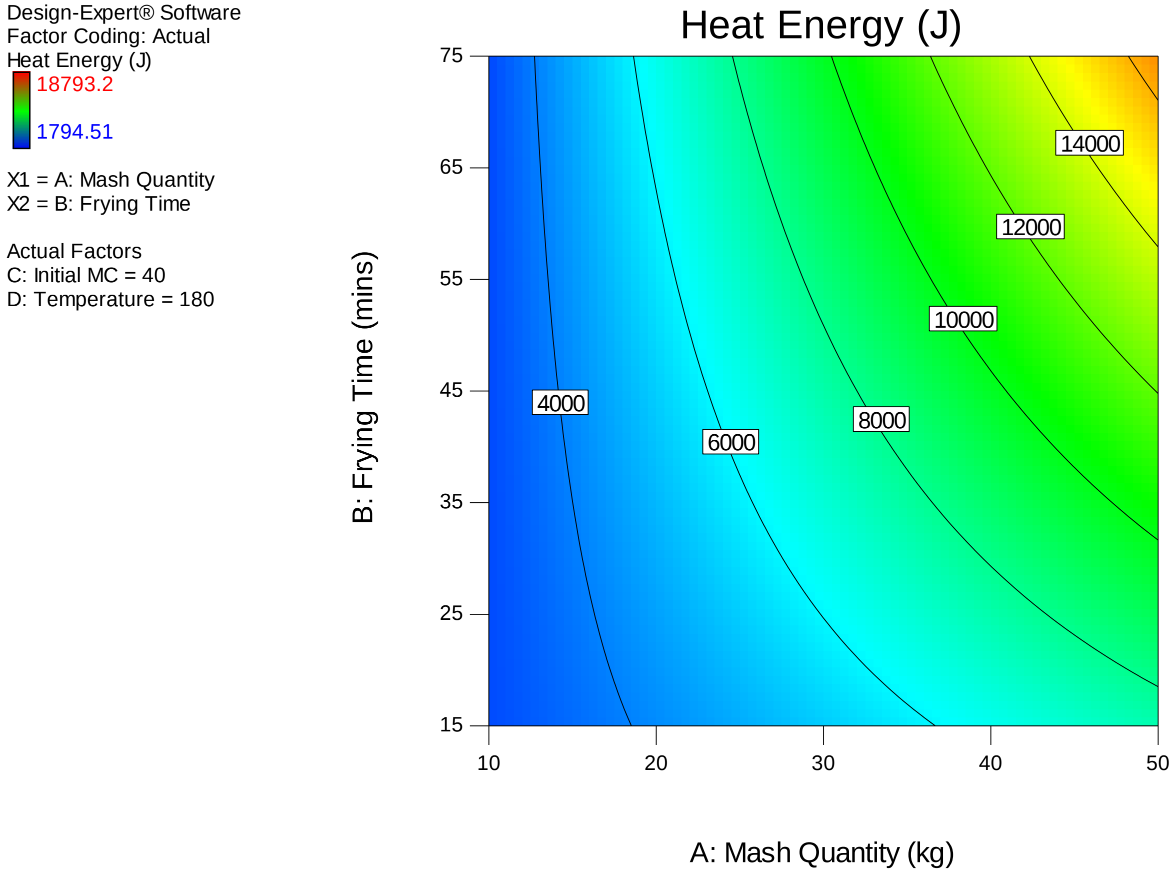

Fig. 4.12: The Contour Graph for the Variation in the Heat Energy at the Initial Moisture Content of 40 % and Frying Temperature 180 ^{o}C

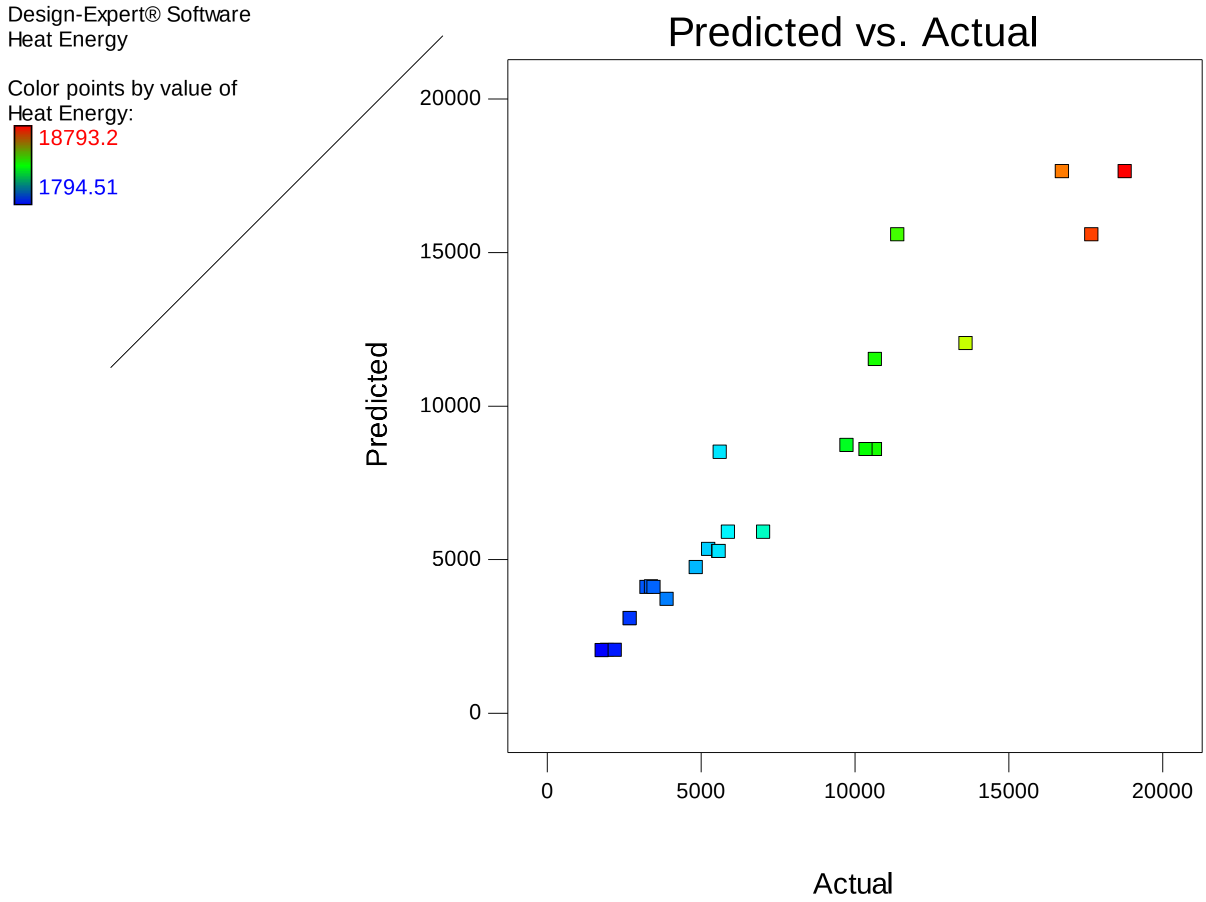

Fig. 4.13: The Graph of the Predicted Values versus Actual Values for Heat Energy

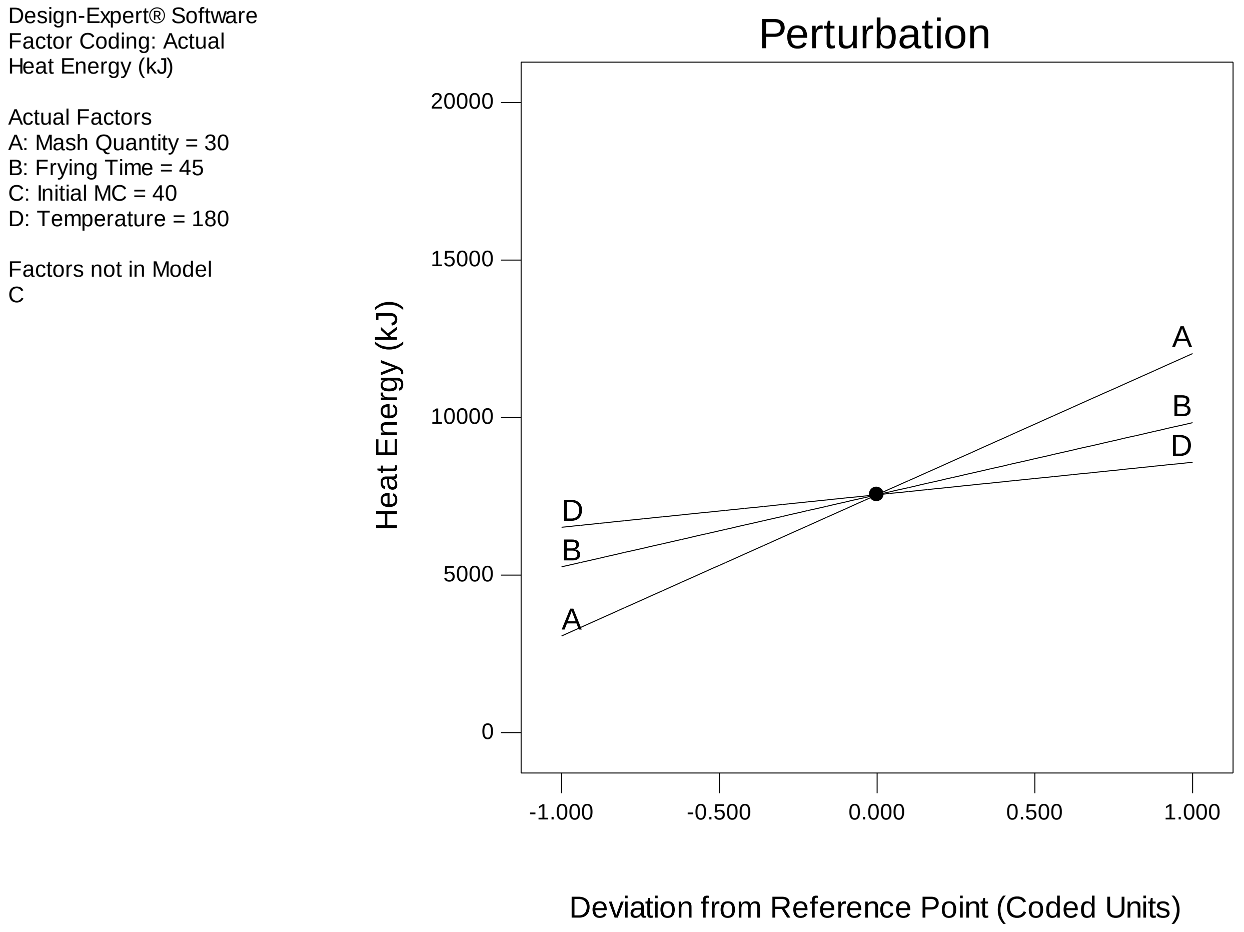

Fig. 4.14: The Perturbation Plot for Heat Energy

4.4.4 The Effect of Mash Quantity, Frying Time, Initial MC, Temperature on the Thermal Efficiency of the Machine

The thermal efficiency of the automated gaari frying equipment is based on the mash quantity, frying time, initial moisture content, and temperature. As shown in Table 4.17, the thermal efficiency of the machine was in the range of 8.49 to 99.12 J, with the maximum fraction to minimum of 11.69. A fraction greater than 10 usually means that a change is needed and a fraction smaller than 3 indicates a small effect. The main impact of the interaction determined for each factor on the thermal efficiency is given in Table 4.21. The variance analysis for response linear model predicting the Thermal efficiency of the automated gaari frying machine was shown in Table 4.21. The linear model F-value of 51.10 implies that the model is significant. It was observed from Table 4 that F-values for mash quantity (x_1), frying time (x_2), and frying temperature (x_4): 144.49, 59.47 and 9.13, respectively and p-values of less than 0.05; 0.0001, 0.0001 and 0.0067, respectively are significant, indicating that there was direct relationship between these independent variable with the thermal efficiency of the machine.

The F-value for initial moisture content (x_3) of 1.85 and p-value of 0.1894 greater than 0.05, indicated that there was no direct significance effect of the variable on the thermal efficiency of the machine. The Lack of fit F-value of 1.2 implies that the Lack of Fit is not significant at 99% confidence level. There is only a 45.22% chance that a Lack of Fit F-value this large could occur due to noise which is good. The value of R^2 (86.24%) and Adj-R^2 (89.31%) are close to 1.0 which is very high indicating that there was a high correlation between the observed values and predicted values. Adequate Precision measures the signal to noise ratio. A ratio greater than 4 is desirable as reported by Montgomery (2001). Therefore, adequate precision ratio of 26.23 indicates an adequate signal. The modified quadratic model was shown in Eq. (4.4) where y_{TE} represented thermal efficiency in RSM.

$$Y_{TE} = 59.95 + 29.75x_1 - 19.91x_2 + 3.77x_3 + 7.48x_4 \qquad \ldots\ldots\ldots\ldots\ldots (4.4)$$

It was observed from the model equation (4.4) above that the coefficients of x_1, x_3, and x_4 are positive while x_2 is negative which means that a change in a

Table 4.21: Model Analysis Data for the Thermal Efficiency Response Variable for the Automated Gaari Fryer.

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	20702.55	4	5175.64	51.10	< 0.0001	Significant
x_1	*14653.16*	*1*	*14653.16*	*144.69*	*< 0.0001*	
x_2	*6022.61*	*1*	*6022.61*	*59.47*	*< 0.0001*	
x_3	*186.94*	*1*	*186.94*	*1.85*	*0.1894*	
x_4	*925.12*	*1*	*925.12*	*9.13*	*0.0067*	
Residual	2025.51	20	101.28			
Lack of Fit	*1586.41*	*15*	*105.76*	*1.20*	*0.4522*	*not significant*
Pure Error	*439.10*	*5*	*87.82*			
Cor Total	22728.07	24				

unit mass increase of mash quantity, initial moisture content and frying temperature will directly result in increase in the thermal efficiency of the automated gaari frying machine by 29.75%, 3.77% and 7.48%, respectively.

However, a unit increase in the frying time will inversely lead to a decrease in the thermal efficiency of the machine by 19.91%. The 3-D surface plot in Figure 4.15 below shows the effect of frying time and mash quantity. The curve explains that there was a sharp increase in the thermal efficiency as the mash quantity increases while a resultant decrease as the frying time increases. The maximum range performance of thermal efficiency of 99.2% was observed as at the frying time of 20.48 minutes and mash quantity of 45.0 kg, constant temperature of 180 ^{o}C and initial moisture content of 40% wb.

The contour graph in Figure 4.16 below shows the points where all processing parameters met. Figure 4.17 shows the graph of the predicted values versus actual values and the closeness of the data along the curve line is the indication that the result better fit the model. While the Figure 4.18 shows the perturbation plot of the thermal efficiency and the independent variables used indicating the line view of the response surface. The plots provides how response change as each factor moves from a chosen reference point with all other factors held constant at the reference point.

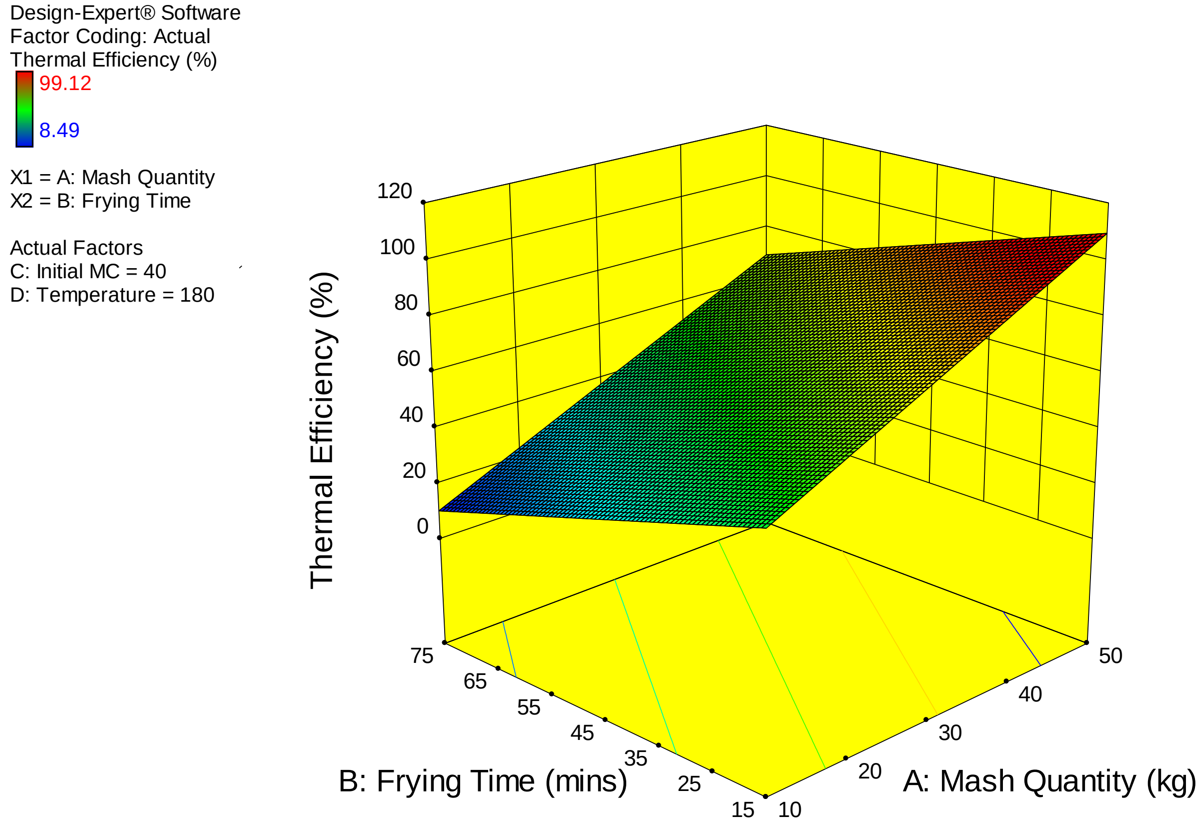

Fig. 4.15: The 3-Dimensional Surface Curve for Variation in the Thermal Efficiency at the Initial Moisture Content of 40% and Frying Temperature 180^{o}C

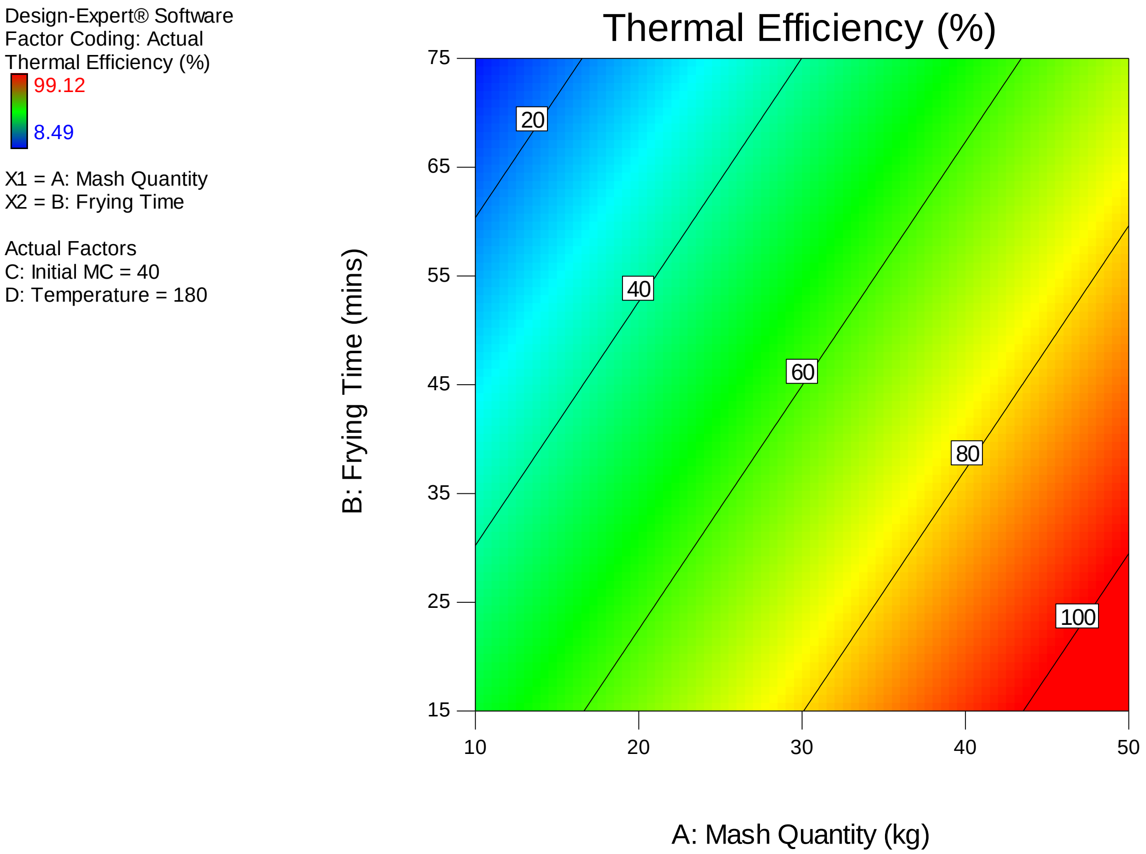

Fig. 4.16: The Contour Graph for the Variation in the Thermal Efficiency at the Initial Moisture Content of 40 % and Frying Temperature 180 ^{o}C

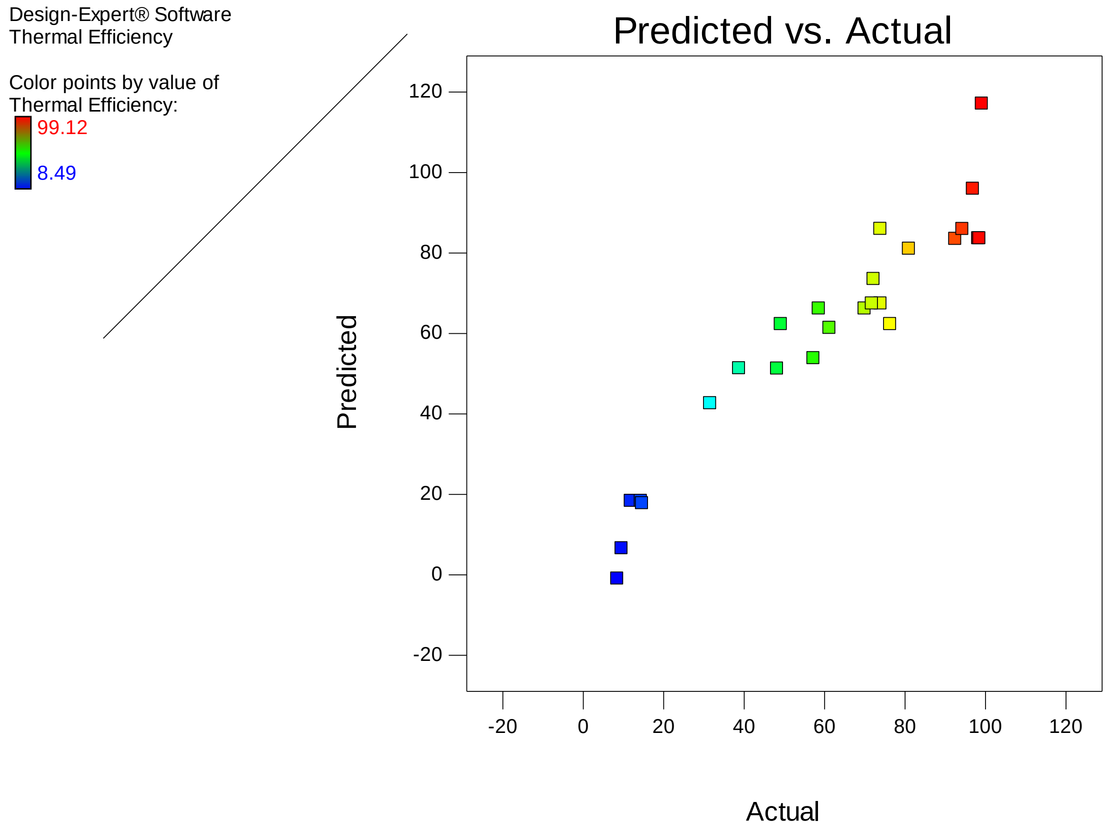

Fig. 4.17: The Perturbation Plot for Thermal Efficiency

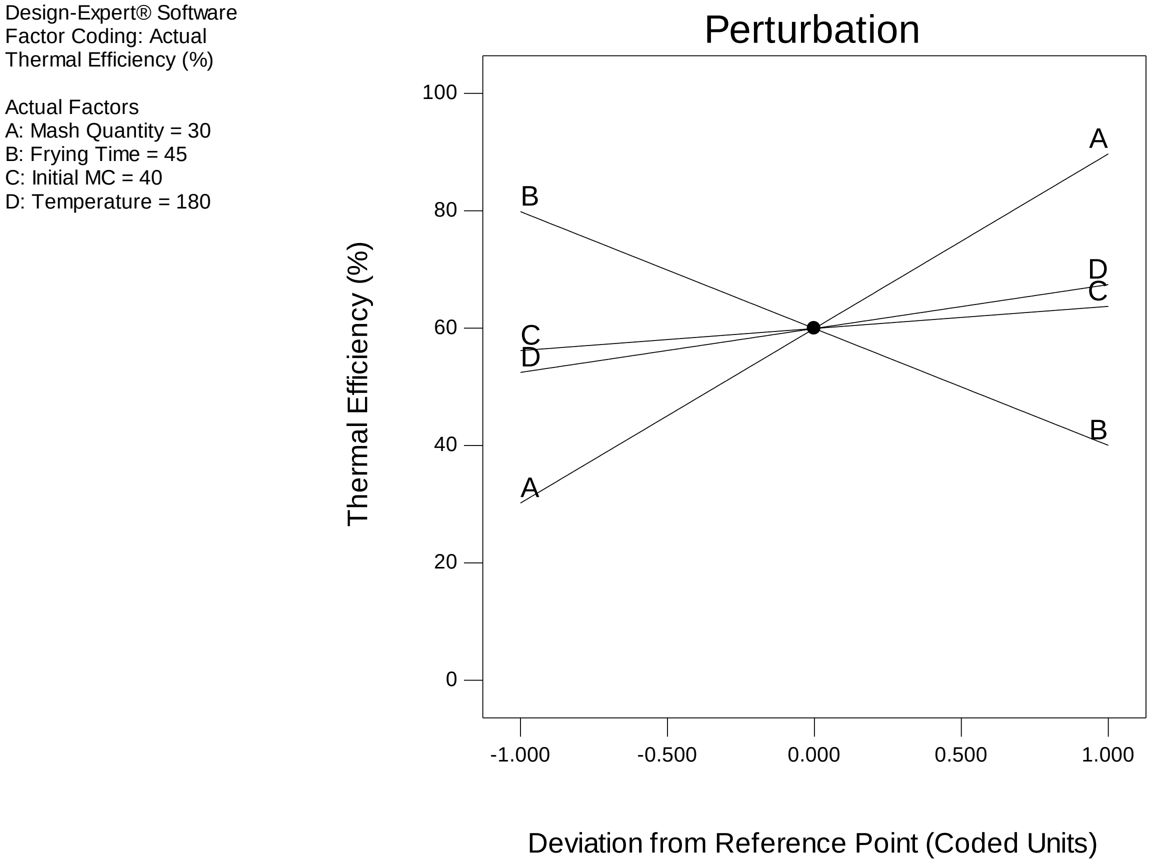

Fig. 4.18: The Perturbation Plot for Thermal Efficiency

4.4.5 Validated Optimum Processing Conditions

The model equations were validated using approaches of Mooney and Swift's (1999) and Subroto *et al.* (2015). Experimental settings were used to assess the model equations' adequacy in predicting optimum response values as shown in Tables 4.22 and 4.23. Using the model equations, the optimum processing conditions were utilized to validate the experimental as well as to predict the values of the answers. Actual (experimental) values were compared with anticipated (calculated) values. Close values were found when the model equation and the experimental values of the response variables at the site of interest were calculated.

At 50 kg mash quantity, 57.80 minutes frying time, 30 percent wb initial MC, and 183 ^oC frying temperature processing conditions, the optimum throughput capacity (43.64 kg/hr), functional efficiency (87%), heat energy (7,919.8) and thermal efficiency (42.7%) were achieved. There was a high desirability of 0.921 and final moisture content of 12.29%. At the identical processing optimal parameters of loading, frying time, initial moisture content, and frying temperature, the actual repeated experiment yielded average optimum throughput capacity, functional efficiency, heat energy and thermal efficiency of 44.46 kg/hr, 87.46%, 7917.8 J and 42.58%, respectively.

The model's validity was also tested applying the Chi-Square (X2) goodness-of-fit test. The differences between experimental and predicted values for throughput, functional efficiency, heat energy and thermal energy were small less than $p < 0.05$ (0.0116, 0.0138, 0.0191 and 0.0303, respectively), demonstrating that there is no significant difference between actual and calculated data for any dependent variables. The model generated is valid at the 95% level of confidence because the X^2 is much smaller than the X^2 cut-off value for the 95% confidence level, and the existence of a close agreement between calculated values obtained with the model equations and experimental values of the response variables at the point of interest signifies the goodness of the result. This high level of agreement between experimental and predicted values indicated that the observations were well-fitting to the model and provided a credibly good measure of the automated garri frying machine's response.

Table 4.22: Validated Optimum Processing Conditions on Repeated Experiment for Throughput and Functional Efficiency

Runs	**Independent Variables**				**Throughput Capacity (Kg/hr)**				**Functionl Efficiency (%)**			
	MQ (Kg)	**FT (Min)**	**MCi (% wb)**	**FTP (°C)**	**Expl**	**Pred**	**Diff**	**X^2**	**Expl**	**Pred**	**Diff**	**X^2**
1	50	57.8	30	183	44.43	44.28	0.15	0.0005	87.48	87.0	0.48	0.0026
2	50	57.8	30	183	43.99	44.28	0.29	0.0019	87.92	87.0	0.92	0.0097
3	50	57.8	30	183	44.62	44.28	0.34	0.0030	87.15	87.0	0.15	0.0005
4	50	57.8	30	183	44.81	44.28	0.53	0.0062	87.30	87.0	0.30	0.0010
							$X^2 \sum =$	**0.0116**			**$X^2 \sum =$**	**0.0138**

MQ – Mash Quantity/Loading, FT – Frying Time, MCi – Initial Moisture Content, HF – Heating Filament, FTP – Frying Temperature, Expl – Experimental Values, Pred – Optimum Predicted/Calculated Values, Diff – Difference between Expl and Pred Values. Average Dev – Percentage Average Deviation between optimum Experiemental and Predicted Values

Expl – Experimental data obtained; Pred – the calculated data, Diff – Difference between Experimental and Predicted values, X^2 – Chi Square

$$X^2 = \sum \frac{(Expl - Pred)^2}{(Pred)}$$

Table 4.23: Validated Optimum Processing Conditions for Heat Energy and Thermal Efficiency

Runs	Independent Variables				Heat Energy (% db)				Thermal Efficiency (Kg/hr)			
	MQ (Kg)	FT (Min)	MCi (% wb)	FTP (°C)	Expl	Pred	Diff	X^2	Expl	Pred	Diff	X^2
1	50	57.8	30	183	7910.2	7919.8	9.7	0.0116	43.5	42.7	0.70	0.0115
2	50	57.8	30	183	7917.9	7919.8	1.9	0.0005	42.6	42.7	0.10	0.0002
3	50	57 .8	30	183	7916.6	7919.8	3.2	0.0013	42.3	42.7	0.40	0.0037
4	50	57.8	30	183	7926.5	7919.8	6.7	0.0057	41.9	42.7	0.80	0.0149
							$X^2\sum$ =	**0.0191**			$X^2\sum$ =	**0.0303**

MQ – Mash Quantity/Loading, FT – Frying Time, MCi – Initial Moisture Content, HF – Heating Filament, FTP – Frying Temperature, Expl – Experimental Values, Pred – Optimum Predicted/Calculated Values, Diff – Difference between Expl and Pred Values

Expl – Experimental data obtained; Pred – the calculated data, Diff – Difference between Experimental and Predicted values, X^2 – Chi Square

$$X^2 = \sum \frac{(Expl - Pred)^2}{(Pred)}$$

CHAPTER FIVE

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

5.1 Summary

This research work was designed to alleviate the problems associated with frying operation in the existing gaari frying machines ranging from manual to mechanized systems. The extensive literature reviews and comparative analysis carried out showed that discomfort and numerous health challenges to operator due to heat, smoke, and sitting posture are connected to only manual fryers. High cost of the acquiring the machine relative to expensive component parts, frequent failure of parts and high operating cost are problems with the mechanized gaari fryer. Also, maintenance cost, high cost of diesel fuel in market, increase in operational down time, regular replacement of key parts at a slight power surge, global warming effect as a result of soots and carbon emissions, etc are major and common issues linked to the mechanized fryers. In view of this, an automated gaari frying machine was developed and tested. The performance evaluation results obtained showed that it performed best based on the timeliness of operation, energy consumption, throughput capacity, efficiency. The machine is gender friendly, with low number of operators, cheap and affordable as an industrial frying equipment.

5.2 Conclusions

From this study, the following conclusion can be drawn:

1. The Analysis of the results showed that the mechanical fryer performed better than the manual fryer in terms of functional efficiency (57%), throughput capacity (18.70 kg/hr) and timeliness of operation with a processing frying time (55 minutes) at an average 30 kg of mash sample. However, the manual fryer had the best production and operating costs but associated with heat stress, health risks and drudgery.

2. An automated gaari frying machine developed was powered electrically with a 2 hp, 3 phase, 220V, 60 hertz frequency, and operational speed of 84 rpm using pulleys, chain and sprocket system.
3. The performance evaluation results showed that the throughput capacity, functional efficiency, heat energy and thermal efficiency of the automated frying machine were 45.0 kg/hr, 87%, 7,919 J and 42.74%, respectively. A unit increase in temperature and frying time had a significant and direct effect ($P < 0.05$) on the final moisture content of the gaari sample produced.
4. The comparative analysis results showed that the developed automated gaari fryer was more cost effective and efficient than the mechanical fryer in terms of production capacity, processing time, performance efficiency, maintenance and operating cost.
5. Optinum efficiency of the automated gaari frying machine were obtained at processing conditions of loading 49.997kg, frying time 57.80 minutes, initial moisture content 30.0%, and frying temperature 183 ^{o}C at the final moisture content and desirability of 0.975 and 12.422 % wb, respectivley.

5.3 Recommendations

The following recommendations could be made during commercialization period of the machine:

1. The automated gaari frying machine’s frying chamber and operational speed could be increased to increase the machine’s production output for the purpose of commercialization.

2. The machine could be fixed on movable wheels or rollers since it does not make a noise or vibrate for easy movement from one processing point to another. Thus, it can be turned into a mobile automated gaari fryer.

3. The power system could be connected to run on a solar system in place of where there is no electrical power supply since it does not consume much electrical power supply. This can also be a medium to test the viability of the business with an alternative power supply.

4. The proximate analysis of the gaari sample produced by this automated gaari could be carried out to test its fit for human consumption.

5.4 Contributions to Knowledge

1. An automated gaari frying machine with electrical filaments as heat source controlled by an electronic system has been developed.
2. The research methodology of this study showed how a high speed of an electric motor can be reduced to any desired operating speed using pulley, chain and sprocket system.
3. The study proved that the automated gaari fryer is better than the mechanical and manual fryers in terms of throughput capacity, efficiencies, and timeliness of operation.
4. The study illustrated that temperature, time, filament, mash quantity have significant impact on the final moisture content of the gaari sample produced.
5. The automated gaari fryer is gender friendly, economical and affordable when compare with other conventional mechanical gaari fryers in existence.
6. The heat stress, health risk and drudgery associated with mechanical and manual gaari fryers were eliminated with the developed automated gaari frying machine.

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APPENDIX ONE

Programming language of the Automated Garri Frying Machine

```
#include <LiquidCrystal.h>
#include <Adafruit_MAX31855.h>
#include <MenuBackend.h>
#include <Wire.h>
#include <PID_v1.h>
#define RelayPin 7    // SSR connected to Arduino digital 7
int thermoDO = 3;    // MAX31855 Data to Arduino digital 3
int thermoCS = 4;    // MAX31855 Chip Select to Arduino digital 4
int thermoCLK = 5;    // MAX31855 Clock to Arduino digital 5
int right;    // boolean for right button
int left;      // boolean for left button
int enter;    // boolean for enter button
int escape;    // boolean for esc button
int setGarriTemp; //boolean variabke for storing whether user is in Garri Set Point part of menu
int setFryerTime;  //boolean variabke for storing whether user is in Fryer Time Set Point part of
        menu
int setOffsetBool; // boolean for storing whether user is in Set Offset part of menu
int setTempScale; // boolean for storing whether user is in Set TempScale part of menu
int setGarring;  // boolean for storing whether user is in Garri fryer part of menu
int setTiming;  // boolena for storing whewther user is in Fryer time part of menu
double garriTempSetting = 250.00; //variable for allowing setting of brew setpoint when in Set
        Brew Temp part of menu
double fryerTimeSetting = 90.00; //variable for allowing setting of time setpoint when in Set
        Brew Temp part of menu
int intGarriTempSetting;  // int for displaying brewTempSetting in integer for to save lcd space
        (MAY NOT BE USED)
int intFryerTimeSetting;  // int for displaying steamTempSetting in integer for to save lcd space
        (MAY NOT BE USED)
double offsetSetting;  // value for changing/displaying temp offset from boiler to grouphead
const int buttonPinLeft = 13; // pin for the Up button
const int buttonPinRight = 10; // pin for the Down button
const int buttonPinEsc = 12; // pin for the Esc button
const int buttonPinEnter = 11; // pin for the Enter button
MenuItem menuItem1SubItem1 menuItem1SubItem2 = MenuItem("STOP");
```

```
MenuItem menuItem1SubItem2 = MenuItem("AUTO/MANUAL");
MenuItem menuItem1SubItem2 menuItem1SubItem1 = MenuItem("AUTO");
MenuItem menuItem1SubItem2 menuItem1SubItem2 = MenuItem("MANUAL");
MenuItem menu1Item2 = MenuItem("Fryer Time");    // select this to load preset steam stepoint
MenuItem menu1Item3 = MenuItem("Garri Temp");    // select this and move to child to change
        garri setpoint
MenuItem menuItem3SubItem1 = MenuItem("Set Garri Point");  // select this to change garri
        setpoint
MenuItem menu1Item4 = MenuItem("Fryer Time");           // select this and move to child to
        change fryer time
MenuItem menuItem4SubItem1 = MenuItem("Set Fryer Time");  // select this to change fryer
        time
MenuItem menu1Item5 = MenuItem("Offset");                // select this & move  to group temp
        offset
MenuItem menuItem5SubItem1 = MenuItem("Set Offset");       // select this  to group temp
        offset
MenuItem menu1Item6 = MenuItem("Scale");                  // select this & move to change temp
        scale
MenuItem menuItem6SubItem1 = MenuItem("Set Scale");        // select this to change temp scale
long unsigned lastMillis;
 myPID.SetOutputLimits(0, WindowSize);   //tell the PID to range between 0 and the full window
        size
  myPID.SetMode(AUTOMATIC);    //turn the PID on
  //configure menu structure
menu.getRoot().add(menu1Item1);
menu1Item1.addRight(menu1Item2).addRight(menu1Item3).addRight(menu1Item4).addRight(m
        enu1Item5).addRight(menu1Item6);
menu1Item3.add(menuItem3SubItem1);
menu1Item4.add(menuItem4SubItem1);
menu1Item5.add(menuItem5SubItem1);
menu1Item6.add(menuItem6SubItem1);
menu.toRoot();    // go to root of menu
}
void loop() {
  tempRead();    // call temp reading method
  if ((millis() - lastMillis) >= 125)  {    //perform calcPID 8 times per second
  calcPID();    // call PID calculation
```

```
  readButtons(); //  button reading and navigation split in two procedures because
  navigateMenus(); //in some situations, the buttons are used for other purpose (eg. to change
            some settings)
  changeValues(); // scans buttons and menu states
  }
}  // end loop
void tempRead()  {
   double c = thermocouple.readCelsius();
   if (isnan(c)) {    //  if c is not a number
     //Serial.println("Something wrong with thermocouple!"); // uncomment if using serial window
     lcd.setCursor(0,0);
     lcd.print("Thermocouple Err");
   } else {
    // Serial.print("C = ");
    // Serial.println(c);
   }
   tempReadF = thermocouple.readFarenheit();  // read temp in degrees F
   tempReadC = c;                         // temp in degrees C
   total= total - readings[index];
   readings[index] = tempReadF;         // read from the sensor:
   total= total + readings[index];     // add the reading to the total:
   index = index + 1;                 // advance to the next position in the array:
   if (index >= numReadings)          // if we're at the end of the array...
   index = 0;                         // ...wrap around to the beginning:
   averageF = total / numReadings;    // calculate the average:
   //Serial.print("Internal Temp = ");        // uncomment these lines if checking MAX31855
   //Serial.println(thermocouple.readInternal());     // internal chip temp via Serial Window
   //Serial.print("Temp ");                   // uncomment these lines if checking MAX31855
   Serial.print(averageF);                 // hot junction temp via Serial Window
   Serial.print("\t");
   lcd.setCursor(9,0);
   lcd.print(averageF);      // print temp to upper RHS of LCD
   lcd.print((char)223);          // print degree symbol
}
void calcPID()  {
  Input = averageF; // PID input is measured averaged temp
  myPID.Compute(); //PID calculation
```

```
  /************************************************
  * turn the output pin on/off based on pid output
  ************************************************/
  unsigned long now = millis();
  if(now - windowStartTime>WindowSize)    //time to shift the Relay Window
    {
    windowStartTime += WindowSize;
    }
  if(Output > now - windowStartTime) digitalWrite(RelayPin,HIGH);
  else digitalWrite(RelayPin,LOW);
  Serial.print(Output);    // uncomment these lines if
  Serial.print("\t");      // logging data to
  timeNowMins = millis() / 90000.0;    //Serial
  Serial.println(timeNowMins);        // Window
}
void menuChanged(MenuChangeEvent changed){
MenuItem newMenuItem=changed.to; //get the destination menu
lcd.setCursor(0,1); //set the start position for lcd printing to the second row, first column
if(newMenuItem.getName()==menu.getRoot()){
  lcd.setCursor(0,0);
  lcd.print("       ");
  lcd.setCursor(0,1);
  lcd.print("Menu            ");
  setGarriTemp = false;
  setFryerTime = false;
  setOffsetBool = false;
  setTempScale = false;
```

APPENDIX TWO

Validation of the Predicted Values for Final Moisture Content and Throughput Capacity

Coded factors final equation:

1/Final MC = 0.073 – 0.011A + 0.021B – 2.239 $x10^{-3}$C + 0.020D – 8.253 $x10^{-3}$AB + 2.232 $x10^{-3}$AC – 1.282AD – 4.183BC + 9.973 $x10^{-3}$BD + 1.692 $x10^{-3}$CD + 7.026 $x10^{-3}A^2$ + 5.515 $x10^{-3}B^2$ + 4.024 $x10^{-3}C^2$ + 0.019D^2

For a processing conditions:

Loading = 10 kg,

Frying time = 15 mins,

Initial moisture content = 30%

Frying temperature = 140 ^oC

The predicted (Calculated) values of the final moisture content and throughput capacity are as follows:

Final Moisture Content (% db)

1/Final MC = – 0.24684 – 1.162 $x10^{-3}$ x 10 – 3.801 $x10^{-4}$ x 15 – 3.912 $x10^{-3}$ x 30 + 4.193 $x10^{-3}$ x 140 – 1.375 $x10^{-5}$ x 10 x 15 + 1.115 $x10^{-3}$ x 10 x 30 – 1.602 $x10^{-6}$ x 10 x 140 – 1.394 $x10^{-5}$ x 15 x 30 + 8.310 $x10^{-6}$ x 15 x 140 + 4.22 $x10^{-6}$ x 30 x 140 + 1.756 $x10^{-5}$ x 10^2 + 6.1273 $x10^{-6}$ x 15^2 + 4.024 $x10^{-5}$ x 30^2 – 1.165 $x10^{-5}$ x 140^2

= – 0.24684 – 0.00116 – 0.0057 – 0.117 + 0.5870 – 0.00206 + 0.0166 – 0.0033 – 0.00224 + 0.00627 +0.0174 + 0.0177 + 0.00175 + 0.0362 – 0.228

= – 0.5750 + 0.664 = 1/0.089 = 11.24%.

While the final equation in terms of actual factors:

1/Final MC = – 0.24684 – 1.162 $x10^{-3}$A – 3.801 $x10^{-4}$B – 3.912 $x10^{-3}$C + 4.193 $x10^{-3}$D – 1.375$x10^{-5}$AB + 1.115 $x10^{-5}$AC – 1.602$x10^{-6}$AD – 1.394$x10^{-5}$BC +

$8.310 \times 10^{-6}BD + 4.229 \times 10^{-6}CD + 1.756 \times 10^{-5}A^2 + 6.127 \times 10^{-6}B^2 + 4.024C^2 - 1.165 \times 10^{-5}D^2$

For Throughput Capacity (Kg/hr)

Throughput Capacity = $6.118 + 0.770 \times 10 + 0.245 \times 15 - 0.384 \times 30 - 0.039 \times 140 + 1.734 \times 10^{-4} \times 10 \times 15 + 8.617 \times 10^{-4} \times 10 \times 30 - 5.122 \times 10^{-5} \times 10 \times 140 - 2.256 \times 10^{-3} \times 15 \times 30 - 4.837 \times 10^{-4} \times 15 \times 140 + 8.363 \times 10^{-4} \times 30 \times 140 + 3.965 \times 10^{-3} \times 10^2 - 1.123 \times 10^{-3} \times 15^2 + 4.465 \times 10^{-3} \times 30^2 + 2.273 \times 10^{-5} \times 140^2$

$= 6.118 + 7.7 + 3.675 - 11.52 - 5.46 + 0.0259 + 0.2585 - 0.7168 - 1.0125 - 1.0157 + 3.5112 + 0.396 - 0.256 + 4.014 + 0.4449$

$= 26.14 - 19.981 = 6.15$ kg/hr.

For processing conditions of;

Loading = 20 kg,

Frying time = 30 mins,

Initial moisture content = 35%

Frying temperature = 160 ^oC

The predicted (Calculated) values of the final moisture content and throughput capacity are as follows:

Final Moisture Content (% db)

1/Final MC = $-0.24684 - 1.162 \times 10^{-3} \times 20 - 3.801 \times 10^{-4} \times 30 - 3.912 \times 10^{-3} \times 35 + 4.193 \times 10^{-3} \times 160 - 1.375 \times 10^{-5} \times 20 \times 30 + 1.115 \times 10^{-3} \times 20 \times 35 - 1.602 \times 10^{-6} \times 20 \times 160 - 1.394 \times 10^{-5} \times 30 \times 35 + 8.310 \times 10^{-6} \times 30 \times 160 + 4.22 \times 10^{-6} \times 35 \times 160 + 1.756 \times 10^{-5} \times 20^2 + 6.1273 \times 10^{-6} \times 30^2 + 4.024 \times 10^{-5} \times 35^2 - 1.165 \times 10^{-5} \times 160^2$

$= -0.24684 - 0.0232 - 0.0114 - 0.136 + 0.670 - 0.0082 + 0.0078 - 0.0051 - 0.0146 + 0.0398 + 0.0236 + 0.0070 + 0.0055 + 0.0492 - 0.298$

$= -0.7424 + 0.8524 = 1/0.11 = 9.09\%$.

For Throughput Capacity (Kg/hr)

Throughput Capacity = 6.118 + 0.770 x 20 + 0.245 x 30 – 0.384 x 35 – 0.039 x 160 + 1.734 $x10^{-4}$ x 20 x 30 + 8.617 $x10^{-4}$ x 20 x 35 – 5.122 x 10^{-5} x 20 x 160 – 2.256 $x10^{-3}$ x 30 x 35 – 4.837 $x10^{-4}$ x 30 x 160 + 8.363 $x10^{-4}$ x 35 x 160 + 3.965 $x10^{-3}$ x 20^2 – 1.123 $x10^{-3}$ x 30^2 + 4.465 $x10^{-3}$ x 35^2 + 2.273 $x10^{-5}$ x 160^2

= 6.118 + 15.4 + 7.35 – 13.44 – 6.24 + 0.1038 + 0.603 – 1.639 – 2.3625 – 2.318 + 4.681 + 1.584 – 1.008 + 5.463 + 0.5811

= 41.87 – 27.05 = 14.82 kg/hr.

For processing conditions of;

Loading = 30 kg,

Frying time = 45 mins,

Initial moisture content = 40%

Frying temperature = 180 ^oC

The predicted (Calculated) values of the final moisture content and throughput capacity are as follows:

Final Moisture Content (% db)

1/Final MC = – 0.24684 – 1.162 $x10^{-3}$ x 30 – 3.801 $x10^{-4}$ x 45 – 3.912 $x10^{-3}$ x 40 + 4.193 $x10^{-3}$ x 180 – 1.375 $x10^{-5}$ x 30 x 45 + 1.115 $x10^{-3}$ x 30 x 40 – 1.602 $x10^{-6}$ x 30 x 180 – 1.394 $x10^{-5}$ x 45 x 40 + 8.310 $x10^{-6}$ x 45 x 180 + 4.22 $x10^{-6}$ x 40 x 180 + 1.756 $x10^{-5}$ x 30^2 + 6.1273 $x10^{-6}$ x 45^2 + 4.024 $x10^{-5}$ x 40^2 – 1.165 $x10^{-5}$ x 180^2

= – 0.24684 – 0.00348 – 0.017 – 0.156 + 0.754 – 0.0184 + 0.0133 – 0.0086 – 0.025 + 0.0673 +0.0303 + 0.0157 + 0.123 + 0.0643 – 0.377

= – 0.9386 + 1.044 = 1/0.10 = 10.0%.

For Throughput Capacity (Kg/hr)

Throughput Capacity = 6.118 + 0.770 x 30 + 0.245 x 45 – 0.384 x 40 – 0.039 x 180 + 1.734 $x10^{-4}$ x 30 x 45 + 8.617 $x10^{-4}$ x 30 x 40 – 5.122 x 10^{-5} x 30 x 180 – 2.256 $x10^{-3}$ x 45 x 40 – 4.837 $x10^{-4}$ x 45 x 180 + 8.363 $x10^{-4}$ x 40 x 160 + 3.965 $x10^{-3}$ x 30^2 – 1.123 $x10^{-3}$ x 45^2 + 4.465 $x10^{-3}$ x 40^2 + 2.273 $x10^{-5}$ x 180^2

$= 6.118 + 23.1 + 11.025 – 15.36 – 7.02 + 0.023 + 1.034 – 2.765 – 4.05 – 3.91 + 6.019 + 3.56 – 0.0504 + 7.136 + 0.7354$

$= 58.91 – 33.609 = 25.20$ kg/hr.

For processing conditions of;

Loading = 40 kg,

Frying time = 60 mins,

Initial moisture content = 45%

Frying temperature = 200 ^oC

The predicted (Calculated) values of the final moisture content and throughput capacity are as follows:

Final Moisture Content (% db)

$1/\text{Final MC} = – 0.24684 – 1.162 \times 10^{-3} \times 40 – 3.801 \times 10^{-4} \times 60 – 3.912 \times 10^{-3} \times 45 + 4.193 \times 10^{-3} \times 200 – 1.375 \times 10^{-5} \times 40 \times 60 + 1.115 \times 10^{-3} \times 40 \times 45 – 1.602 \times 10^{-6} \times 40 \times 200 – 1.394 \times 10^{-5} \times 60 \times 45 + 8.310 \times 10^{-6} \times 60 \times 200 + 4.22 \times 10^{-6} \times 45 \times 200 + 1.756 \times 10^{-5} \times 40^2 + 6.1273 \times 10^{-6} \times 60^2 + 4.024 \times 10^{-5} \times 45^2 – 1.165 \times 10^{-5} \times 200^2$

$= – 0.24684 – 0.0464 – 0.0228 – 0.176 + 0.8.38 – 0.0328 + 0.020 – 0.0128 – 0.0375 + 0.0997 +0.0380 + 0.028 + 0.022 + 0.081 – 0.4.66$

$= – 1.0511 + 1.130 = 1/0.0789 = 12.67\%$.

For Throughput Capacity (Kg/hr)

$\text{Throughput Capacity} = 6.118 + 0.770 \times 40 + 0.245 \times 60 – 0.384 \times 45 – 0.039 \times 200 + 1.734 \times 10^{-4} \times 40 \times 60 + 8.617 \times 10^{-4} \times 40 \times 45 – 5.122 \times 10^{-5} \times 40 \times 200 – 2.256 \times 10^{-3} \times 60 \times 45 – 4.837 \times 10^{-4} \times 60 \times 200 + 8.363 \times 10^{-4} \times 45 \times 200 + 3.965 \times 10^{-3} \times 40^2 – 1.123 \times 10^{-3} \times 60^2 + 4.465 \times 10^{-3} \times 45^2 + 2.273 \times 10^{-5} \times 200^2$

$= 6.118 + 30.8 + 14.7 – 17.28 – 7.8 + 0.415 + 1.551 – 4.096 – 6.075 – 5.796 +7.524 + 6.336 – 4.032 + 9.031 + 0.908$

$= 77.383 – 45.08 = 32.30$ kg/hr.

For processing conditions of;

Loading = 50 kg,

Frying time = 75 mins,

Initial moisture content = 50%

Frying temperature = 220 ^oC

The predicted (Calculated) values of the final moisture content and throughput capacity are as follows:

Final Moisture Content (% db)

1/Final MC = – 0.24684 – 1.162 $x10^{-3}$ x 50 – 3.801 $x10^{-4}$ x 75 – 3.912 $x10^{-3}$ x 50 + 4.193 $x10^{-3}$ x 220 – 1.375 $x10^{-5}$ x 50 x 75 + 1.115 $x10^{-3}$ x 50 x 50 – 1.602 $x10^{-6}$ x 50 x 220 – 1.394 $x10^{-5}$ x 75 x 50 + 8.310 $x10^{-6}$ x 75 x 220 + 4.22 $x10^{-6}$ x 50 x 200 + 1.756 $x10^{-5}$ x 50^2 + 6.1273 $x10^{-6}$ x 75^2 + 4.024 $x10^{-5}$ x 50^2 – 1.165 $x10^{-5}$ x 220^2

= – 0.24684 – 0.058 – 0.0285 – 0.1955 + 0.921 – 0.0514 + 0.0277 – 0.0176 – 0.0521 + 0.1371 + 0.0464 + 0.0437 + 0.0344 + 0.10 – 0.5614

= – 1.2622 + 1.3410 = 1/0.07881 = 12.69%.

For Throughput Capacity (Kg/hr)

Throughput Capacity = 6.118 + 0.770 x 50 + 0.245 x 75 – 0.384 x 50 – 0.039 x 220 + 1.734 $x10^{-4}$ x 50 x 75 + 8.617 $x10^{-4}$ x 50 x 50 – 5.122 x 10^{-5} x 50 x 220 – 2.256 $x10^{-3}$ x 75 x 50 – 4.837 $x10^{-4}$ x 75 x 220 + 8.363 $x10^{-4}$ x 50 x 220 + 3.965 $x10^{-3}$ x 50^2 – 1.123 $x10^{-3}$ x 75^2 + 4.465 $x10^{-3}$ x 50^2 + 2.273 $x10^{-5}$ x 220^2

= 6.118 + 38.5 + 18.37 – 19.25 – 7.45 + 0.648 + 2.1525 – 5.634 – 8.437 – 7.969 + 9.196 + 9.90 – 6.30 + 11.15 + 1.098

= 97.87 – 53.90 = 43.97 kg/hr.

From the optimum parameters loading 50 kg, frying time 57.80 mins, initial moisture content 30%, and frying temperature 183 ^{o}C, the predicted (Calculated) values can be substituted in Equation (38):

For Final Moisture Content (% db)

1/Final MC = – 0.24684 – 1.162 $x10^{-3}$ x 50 – 3.801 $x10^{-4}$ x 57.8 – 3.912 $x10^{-3}$ x 30 + 4.193 $x10^{-3}$ x 183 – 1.375 $x10^{-5}$ x 50 x 57.8 + 1.115 $x10^{-3}$ x 50 x 30 – 1.602 $x10^{-6}$ x 50 x 183 – 1.394 $x10^{-5}$ x 57.8 x 30 + 8.310 $x10^{-6}$ x 57.8 x 183 + 4.22 $x10^{-6}$ x 30 x 183 + 1.756 $x10^{-5}$ x 50^2 + 6.1273 $x10^{-6}$ x 57.8^2 + 4.024 $x10^{-5}$ x 30^2 – 1.165 $x10^{-5}$ x 183^2

= – 0.24684 – 0.0581 – 0.0296 – 0.117 + 0.767 – 0.0397 + 0.0166 – 0.0146 – 0.0241 + 0.0878 +0.0231 + 0.0437 + 0.0204 + 0.0036 – 0.5525

= – 1.07476 + 0.09900 = 1/0.84 = 11.91%.

For Throughput Capacity (Kg/hr)

Throughput Capacity = 6.118 + 0.770 x 50 + 0.245 x 57.8 – 0.384 x 30 – 0.039 x 140 + 1.734 $x10^{-4}$ x 50 x 57.8 + 8.617 $x10^{-4}$ x 50 x 30 – 5.122 x 10^{-5} x 50 x 183 – 2.256 $x10^{-3}$ x 57.8 x 30 – 4.837 $x10^{-4}$ x 57.8 x 183 + 8.363 $x10^{-4}$ x 30 x 183 + 3.965 $x10^{-3}$ x 50^2 – 1.123 $x10^{-3}$ x 57.8^2 + 4.465 $x10^{-3}$ x 30^2 + 2.273 $x10^{-5}$ x 183^2

= 6.118 + 38.5 + 14.16 – 11.52 – 7.137 + 0.4999 + 1.2925 – 2.8119 – 3.902 – 5.109 + 4.589 + 9.9 – 3.741 + 4.014 + 0.7602

= 79.833 – 35.52 = 44.28 kg/hr.

APPENDIX THREE

Raw Data for the Optimization Process

Table A3.1: Experimental data for Final MC and Throughput Capacity Optimization

Run	Factor 1 A:Mash Quantity Kg	Factor 2 B:Frying Time Min	Factor 3 C:Initial MC %	Factor 4 D:Frying Temperature Degree Cel	Response 1 Throughput Capacity Kg/hr	Response 2 final MC %
1	29.2839	75	42.6	220	18.9	8.4
2	30.6	15	50	140	26.4	40.5
3	50	15	33.1	220	41.2	24.2
4	10	53.1	37.7	170.4	6.2	12.7
5	50	15	50	220	44.5	15.5
6	29.2839	75	42.6	220	18.4	9.8
7	10	26.4	30	140	6.6	19.4
8	50	46.5	42.8	140	46.1	32.3
9	34	38.4048	30	188.8	26.3	14.5
10	10	75	30	205.6	3.5	6.5
11	50	75	50	182.4	42.2	12.4
12	34	38.4048	30	188.8	26.7	13.7
13	10	43.8	50	220	5.9	11.2
14	42.674	75	30	140	37.8	20.1
15	50	15	30	140	45.5	25.9
16	31	75	42	157.2	24.6	13
17	10	15	30	220	5.5	15.6
18	50	48.3	41	206.8	45	12.5
19	31.8	42.3	50	183.6	27.2	12.2
20	10	15	42.7	178.509	5.7	14.4
21	50	75	30	220	40.4	9.5
22	50	46.5	42.8	140	44.8	26.6
23	10	75	50	140	5.2	13.1
24	34	38.4048	30	188.8	26	12
25	10	15	42.7	178.509	5.6	13.5

APPENDIX FOUR

Design Summary of the Optimization Results/Outcomes

File Version	10.0.1.0				
Study Type	Response Surface	**Subtype**	Randomized		
Design Type	*I-optimal* Coordinate Exchange	**Runs**	25		
Design Model	Quadratic	**Blocks**	No Blocks	**Build Time (ms)**	522.00

Factor	Name	Units	Type	Subtype	Minimum	Maximum	Coded	Values	Mean	Std. Dev.
A	Mash Quantity	Kg	Numeric	Continuous	10	50	-1.000=10	1.000=50	31.0657	16.5654
B	Frying Time	Min	Numeric	Continuous	15	75	-1.000=15	1.000=75	45.0846	24.2092
C	Initial MC	%	Numeric	Continuous	30	50	-1.000=30	1.000=50	39.2	8.12835
D	Frying Temperature	Degree Cel	Numeric	Continuous	140	220	-1.000=140	1.000=220	181.977	31.9788

Response	Name	Units	Obs	Analysis	Minimum	Maximum	Mean	Std. Dev.	Ratio	Trans	Model
R1	Throughput Capacity	Kg/hr	25	Polynomial	3.5	46.1	25.048	15.9824	13.1714	None	Quadratic
R2	final MC	%	25	Polynomial	6.5	40.5	16.38	7.96021	6.23077	Inverse	Quadratic

APPENDIX FIVE

Summary Details for Optimal Throughput Capacity

Source	Sequential p-value	Lack of Fit p-value	Adjusted R-Squared	Predicted R-Squared	
Linear	< 0.0001	0.0033	0.6509	0.5049	
2FI	0.0686	0.0067	0.7625	0.2672	
Quadratic	0.0037	0.0642	0.9209	0.4072	Suggested
Cubic	0.0642		0.9708		Aliased

Sequential Model Sum of Squares [Type I]

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Mean vs Total	62051.81	1	62051.81			
Linear vs Mean	34289.87	4	8572.47	12.19	< 0.0001	
2FI vs Linear	7368.96	6	1228.16	2.57	0.0686	
Quadratic vs 2FI	5106.35	4	1276.59	8.00	0.0037	Suggested
Cubic vs Quadratic	1300.73	5	260.15	4.42	0.0642	Aliased
Residual	294.09	5	58.82			
Total	1.104E+005	25	4416.47			

Lack of Fit Tests

Source	Sum of Squares	Df	Mean Square	F Value	p-value Prob > F	
Linear	13776.04	15	918.40	15.61	0.0033	
2FI	6407.08	9	711.90	12.10	0.0067	
Quadratic	1300.73	5	260.15	4.42	0.0642	Suggested
Cubic	0.000	0				Aliased
Pure Error	294.09	5	58.82			

Model Summary Statistics

Source	Std. Dev.	R-Squared	Adjusted R-Squared	Predicted R-Squared	PRESS	
Linear	26.52	0.7091	0.6509	0.5049	23945.10	
2FI	21.88	0.8614	0.7625	0.2672	35438.64	
Quadratic	12.63	0.9670	0.9209	0.4072	28667.21	Suggested
Cubic	7.67	0.9939	0.9708		+	Aliased

Table A5.1: Standard Error Values for Throughput Capacity

Factor	Coefficient Estimate	df	Standard Error	95% CI Low	95% CI High	VIF
Intercept	29.09	1	3.96	20.78	37.40	
A-Mash Quantity	40.82	1	2.55	35.46	46.17	1.08
B-Frying Time	-38.94	1	2.63	-44.47	-33.41	1.08
C-Initial MC	-2.44	1	2.79	-8.30	3.42	1.04
AB	-28.12	1	3.03	-34.50	-21.75	1.10
B^2	39.72	1	5.08	29.05	50.40	1.16
C^2	-7.64	1	4.38	-16.84	1.56	1.11

APPENDIX SIX

Summary Details for Optimal Functional Efficiency

Source	Sequential p-value	Lack of Fit p-value	Adjusted R-Squared	Predicted R-Squared	
Linear	< 0.0001	0.0021	0.9299	0.9029	
2FI	0.0336	0.0057	0.9579	0.6405	
Quadratic	0.0375	0.0170	0.9769	0.6854	Suggested
Cubic	0.0170		0.9952		Aliased

Sequential Model Sum of Squares [Type I]

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Mean vs Total	1.538E+005	1	1.538E+005			
Linear vs Mean	3395.46	4	848.87	80.60	< 0.0001	
2FI vs Linear	122.06	6	20.34	3.22	0.0336	
Quadratic vs 2FI	53.83	4	13.46	3.87	0.0375	Suggested
Cubic vs Quadratic	31.12	5	6.22	8.59	0.0170	Aliased
Residual	3.62	5	0.72			
Total	1.574E+005	25	6294.69			

Lack of Fit Tests

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Linear	207.01	15	13.80	19.05	0.0021	
2FI	84.95	9	9.44	13.03	0.0057	
Quadratic	31.12	5	6.22	8.59	0.0170	Suggested
Cubic	0.000	0				Aliased
Pure Error	3.62	5	0.72			

Model Summary Statistics

Source	Std. Dev.	R-Squared	Adjusted R-Squared	Predicted R-Squared	PRESS	
Linear	3.25	0.9416	0.9299	0.9029	350.13	
2FI	2.52	0.9754	0.9579	0.6405	1296.57	
Quadratic	1.86	0.9904	0.9769	0.6854	1134.46	Suggested
Cubic	0.85	0.9990	0.9952		+	Aliased

Table A6.1: Standard Error Values for the Functional Efficiency

Factor	Coefficient Estimate	df	Standard Error	95% CI Low	95% CI High	VIF
Intercept	79.75	1	0.55	78.58	80.91	
A-Mash Quantity	12.84	1	0.46	11.87	13.81	1.07
B-Frying Time	-5.83	1	0.47	-6.83	-4.82	1.08
C-Initial MC	0.82	1	0.50	-0.24	1.88	1.04
D-Temperature	-2.66	1	0.45	-3.62	-1.71	1.04
AB	2.86	1	0.55	1.70	4.02	1.11
AD	1.73	1	0.53	0.61	2.84	1.08
CD	1.36	1	0.61	0.069	2.65	1.02
C^2	-3.07	1	0.77	-4.71	-1.43	1.07

APPENDIX SEVEN

Summary Details for Optimal Heat Energy of the Automated Machine

Source	Sequential p-value	Lack of Fit p-value	Adjusted R-Squared	Predicted R-Squared	
Linear	< 0.0001	0.3910	0.8007	0.7159	
2FI	0.0303	0.7546	0.8824	0.7164	Suggested
Quadratic	0.3172	0.8547	0.8931	0.6614	
Cubic	0.8547		0.8432		Aliased

Sequential Model Sum of Squares [Type I]

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Mean vs Total	1.369E+009	1	1.369E+009			
Linear vs Mean	5.252E+008	4	1.313E+008	25.11	< 0.0001	
2FI vs Linear	6.140E+007	6	1.023E+007	3.32	0.0303	Suggested
Quadratic vs 2FI	1.517E+007	4	3.792E+006	1.35	0.3172	
Cubic vs Quadratic	7.471E+006	5	1.494E+006	0.36	0.8547	Aliased
Residual	2.057E+007	5	4.114E+006			
Total	1.999E+009	25	7.995E+007			

Lack of Fit Tests

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Linear	8.403E+007	15	5.602E+006	1.36	0.3910	
2FI	2.264E+007	9	2.515E+006	0.61	0.7546	Suggested
Quadratic	7.471E+006	5	1.494E+006	0.36	0.8547	
Cubic	0.000	0				Aliased
Pure Error	2.057E+007	5	4.114E+006			

Model Summary Statistics

Source	Std. Dev.	R-Squared	Adjusted R-Squared	Predicted R-Squared	PRESS	
Linear	2286.96	0.8339	0.8007	0.7159	1.789E+008	
2FI	1756.79	0.9314	0.8824	0.7164	1.786E+008	Suggested
Quadratic	1674.58	0.9555	0.8931	0.6614	2.132E+008	
Cubic	2028.33	0.9673	0.8432		+	Aliased

Table A.7.1 Standard Error Values for the Heat Energy

	Coefficient		Standard	95% CI	95% CI	
Factor	**Estimate**	**df**	**Error**	**Low**	**High**	**VIF**
Intercept	7551.88	1	312.08	6900.88	8202.88	
A-Mash Quantity	4482.01	1	389.13	3670.30	5293.71	1.06
B-Frying Time	2288.41	1	393.33	1467.94	3108.87	1.02
D-Temperature	1030.86	1	382.24	233.52	1828.21	1.02
AB	2280.69	1	461.64	1317.71	3243.66	1.08

APPENDIX EIGHT

Summary Details for the Thermal Efficiency of the Machine

Source	Sequential p-value	Lack of Fit p-value	Adjusted R-Squared	Predicted R-Squared	
Linear	< 0.0001	0.4522	0.8931	0.8624	Suggested
2FI	0.9752	0.2648	0.8586	0.4369	
Quadratic	0.1413	0.4008	0.8949	0.4116	
Cubic	0.4008		0.9073		Aliased

Sequential Model Sum of Squares [Type I]

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Mean vs Total	90291.84	1	90291.84			
Linear vs Mean	20702.55	4	5175.64	51.10	< 0.0001	Suggested
2FI vs Linear	151.15	6	25.19	0.19	0.9752	
Quadratic vs 2FI	878.97	4	219.74	2.21	0.1413	
Cubic vs Quadratic	556.29	5	111.26	1.27	0.4008	Aliased
Residual	439.10	5	87.82			
Total	1.130E+005	25	4520.80			

Lack of Fit Tests

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Linear	1586.41	15	105.76	1.20	0.4522	Suggested
2FI	1435.27	9	159.47	1.82	0.2648	
Quadratic	556.29	5	111.26	1.27	0.4008	
Cubic	0.000	0				Aliased
Pure Error	439.10	5	87.82			

Model Summary Statistics

Source	Std. Dev.	R-Squared	Adjusted R-Squared	Predicted R-Squared	PRESS	
Linear	10.06	0.9109	0.8931	0.8624	3126.93	Suggested
2FI	11.57	0.9175	0.8586	0.4369	12797.81	
Quadratic	9.98	0.9562	0.8949	0.4116	13373.67	
Cubic	9.37	0.9807	0.9073		+	Aliased

Table A8.1: Standard Error Values for the Thermal Energy

Factor	Coefficient Estimate	df	Standard Error	95% CI Low	95% CI High	VIF
Intercept	59.95	1	2.02	55.72	64.17	
A-Mash Quantity	29.75	1	2.47	24.59	34.91	1.01
B-Frying Time	-19.91	1	2.58	-25.30	-14.52	1.03
C-Initial MC	3.77	1	2.78	-2.02	9.56	1.03
D-Temperature	7.48	1	2.47	2.32	12.64	1.01

APPENDIX NINE

Summary Details for Optimal Final Moisture Content Estimation

Source	Sequential p-value	Lack of Fit p-value	Adjusted R-Squared	Predicted R-Squared	
Linear	< 0.0001	0.0684	0.7773	0.6774	Suggested
2FI	0.2750	0.0747	0.8022	0.2902	
Quadratic	0.0577	0.1739	0.8804	0.2783	Suggested
Cubic	0.1739		0.9307		Aliased

Sequential Model Sum of Squares [Type I]

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Mean vs Total	0.13	1	0.13			
Linear vs Mean	0.016	4	4.048E-003	21.94	< 0.0001	Suggested
2FI vs Linear	1.395E-003	6	2.325E-004	1.42	0.2750	
Quadratic vs 2FI	1.303E-003	4	3.258E-004	3.29	0.0577	Suggested
Cubic vs Quadratic	7.035E-004	5	1.407E-004	2.45	0.1739	Aliased
Residual	2.872E-004	5	5.744E-005			
Total	0.15	25	6.072E-003			

Lack of Fit Tests

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Linear	3.402E-003	15	2.268E-004	3.95	0.0684	Suggested
2FI	2.007E-003	9	2.230E-004	3.88	0.0747	
Quadratic	7.035E-004	5	1.407E-004	2.45	0.1739	Suggested
Cubic	0.000	0				Aliased
Pure Error	2.872E-004	5	5.744E-005			

Model Summary Statistics

Source	Std. Dev.	R-Squared	Adjusted R-Squared	Predicted R-Squared	PRESS	
Linear	0.014	0.8144	0.7773	0.6774	6.413E-003	Suggested
2FI	0.013	0.8846	0.8022	0.2902	0.014	
Quadratic	9.954E-003	0.9502	0.8804	0.2783	0.014	Suggested
Cubic	7.579E-003	0.9856	0.9307		+	Aliased

Table A9.1: Standard Error Values for the Final Moisture Content

Factor	Coefficient Estimate	df	Standard Error	95% CI Low	95% CI High	VIF
Intercept	0.073	1	5.413E-003	0.061	0.085	
A-Mash Qunatity	-0.011	1	2.580E-003	-0.017	-5.640E-003	1.11
B-Frying Time	0.021	1	2.633E-003	0.015	0.027	1.09
C-Initial MC	-2.239E-003	1	2.626E-003	-8.090E-003	3.611E-003	1.10
D-Frying Temperature	0.020	1	2.632E-003	0.014	0.026	1.07
AB	-8.253E-003	1	3.229E-003	-0.015	-1.058E-003	1.14
AC	2.232E-003	1	3.194E-003	-4.885E-003	9.349E-003	1.07
AD	-1.282E-003	1	3.162E-003	-8.327E-003	5.763E-003	1.14
BC	-4.183E-003	1	3.186E-003	-0.011	2.915E-003	1.06
BD	9.973E-003	1	3.151E-003	2.951E-003	0.017	1.12
CD	1.692E-003	1	3.194E-003	-5.425E-003	8.808E-003	1.06
A^2	7.026E-003	1	4.784E-003	-3.633E-003	0.018	1.21
B^2	5.515E-003	1	4.728E-003	-5.020E-003	0.016	1.22
C^2	4.024E-003	1	4.702E-003	-6.452E-003	0.015	1.12
D^2	-0.019	1	5.246E-003	-0.030	-6.965E-003	1.39

Table A9.2: The Optimization Constraints

Name	Goal	Lower Limit	Upper Limit	Lower Weight	Upper Weight	Importance
A:Mash Qunatity	maximize	10	50	1	1	3
B:Frying Time	is in range	15	75	1	1	3
C:Initial MC	is in range	30	50	1	1	3
D:Frying Temperature	is in range	140	220	1	1	3
Throughput Capacity	maximize	3.5	46.1	1	1	3
final MC	minimize	6.5	40.5	1	1	3

Table A9.3: Optimization Solution Results

Number	Mash Quantity	Frying Time	Initial MC	Frying Temperature	Throughput Capacity	final MC	Desirability	
1	50.000	74.965	30.001	187.736	42.440	10.132	0.935	Selected
2	50.000	74.665	30.001	187.123	42.503	10.194	0.934	
3	49.998	74.745	30.000	183.636	42.733	10.387	0.934	
4	50.000	74.999	30.126	184.600	42.640	10.317	0.934	
5	49.991	74.999	30.191	188.172	42.381	10.129	0.934	
6	50.000	74.994	30.000	194.538	41.976	9.850	0.934	
7	49.993	74.999	30.527	188.588	42.327	10.150	0.933	
8	50.000	72.698	30.000	190.772	42.395	10.227	0.933	
9	50.000	75.000	30.699	185.509	42.530	10.335	0.933	
10	50.000	75.000	30.815	188.624	42.310	10.182	0.933	
11	50.000	74.871	30.006	198.884	41.691	9.747	0.933	
12	49.998	73.877	30.000	177.763	43.191	10.912	0.932	
13	50.000	70.072	30.000	188.065	42.746	10.628	0.932	
14	49.777	74.988	30.001	184.682	42.398	10.288	0.931	
15	49.990	66.924	30.001	187.827	42.934	10.980	0.930	
16	50.000	68.198	30.000	198.912	42.159	10.463	0.929	
17	50.000	74.999	31.092	204.482	41.230	9.760	0.929	
18	49.978	74.984	33.214	193.020	41.838	10.244	0.928	
19	50.000	74.981	30.006	208.875	41.009	9.632	0.928	
20	50.000	67.515	30.000	177.817	43.560	11.607	0.928	
21	50.000	72.862	30.000	207.532	41.269	9.865	0.928	
22	50.000	72.419	50.000	197.135	42.329	10.720	0.928	
23	50.000	72.001	49.998	197.407	42.364	10.747	0.928	
24	50.000	72.348	50.000	198.119	42.289	10.690	0.928	
25	50.000	70.413	49.999	197.535	42.539	10.883	0.928	

Table A9.4: Optimization Solution Results Continuation

Number	Mash Quantity	Frying Time	Initial MC	Frying Temperature	Throughput Capacity	Final MC	Desirability
26	50.000	71.232	50.000	199.808	42.335	10.734	0.928
27	49.995	73.310	49.999	196.942	42.228	10.649	0.928
28	49.999	74.966	50.000	197.558	42.003	10.479	0.928
29	50.000	68.413	49.977	198.581	42.707	11.026	0.927
30	50.000	73.038	49.957	194.196	42.400	10.794	0.927
31	50.000	73.650	50.000	200.751	42.003	10.490	0.927
32	50.000	74.993	34.315	192.148	41.865	10.383	0.927
33	50.000	67.188	50.000	197.973	42.869	11.153	0.927
34	50.000	64.881	49.998	196.911	43.155	11.393	0.927
35	49.993	73.450	49.926	192.613	42.420	10.839	0.927
36	50.000	74.996	34.511	193.686	41.758	10.336	0.927
37	50.000	64.115	49.999	197.056	43.224	11.455	0.927
38	50.000	74.941	49.548	196.628	42.010	10.540	0.927
39	49.985	65.851	50.000	198.934	42.946	11.241	0.927
40	50.000	74.964	49.567	199.646	41.854	10.428	0.927
41	50.000	72.105	49.451	198.744	42.228	10.721	0.927
42	50.000	74.132	50.000	190.213	42.477	10.912	0.927
43	50.000	74.995	34.915	190.434	41.950	10.516	0.927
44	50.000	62.760	30.000	186.733	43.221	11.498	0.927
45	50.000	61.623	49.998	198.087	43.415	11.639	0.927
46	49.999	74.930	49.999	188.679	42.461	10.940	0.926
47	49.987	65.736	30.815	197.056	42.365	10.871	0.926
48	50.000	74.997	35.264	185.872	42.227	10.808	0.926
49	50.000	59.220	50.000	198.346	43.620	11.841	0.926
50	50.000	59.629	50.000	194.563	43.749	11.935	0.926

Table A9.5: Optimization Solution Results Continuation

Number	Mash Quantity	Frying Time	Initial MC	Frying Temperature	Throughput Capacity	Final MC	Desirability
51	50.000	58.027	50.000	195.568	43.842	12.030	0.926
52	50.000	74.991	48.245	196.501	41.893	10.594	0.925
53	50.000	74.997	30.000	166.042	43.925	12.119	0.925
54	50.000	56.889	50.000	194.713	43.972	12.157	0.925
55	50.000	74.999	50.000	210.129	41.363	10.211	0.925
56	50.000	75.000	30.001	214.038	40.662	9.662	0.925
57	50.000	72.811	30.000	167.434	43.961	12.181	0.925
58	50.000	74.995	47.396	193.627	41.977	10.750	0.925
59	50.000	67.332	30.000	207.910	41.639	10.502	0.924
60	50.000	75.000	37.183	190.476	41.879	10.692	0.924
61	50.000	74.998	50.000	182.594	42.767	11.409	0.924
62	50.000	73.067	30.000	214.248	40.809	9.889	0.924
63	50.000	72.425	46.581	195.713	42.093	10.920	0.924
64	50.000	74.999	46.198	196.739	41.725	10.638	0.924
65	50.000	74.999	38.388	193.345	41.688	10.629	0.923
66	50.000	53.203	50.000	190.756	44.414	12.628	0.923
67	50.000	57.679	50.000	208.043	43.343	11.881	0.923
68	50.000	73.002	37.826	191.078	42.011	10.916	0.923
69	49.535	74.999	32.258	187.748	41.748	10.372	0.923
70	49.680	68.859	30.000	175.867	43.261	11.625	0.923
71	50.000	51.402	49.800	192.784	44.426	12.695	0.923
72	50.000	75.000	43.646	193.423	41.772	10.796	0.922
73	50.000	74.996	43.045	194.749	41.675	10.729	0.922
74	50.000	74.997	41.450	193.710	41.689	10.742	0.922
75	50.000	47.018	50.000	194.368	44.670	12.938	0.922

Table A9.6: Optimization Solution Results Continuation

Number	Mash Quantity	Frying Time	Initial MC	Frying Temperature	Throughput Capacity	Final MC	Desirability
76	50.000	66.771	35.676	193.894	42.356	11.321	0.922
77	50.000	75.000	40.427	201.255	41.227	10.450	0.922
78	50.000	45.516	50.000	192.201	44.835	13.120	0.921
79	50.000	57.548	30.000	180.113	43.820	12.536	0.920
80	49.931	75.000	30.000	162.450	44.096	12.694	0.920
81	50.000	54.628	50.000	182.212	44.666	13.132	0.920
82	50.000	75.000	42.803	182.254	42.382	11.542	0.919
83	50.000	62.460	44.075	193.190	42.970	12.078	0.918
84	50.000	35.715	50.000	191.008	45.291	13.746	0.917
85	50.000	36.112	50.000	189.478	45.329	13.782	0.917
86	50.000	55.552	50.000	217.426	43.143	12.331	0.917
87	50.000	33.843	50.000	192.110	45.312	13.806	0.917
88	50.000	33.110	50.000	191.803	45.341	13.848	0.917
89	49.992	33.627	50.000	191.101	45.340	13.844	0.917
90	50.000	74.997	35.248	219.213	40.126	10.201	0.915
91	50.000	28.335	49.996	189.630	45.499	14.093	0.915
92	50.000	27.524	50.000	189.380	45.518	14.124	0.915
93	50.000	26.787	50.000	189.908	45.511	14.132	0.915
94	50.000	16.263	50.000	187.359	45.556	14.331	0.913
95	50.000	15.911	50.000	187.792	45.541	14.323	0.913
96	50.000	15.001	49.569	187.449	45.437	14.437	0.910
97	50.000	15.001	50.000	178.007	45.747	14.708	0.909
98	49.183	62.794	30.000	208.678	40.971	11.036	0.907
99	49.782	15.000	50.000	195.857	45.105	14.388	0.907
100	50.000	47.194	30.001	177.296	44.163	13.972	0.906

APPENDIX TEN

Picture Gallery for the Automated, Mechanical and Manual Garri Fryers

Plate 10.1: The Bottom of the Frying Pan Showing the Outlet of the Heat Resistant Cable that Connects the Electrical Filament to the Distribution Cabinet

Plate 10.2: One of the Diesel Tanks for the Mechanized Fryer and a Burner that was broken down during a Frying Operation

Plate 10.3: A Burner Chamber and Connection to the Mechanized Fryer in IITA

Plate 10.4: Manual Garri Frying Operation

Plate 10.5: A Sample of 10 kg during Weighing Operation

APPENDIX ELEVEN

Raw Data for 125 Runs for Effect of Time, and Mash Quantity on Final MC

Table A11.1: Experimental Values of Frying Time, Mash Sample, Initial MC and Final Moisture

DAY 1			
Mash Sample (kg)	**Time of Frying (mins)**	**Initial MC (%)**	**Final MC (%)**
10 kg	15 mins	30, 35, 40, 45, and 50%	13.6%, 15.4%, 16.9%, 19.1% and 20.6%
10 kg	30 mins	30, 35, 40, 45, and 50%	10.2%, 11.8%, 12.0%, 12.6% and 15.2%
10 kg	45 mins	30, 35, 40, 45, and 50%	8.2%, 9.3%, 11.5%, 12.4%, and 13.1%
10 kg	60 mins	30, 35, 40, 45, and 50%	7.7%, 9.4%, 10.5%, 10.9, and 11.6%
10kg	75 mins	30, 35, 40, 45, and 50%	5.2%, 7.1%, 8.8%, 9.2% and 10.4%

Table A11.2: Experimental Values of Frying Time, Mash Sample, Initial MC and Final Moisture

DAY 2			
Mash Sample (kg)	**Time of Frying (mins)**	**Initial MC (%)**	**Final MC (%)**
20 kg	15 mins	30, 35, 40, 45, and 50%	15.3%, 19.8%, 22.1%, 26.0 and 27.5%
20 kg	30 mins	30, 35, 40, 45, and 50%	12.2%,14.5%, 17.9%, 20.1% and 21.9%
20 kg	45 mins	30, 35, 40, 45, and 50%	10.4%, 11.1%, 11.7%, 12.5% and 17.8%
20 kg	60 mins	30, 35, 40, 45, and 50%	8.1%, 10.2%, 11.5%, 12.1% and 13.6%
20 kg	75 mins	30, 35, 40, 45, and 50%	6.7%, 8.2%, 9.6%, 10.3% and 12.0%

Table A11.3: Experimental Values of Frying Time, Mash Sample, Initial MC and Final Moisture

DAY 3

Mash Sample (kg)	**Time of Frying (mins)**	**Initial MC (%)**	**Final MC (%)**
30 kg	15 mins	30, 35, 40, 45, and 50%	19.9%, 22.2%, 25.6%, 29.1%, and 30.4%
30 kg	30 mins	30, 35, 40, 45, and 50%	15.1%, 17.0%, 22.6%, 23.3%, and 26.1%
30 kg	45 mins	30, 35, 40, 45, and 50%	12.4%, 14.7%, 16.5%, 19.4% and 20.9%
30 kg	60 mins	30, 35, 40, 45, and 50%	9.5%, 10.9%, 11.8%, 12.3%, and 14.0%
30 kg	75 mins	30, 35, 40, 45, and 50%	8.1%, 9.2%, 10.6%, 11.5% and 12.5%

Table A11.4: Experimental Values of Frying Time, Mash Sample, Initial MC and Final Moisture

DAY 4

Mash Sample (kg)	**Time of Frying (mins)**	**Initial MC (%)**	**Final MC (%)**
40 kg	15 mins	30, 35, 40, 45, and 50%	24.9, 26.0%, 30.2%, 33.7%, and 35.8%
40 kg	30 mins	30, 35, 40, 45, and 50%	18.7%, 20.5%, 22.6%, 23.9%, and 28.4%
40 kg	45 mins	30, 35, 40, 45, and 50%	11.5%, 12.0%, 12.9%, 13.5%, and 22.0%
40 kg	60 mins	30, 35, 40, 45, and 50%	9.8%, 10.7%, 11.3%, 14.2% and 15.4%
40 kg	75 mins	30, 35, 40, 45, and 50%	10.5%, 11.8%, 12.0%, 12.6% and 13.1%

Table A11.5: Experimental Values of Frying Time, Mash Sample, Initial MC and Final Moisture

DAY 5

Mash Sample (kg)	**Time of Frying (mins)**	**Initial MC (%)**	**Final MC (%)**
50 kg	15 mins	30, 35, 40, 45, and 50%	26.1%, 28.5%, 33.3%, 36.6%, and 39.0%
50 kg	30 mins	30, 35, 40, 45, and 50%	20.2%, 23.0%, 27.4%, 30.1%, and 32.9%
50 kg	45 mins	30, 35, 40, 45, and 50%	15.5%, 19.8%, 21.2%, 22.3%, and 24.2%
50 kg	60 mins	30, 35, 40, 45, and 50%	12.0%, 12.6%, 13.0%, 13.8% and 14.0%
50 kg	75 mins	30, 35, 40, 45, and 50%	9.1%, 10.9%, 11.6%, 12.1% and 13.3%