CHAPTER ONE

INTRODUCTION

1.1 Background Information

Oils and fats being a natural source have extensive applications in our modern industrial world. Global industrialization and the increasing demand for environmentally acceptable materials have led to the investigation and exploitation of more vegetable oils as a renewable feed stock in the preparation of oleo chemicals in order to meet the growing needs of human society. Oils and fats are important parts of human diet and more than ninety percent of the world production from vegetable, animals and marine sources is used as food or as an ingredient in food products. Oils and fats constitute one of the three major classes of food constituents besides proteins and carbohydrates (Lawson, 1995). Their functional and textural characteristics contribute to the flavour and palatability of natural and prepared foods. They contain certain fatty acids which play an important role in nutrition and are also carriers of fat soluble vitamins. Vegetable oils are essential in meeting global nutritional demands and are utilized for many food and other industrial purposes (Idouraine *et al.*, 1996). Despite the broad range of sources for vegetable oils, the world consumption is dominated by soybean, palm, rapeseed and sunflower oils with 31.6, 30.5, 15.5 and 8.6 million tonnes consumed per year respectively (Stevenson *et al.*, 2007). In developing countries, *Moringa oleifera* (moringa) has potential to improve nutrition, boost food security, foster rural development and support sustainable land care (National Research Council, 2006).

Due to ever diminishing sources of fats and oils, there is the growing need for the search for new sources of oil, as well as exploiting sources that are currently unexploited in order to supplement the existing ones, since these conventional sources of vegetable oil no longer meet the ever increasing demands of domestic and industrial sectors. Olajide (2000) identified the locally available oilseeds in Nigeria that have been mostly exploited as groundnut, soybean, sunflower seed, melon, locust bean, conophor, beniseed, cocoa bean, palm kernel coconut, shea butter and cotton seeds while melon seeds, locust bean, oil bean, pumpkin seed, conophor nut, sheanut and moringa seeds are some of the underutilized oilseeds which are mainly used as ingredients in traditional food preparation even though they contain significant amount of oil. However, within the past few years, *Moringa oleifera*, a tropical, multipurpose tree has grown from being practically unknown, even unheard of, to being a new and promising nutritional and economic resource for developing countries, especially Nigeria. It is a very rapid growing tree found growing in a varying range of climatic conditions. The characteristics of *Moringa oleifera* seed oil can be highly desirable especially with the current trend of replacing polyunsaturated vegetable oils with those containing high amounts of monounsaturated acids.

1.2 The Research Problem

Previous studies on moringa have focused on its medicinal uses and nutritional aspects of the tree parts (Lowell, 1999) and on the use of the seed in the clarification of waste-water during treatment (Folkard *et al.*, 1993). Though some previous researchers have reported on the oil extraction from moringa seeds, methods such as solvent and aqueous enzymatic extractions were used (Abdulkarim *et al.*, 2005). Expellers represent one of the best choices for the extraction of oil from oilseeds. Methods such as water extraction and manual pressing only produce small amounts of oil; the extraction efficiencies (the percentage recovered from a possible maximum) are low and labour requirements high. Solvent extraction, while highly efficient involves very substantial capital cost and is only economic on a large scale. There is also a health and safety risk from using inflammable solvents. From the foregoing, the development of an oil expeller for moringa becomes highly desirable.

In order to design efficient equipment for the expression of oil from moringa, determination of the engineering properties, most especially the physical and mechanical properties is required. Some physical and thermal properties of moringa seeds have been determined (Aviara *et al.* 2011, Aviara *et al.* 2012, Adejumo and Abayomi 2012). The potential of moringa in producing oil and fat is far from being fully exploited as a result of lack of defined processing conditions necessary for optimum oil yield from the crop. Some of the needs triggering technology innovation in the oil extraction sector such as cost savings, environmental and safety concerns seem to be achievable by successful development of oil expeller. There is an extensive need to develop optimised and comprehensive protocols for oilseeds extraction to enhance greater oil recoveries. The high oil content of moringa which is between 30-40% (Mohammed *et al.*, 2003; Anwar *et al.*, 2006; Anwar and Rashid, 2007; Nzikou *et al.*, 2009; Uzama *et al.*, 2011; Adejumo *et al.*, 2013; Ogunsina *et al.*, 2011, Goja, 2013 and Orhevba, 2013) justifies the attraction of more interest to the need to optimise the oil expression process from the seed. To date, the optimisation of the oil expression process from moringa seeds has not yet been reported. In fact, a survey of literature revealed little information pertaining to the mechanical expression of oil from moringa seeds and no information as regards the optimisation of the various process parameters that influence oil expression from this crop using oil expeller. The present research will therefore be undertaken to optimise the oil expression process from moringa seeds.

According to Hamzat and Clarke (1993), to have an efficient process, it is necessary to have a clear knowledge of the mechanisms of oil expression and an understanding of the important variables. This can be achieved by modeling oil recovery from oilseeds by using both theoretical and experimental methods. Prediction of oil yield can then be obtained in terms of process parameters. Development of mathematical models would be useful in predicting yield for moringa seeds at different processing conditions.

Overall, the research work would generate data that can serve as a useful tool in process and equipment design for the moringa oil processors in developing countries, most especially Nigeria. This will assist in improving the yield and quality attributes, thereby making more oil and fat available both for domestic and industrial purposes.

1.3 Objectives of the Study

The primary objective of this research work is to optimise mechanical oil expression from moringa seeds. In pursuance of this, the following objectives arose which were to:

(1). study the engineering properties of moringa seeds in relation to the design of an oil expeller,

(2). develop and evaluate the performance of an oil expeller for moringa seeds,

(3). develop mathematical models relating oil yield to the processing variables.

(4). optimise the oil yield and process parameters for moringa using Response Surface Methodology (RSM), and

(5). investigate the effects of processing conditions on some physicochemical properties of the expressed oil.

CHAPTER TWO

LITERATURE REVIEW

2.1 Moringa oleifera

Moringa oleifera is the most widely cultivated species of the genus Moringa, which is the only genus in the family Moringaceae. There are about thirteen species of moringa trees in the family (Price, 2007). They are native to India, the Red Sea area and parts of Africa. Of these species, *Moringa oleifera* is the most widely known. In this research work, the term “Moringa” refers to *Moringa oleifera*. Moringa is esteemed as a versatile plant due to its multiple uses. The leaves, fruits, flowers and immature pods of this tree are edible; and they form a part of traditional diets in many countries of the tropics and sub-tropics (Siddhuraju and Becker, 2003; Anhwange *et al.*, 2004). The leaves are a good source of protein, vitamins A, B and C and minerals such as calcium and iron (Dahot, 1988). In addition to its substantial uses and nutritional benefits, it also has a great potential as a medicinal plant. The flowers, leaves and roots are used for the treatment of ascites, rheumatism and venomous bites and as cardiac and circulatory stimulants (Metha and Aggarawal 2008). The roots of the young tree and also root bark are vesicant (Hartwell, 1995; Anwar & Bhanger, 2003; Anwar *et al.*, 2007). The seeds from this plant contain active coagulating agents characterized as dimeric cationic proteins. They also have antimicrobial activity and are utilized for waste water treatment. In some developing countries, the powdered seeds of moringa are traditionally utilized as a natural coagulant for water purification because of their strong coagulating properties for sedimentation of suspended undesired particles (Kalogo *et al.*, 2000; Anwar *et al.*, 2007).

Moringa seed kernels contain a significant amount of oil that is commercially known as "Ben oil" or "Behen oil". Moringa seeds, harvested from their pods, yield approximately 30-40% of non-drying moringa oil (Mohammed *et al.*, 2003; Anwar *et al.*, 2006; Anwar and Rashid, 2007; Nzikou *et al.*, 2009; Uzama *et al.*, 2011; Adejumo *et al.*, 2013; Goja, 2013 and Orhevba *et al.*, 2013). Orhevba *et al.* (2013) reported that about 3000 kg of seeds could be obtained from one hectare, equivalent to about 900 kg oil/hectare, comparable to soybean which also yields an average of 3000 kg seeds/hectare but with only 20% oil yield. The oil is edible and closely resembles olive oil in its fatty acid composition. The free fatty acid content varies from 0.5 to 3%. The seed oil contains approximately 13% saturated fatty acid and 82% unsaturated fatty acid. It has a particularly high level of oleic acid (70%). Other vegetable oils normally contain only about 40% oleic acid. It can be used in cooking, cosmetics, fuel and lubrications amongst others. It is a non-drying nutty flavoured oil with a clear or slightly pale yellow consistency. Moringa seed oil content and its properties show a wide variation depending mainly on the species and environmental conditions (Ibrahim *et al.*, 1974). The oil is obtained by mechanically pressing the seeds of moringa or by solvent extraction. Moringa seed oil is clear and odourless. Due to the numerous antioxidants in it, the oil does not become rancid for several years after it is produced. This makes it sought after for a number of health and beauty applications. Although it is viable for use as cooking oil, its high demand and low levels of production do not make it conducive for everyday use as a dietary product.

Moringa is an exceptionally nutritious vegetable tree with a variety of potential uses. Every part of it such as the seed, root and stem is useful. In the tropics, it is used as forage for livestock; in many countries, it is used as a micronutrient powder to treat diseases. The green pods, fresh and dried leaves are used as vegetable (Folkard *et al.*, 2004; National Research Council, 2006). The seeds contain 30-40% of oil by weight which is used for cooking, soap manufacture, cosmetic base and in lamps. All parts of the plant are used in a variety of traditional medicines. The press cake, obtained following oil extraction, is useful as a soil conditioner; the plants are grown as live fences and windbreaks. It is also used as an intercrop with other crops and the wood pulp may be used for paper-making (Folkard *et al.*, 2004). Moringa trees have been used to combat malnutrition, especially among infants and nursing mothers. The leaves can be eaten fresh, cooked, or stored as dried powder for many months without refrigeration, and reportedly without loss of nutritional value. It is especially promising as a food source in the tropics because the tree is in full leaf at the end of the dry season when other foods are typically scarce (Brett, 2005; Fahey, 2005). According to Oliver-Bever (1986), moringa leaves contain more Vitamin A than carrots, more calcium than milk, more iron than spinach, more Vitamin C than oranges, and more potassium than bananas, and that the protein quality of the leaves rivals that of milk and eggs. However, the leaves and stem are known to have large amounts of their calcium bound in calcium oxalate crystals (Olson and Carlquist, 2001).

The tree's bark, roots, fruit, flowers, leaves, seeds, and gum are also used medicinally. The flowers, leaves and roots are widely used as remedies for several ailments. The bark of the moringa tree should be scraped off because of its toxicity and the flesh of the root should be eaten sparingly (Oliver-Bever, 1986). Moringa seeds are effective against skin-infecting bacteria, *Staphylococcus aureus* and *Pseudomonas aeruginosa* (Oliver-Bever, 1986). They contain the potent antibiotic and fungicide terygospemin. Moringa seems to have most of the food nutrients required by the body to replenish its defensive mechanisms. The Tonga people of Binga District in Zimbabwe use the root powder as an aphrodisiac and when it is mixed with milk, it is considered useful against asthma, gout and enlarged spleen or liver (Maroyi, 2007). It also helps in the removal of wind from the stomach and can be used to alleviate ear and toothache (Oliver-Bever, 1986; Maroyi, 2007). The leaf juice has a stabilizing effect on blood pressure. The leaf juice controls glucose levels in diabetic patients. Fresh leaves and leaf powder are recommended for tuberculosis patients because of the availability of vitamin A that boosts the immune system. If leaf juice is used as diuretic, it increases urine flow and cures gonorrhea. Leaf juice mixed with honey treats diarrhoea, dysentery and colitis (colon inflammation). Fresh leaves are good for pregnant and lactating mothers; they improve milk production and are prescribed for anaemia. Paste from ground bark can be applied to relieve pain caused by snake, scorpion and insect bites. Oil is sometimes applied externally for skin diseases (Maroyi, 2007).

Fully mature, dried seeds are round or triangular in shape, where the kernel is surrounded by light wooded shell with three papery wings. When mature, the seeds from the pods can be extracted and treated like green peas and can be fried or roasted and eaten like peanuts. The seeds also contain oleic acid-type oil. The oil possesses about 75% oleic acid, a monounsaturated fatty acid that is less vulnerable to oxidative stress than unsaturated fats. Oleic acid has the ability to reduce inflammation in the system, since oleic acid appears to be one of the main protective agents in reducing the levels of cardiovascular disease, breast and skin cancer (Pauwels, 2011). The oil has high antioxidant properties, making it a valuable source of vitamin A, C and E. It is one of the highest naturally occurring sources of antioxidants (Dogra *et al.*, 1975). The oil is good for skin formulation products because of its potent antioxidant inhibition which prevents bacterial infections, reduces inflammation and provides a smooth and healthy tone to the arms, legs and face. The oil possesses the following properties of anti-flammatory, anti-hypertensive, anti-epileptic, anti-oxidant, anti-bacterial, antifungal and antipyretic (Ojiako and Okeke, 2013). It is used in all kinds of cosmetic products and soap (Delaveau *et al.*, 1980). The oil can also be used as a natural source of behenic acid, which has been used as an oil structuring and solidifying agent in margarine, shortening, and foods containing semi-solid and solid fats, eliminating the need to hydrogenate the oil (Foidl *et al.*, 2001).

Moringa seeds are widely used as a natural coagulant for water treatment in developing countries (Santos *et al.*, 2005). It is very good and safe for water treatment as synthetic chemical compounds (alum) may be carcinogenic (Ayotunde *et al.*, 2011). Solutions of moringa seeds for water treatment may be prepared from seed kernels or from the solid residue left over after oil extraction (press cake). Moringa seeds, seed kernels or dried press cake can be stored for long periods, but moringa solutions for treating water should be prepared fresh each time. In general, one seed kernel will treat one liter (1.056 qt) of water (Doerr, 2005). Moringa seeds treat water on two levels, acting both as a coagulant and an antimicrobial agent. Moringa works as a coagulant due to positively charged, water-soluble proteins, which bind with negatively charged particles (silt, clay, bacteria, toxins etc) allowing the resulting flocs to settle to the bottom or be removed by filtration. The antimicrobial aspects of moringa continue to be researched into. Findings support recombinant proteins both removing microorganisms by coagulation as well as acting directly as growth inhibitors of the microorganisms. While there is ongoing research being conducted on the nature and characteristics of these components, treatments with moringa solutions will remove 90-99.9% of the impurities in water (Doerr, 2005).

Plates 2.1-2.5 show the moringa plant, tree and seeds.

2.2 Engineering Properties of Agricultural Materials

According to Mohsenin (1970), the ever increasing importance of agricultural products together with the complexity of modern technology for their production, processing and storage need a better knowledge of their engineering properties so that machines, processes and handling operations can be designed for maximum efficiency and the highest quality of the final end products. A rational approach to the design of agricultural machinery and equipment involves the knowledge of the engineering properties of the agricultural product concerned. There are several engineering properties of agricultural materials namely physical, mechanical, thermal, electrical, optical and electromagnetic properties. Often times, the physical and mechanical properties are the most determined. Peleg and Bagly (1982) defined physical properties of agricultural materials as those properties that lend themselves to description and quantification by physical means. Chukwu and Sunmonu (2010) defined mechanical properties as properties that have to do with the behaviour of agricultural products under applied forces. According to Corrêa *et al.* (2007), the knowledge of physical and mechanical properties of the agricultural products is of fundamental importance for proper storage procedure and for design, dimensioning, manufacturing, and operating different equipment used in postharvest and processing operations of these products. The knowledge of the engineering properties is useful for both engineers and food scientists, plant and animal breeders and it is also important in data collection in the design of machines, structures, processes and controls, and in determining the efficiency of a machine or an operation (Chukwu and Sunmonu, 2010).

Plate 2.1. The Moringa Plant

Plate 2.2. The Moringa Tree

Plate 2.3. Moringa Pods

Plate 2.4. Hulled Moringa Seeds

Plate 2.5. Dehulled Moringa Seeds

The size and shape are important in the electrostatic separation of agricultural materials from undesirable materials and in the development of sizing and grading machinery (Mohsenin, 1980). The size and shape of agricultural materials also affect handling losses during cleaning and oil expression. According to Olayanju (2002), if the screen hole of the cleaner is too big, it may result in uncleaned seeds and if the screen hole is too small, it may lead to reduced efficiency. İf the oil barrel clearance is too big, it may result in partial crushing of seeds and if it is too small, it may lead to excessive choking of the discharge section as the seeds are crushed. For optimum performance of the cleaner and oil expeller, the size of perforations and barrel clearance have to be carefully selected (Olayanju, 2002).

Sphericity will be useful in handling operations such as conveying and discharge from chutes. Since agricultural materials are transferred from one placement unit to the other, the sphericity will be taken into consideration for designing the slope of the transfer unit. Bulk density, true density, and porosity (the ratio of intergranular space to the total space occupied by the grain) can be useful in sizing grain hoppers and storage facilities; they can affect the rate of heat and mass transfer of moisture during aeration and drying processes. Grain bed with low porosity will have greater resistance to water vapour escape during the drying process, which may lead to higher power to drive the aeration fans (Olayanju, 2002). Cereal grain densities are useful in breakage susceptibility and hardness studies (Seifi and Alimardani, 2010). The bulk density is important in calculating thermal properties in heat transfer processes, in determining Reynolds number in pneumatic and hydraulic handling of the material, in separating the product from undesirable materials and in predicting physical structures and chemical composition. The porosity gives a knowledge of the percentage void of the agricultural materials and is important in heat and airflow studies (Olayanju, 2002). Bulk density, grain density and porosity are major considerations in designing the drying, aeration and storage systems, as these properties affect the resistance to air flow of the mass. The static coefficient of friction is used to determine the angle at which chutes must be positioned in order to achieve consistent flow of materials through the chute. Such information is useful in sizing motor requirements for grain transportation and handling (Ghasemi Varnamkhasti *et al.*, 2007). Gumble and Maina (1990) observed that angle of repose and coefficient of friction are important in designing equipment for solid flow and storage structures and the coefficient of friction between seed and wall in the prediction of seed pressure on walls. It is important in filling flat storage facility when grain is not piled at a uniform bed depth but rather is peaked (Mohsenin, 1980).

A vast knowledge of mechanical properties such as hardness and compression tests is vital to engineers handling agricultural products. According to Anazodo (1983), the determination of mechanical properties of agricultural products under static or dynamic loading is aimed at the reduction of mechanical damage to agricultural produce during postharvest handling, processing, and storage and the determination of design parameters for harvesting and postharvest systems. Sitkei (1986) reported that most agricultural products are visco-elastic in nature, they respond differently to tensile or compressive forces and also behave differently when they are subjected to vibration.

2.3 Oil Extraction Methods

The common methods of extracting oil include: water assisted (finely ground oilseed is either boiled in water and the oil that floats on the surface is skimmed off; or ground kernels are mixed with water, squeezed and mixed by hand to release the oil); manual pressing (oilseeds, usually pre-ground, are pressed in manual screw presses); expelling (using an expeller which consists of a motor driven screw turning in a perforated cage; the screw pushes the material against a small outlet, called the choke; great pressure is exerted on the oilseed fed through the machine to extract the oil); ghanis (consisting of a large pestle and mortar rotated either by animal power or by a motor; seed is fed slowly into the mortar and the pressure exerted by the pestle breaks the cells and releases the oil); and solvent extraction (where oil from seeds or the cake remaining from expelling is extracted with solvents and the oil is recovered after distilling off the solvent under vacuum).

2.3.1 Water Assisted

Oilseeds in most cases are ground to a paste without removing the husk or outer covering. In some instances, for example, sunflower, the seeds are husked. The seeds are ground manually and the paste is heated alone at first and then with boiling water. The mixture is stirred and boiled. After boiling, the mixture is allowed to cool and the oil settles at the top where it is scooped off. With this method of processing, the extraction efficiency is about 40%, that is percentage of oil extracted based on the total theoretical content (Ibrahim and Onwualu, 2005). For oilnuts, the processing methods vary because of the variation in the procedures. For a seed like groundnuts, they are shelled, cleaned and roasted lightly. The roasted nuts are skinned by placing them on a mat and rolling a wooden block over them, and winnowing them to separate the skin from the nuts. The skinned nuts may be pounded with a mortar and pestle or ground using grinding stones to a smooth paste. The paste is kneaded and pressed by hand to remove the oil-water mixture. Then the oil-water mixture is fried to remove most of the water (Ibrahim and Onwualu, 2005).

2.3.2 Manual Pressing

Mechanical pressing (hydraulic and screw) is the oldest and simplest method for oil extraction from seeds. No chemical is used for oil extraction and therefore the residue is free of chemical. It is a labour intensive technique and its use declined over the years. Continuous screw-presses (expellers) have replaced the hydraulic equipment (Bargale 1997). It consists of an extruder with a perforated body (slots or holes) and a helical screw is used to convey and press out the oil (Balke 2006). A major drawback of this process is the lower oil extraction. Heat pre-treatment improves the malleability of the seed, lower the shattering and denature some proteins to improve oil extractability (Balke 2006). Before pressing, the seed are flaked to crush the seed shell and for better oil diffusion (Ward 1982). The extracted oil is of superior quality, but intense pressure and heat damages the seed protein (Balke 2006). This method is popular in developing countries for low operating costs than the solvent extraction (Bargale 1997). The extreme heat generation during this method causes darkening of the oil (Bargale 1997). The choking and plugging problem results in loss of production capacity and increases in energy, labour and other resource requirements (Rosenthal *et al.,* 1996).

Types of manual press include spindle press, bridge press (also known as a screw press), ram press and hydraulic press. Some different types of manual press are shown in Figures 2.1-2.5. Manually powered spindle presses are usually small table mounted devices with a capacity of around 2-5 kg per hour. The bridge press comprises of a cylinder that contains the seed which is compressed by rotating a screw down onto the seed. The screw is held in place by a frame that bridges over the seed container. As the seed is compressed, the oil drains through holes in the cylinder onto a collection tray. The process is relatively slow as the cylinder needs to be filled, compressed and then the remaining cake needs to be removed. Ram presses use a lever mechanism to produce high pressures on a piston that forces the oil out of the seed. Hydraulic presses use a hydraulic pump to exert a high pressure on the seed. Hydraulic jacks from cars and trucks can be used. The process is similar to a screw press, in that the seed has to be loaded into a cylinder and then pressed to extract the oil, which runs onto a collection tray. Once the seed has been pressed, the remaining cake needs to be removed. Capacities are from around 1 kg per press (Practical Action, 2008).

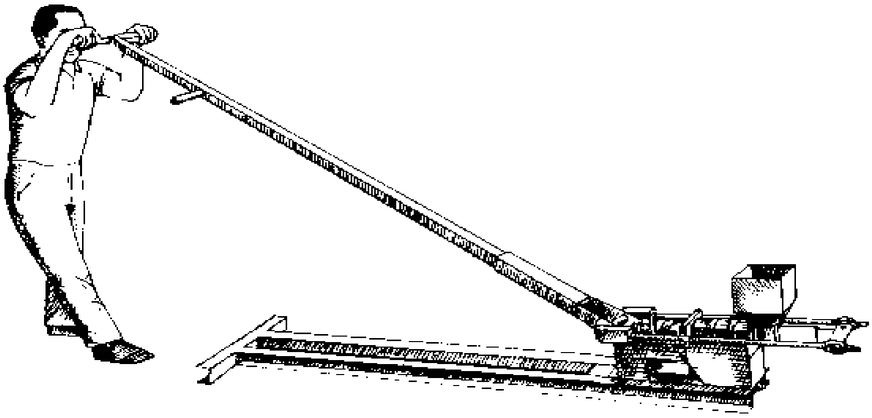

Figure 2.1. Ram Press

(Source: http://www.fao.org)

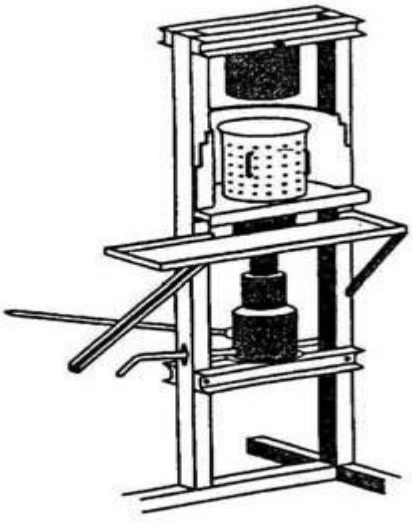

Figure 2.2. Oil Press with Hydraulic Jack

(Source: http://www.fao.org)

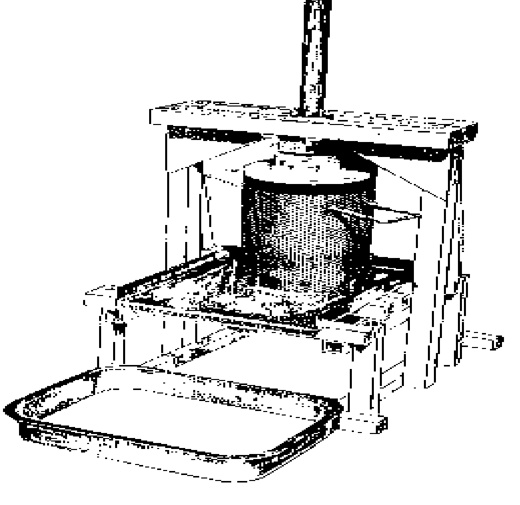

Figure 2.3. Bridge Press (NRI design)

(Source: http://www.appropedia.org)

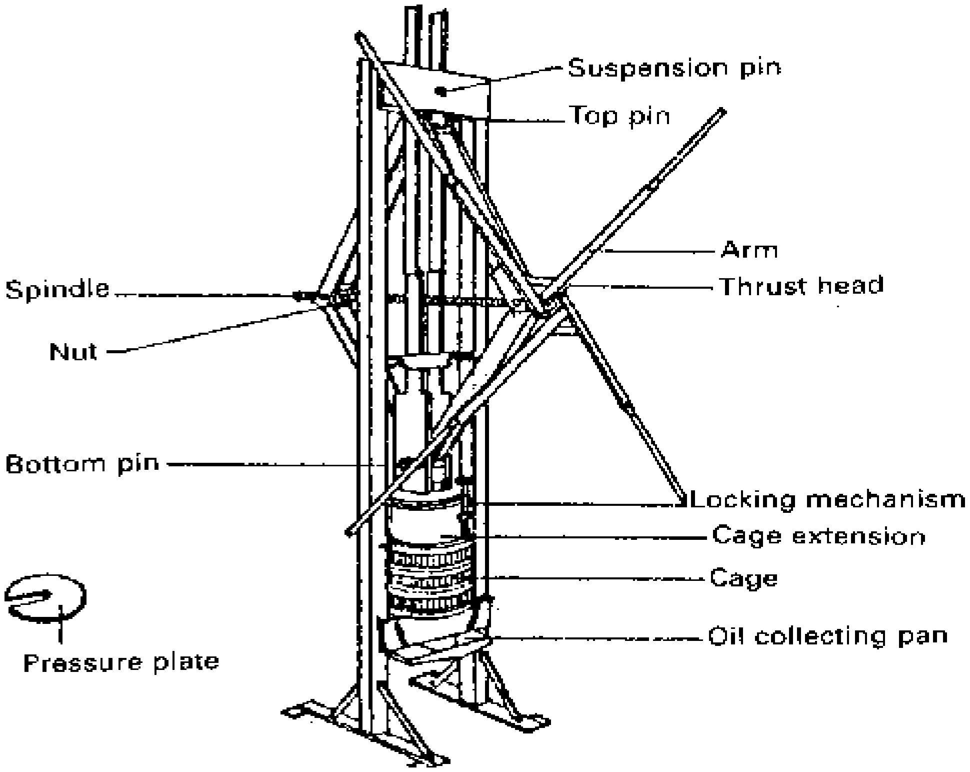

Figure 2.4. Scissor Press (IPI design)

(Source: http://www.appropedia.org)

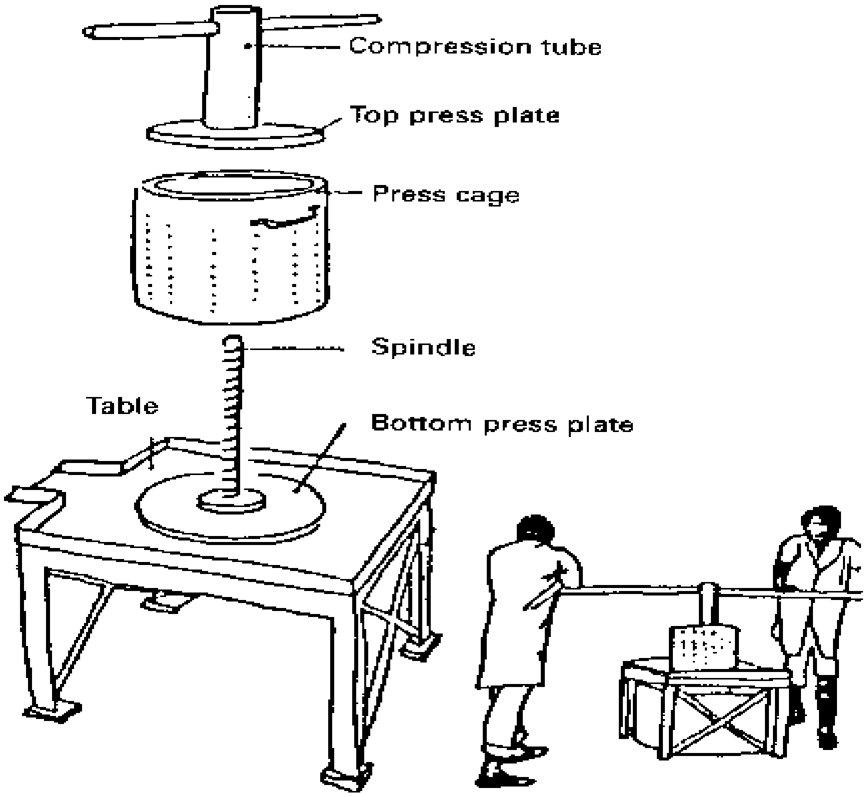

Figure 2.5. Curb Press (TCC design)

(Source: http://www.appropedia.org)

2.3.3 Oil Expellers

Expellers use a horizontally rotating metal screw, which conveys oil-bearing products into a barrel shaped outer casing with perforated walls (Figure 2.6). The products are continuously fed to the expeller, which grinds and presses the oil out as it passes through the machine. The pressure ruptures the oil cells in the product and oil flows through the perforations in the casing and is collected in a trough underneath (Gate, 1979). The residue of the material from which oil has been expressed exits from the unit, and is known as the cake. Most expellers are power-driven, and are able to process between 8 and 45 kg/hr of product depending upon the type of expeller used. Bigger units, processing greater quantities of oil are available for use in larger mills. The percentage of oil expressed by expellers is as high as 90% depending upon the type and kind of products as well as the expeller being employed (Gate, 1979). The friction created by the products being expressed wears down the worm shaft and other internal parts. With small machines, this occurs often after expressing as little as 50 tons, after which parts must be replaced or repaired through resurfacing by welding. The use of oil expellers are most unlikely at the village/small town level because the maintenance requires machinery and equipment that are rarely found in small repair shops and local manufacture of expellers.

2.3.4 Ghanis

Ghanis originated in India where they are primarily used to express oil from mustard and sesame seeds, although in some cases they can be used for coconut and groundnut processing. Traditionally, ghanis are operated by animals and can be manufactured locally. They consist of a wooden mortar and wood or stone pestle. The mortar is fixed to the ground while the pestle, driven by one or a pair of bullocks or draught animals is located in the mortar where the seeds are crushed by friction and pressure (Figure 2.7). Oil runs through a hole at the bottom of the mortar, while the residue or cake is scooped out. Depending on the size of mortar and type of seeds, its capacity is approximately 40 kg a day (Practical Action, 2008); although this will vary depending on the size, strength and number of animals used. Animals need to be replaced after 3 or 4 hours work as they tire. Mechanized versions of the traditional animal-powered ghanis are common. In these power-driven ghanis, the pestle and mortar units are usually arranged in pairs with either the pestle or mortar held stationary, while the other is rotated (Ibrahim and Onwualu, 2005). Power ghanis (Figure 2.8) have a greater capacity than the traditional ghanis and can process about 1000 kg of seeds per day (Srikanta Rao, 1978). Power ghanis yield an oil with a lower pungency.

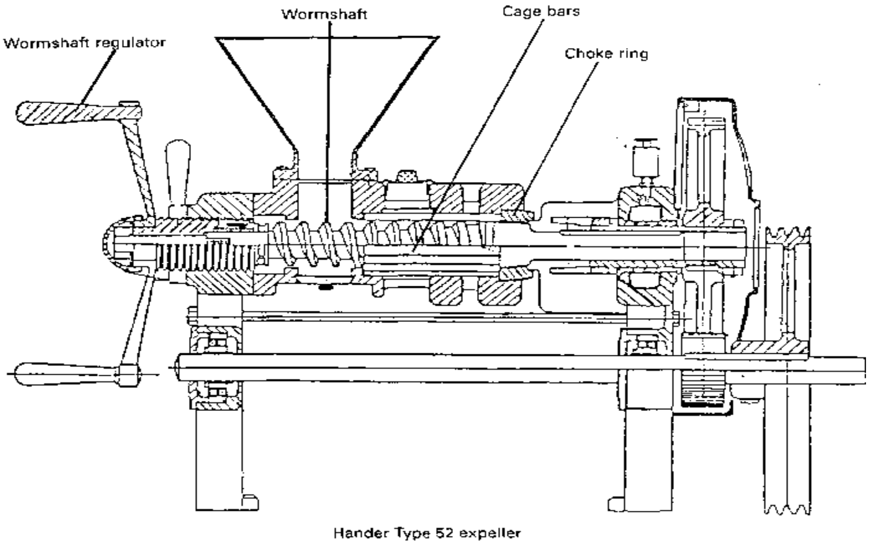

Figure 2.6. Outline Drawing of a Typical Small-Scale Expeller (CeCoCo Type 52)

(Source: http://www.appropedia.org)

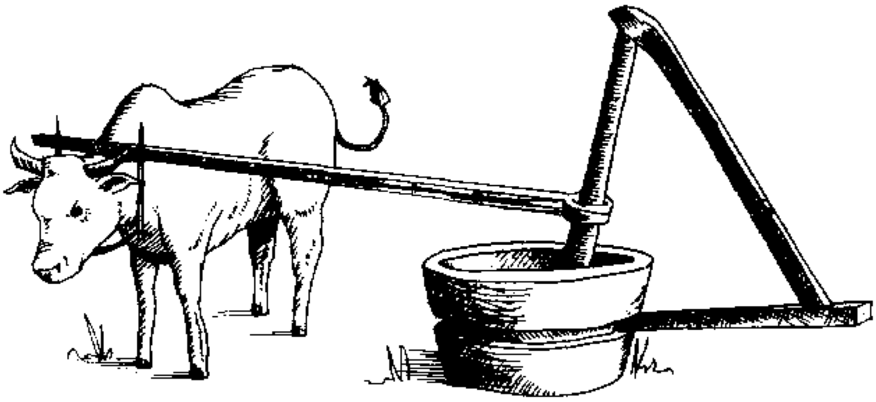

Figure 2.7. Traditional Animal Powered Ghani

(Source: http://www.fao.org)

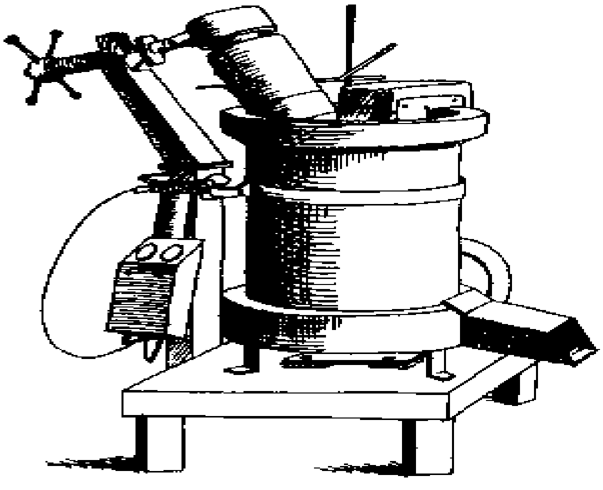

Figure 2.8. Power Ghani

(Source: http://www.fao.org)

2.3.5 Solvent Extraction

Solvent extraction of oil from oilseeds is the most efficient and attractive method for low oil content seeds (Anjou 1972; Caviedes 1996), for high oil content seeds like sunflower, peanut and canola, and also for medium oil content seeds like cottonseed and corn germ (Ward 1976). Therefore, vegetable oils are mostly extracted by using solvent extraction (Kemper 2005). Solvent extraction method involves the use of organic solvents such as straight chain hydrocarbons, chlorinated hydrocarbons, alcohols and ketones to recover the oil from the sources. The process for solvent extraction of nut like groundnut is similar to that of seeds like soyabean. Generally, nuts or seeds are shelled and winnowed to remove fibre-rich shells. Next, the nuts or seeds are cracked into pieces and conditioned to 10-11% moisture at 70^oC or more, and then flaked by passing through rolls. Sometimes the nuts or seeds flakes are cooked before they are conveyed to the extractor. In the extractor, the oil is removed by means of a solvent. The solvent ladden flakes are then passed through a desolventizer, which recovers the solvents. The defatted and desolventized cake may undergo further treatment before it is used as feed. The crude oil may be clarified by passing it through a filter press (Ibrahim and Onwualu, 2005). Solvent extraction is capable of removing nearly all the available oil from oilseeds or nuts. About 98% of the oil is being extracted by solvent method (Ngoddy and Iherokoronye, 1985; Cecoco, 1988). In addition to the high yield of oil, the method produces oil with better qualities, and a higher protein meal (Khan and Hanna, 1983). The method generally requires more capital expenditure, and refining the oil before use. There are also possibilities of toxicity from the solvent used and danger of fire explosion from the use of volatile organic solvent.

2.4 Effects of Processing Factors on Mechanical Expression of Oil from Oilseeds

Efficient expression of vegetable oils from oil bearing seeds by mechanical method requires optimum preliminary processing before the expression (Ibrahim and Onwualu, 2005; Mwthiga and Moriasi, 2007). Moisture content, heating temperature, heating time and applied pressure affect the yield of fats and oil during expression (Khan and Hanna, 1984). For maximum oil recovery and least residual oil in the cake, it is necessary to control these factors during the oil or fat expression process. Inability to control them could lead to failure in getting high yield and good quality fats and oil during expression (Bamgboye and Adejumo, 2011a). Therefore, efficient processing of the oil bearing materials prior to expression is necessary in order to achieve higher yield and subsequently cheaper end product.

2.4.1 Effects of Moisture Content

The optimum moisture contents for oil expression have been established for different oilseeds. Investigations by Abidakun *et al.* (2012) while working on dika nut revealed that oil yield was higher at the higher moisture contents of 6 and 9% wet basis, with the maximum oil recovery obtainable at 6% moisture content. Olajide (2000) reported that the increase in moisture content showed a substantial improvement in oil recovery in both groundnut and sheanut kernels. However, further increase in moisture content resulted in a decline in oil expression from both the groundnut and sheanut kernels. Optimum moisture content of 6.6% w.b. and 13% w.b. were obtained for groundnut and sheanut kernels respectively. Bamgboye and Adejumo (2011a) while working on roselle seeds observed oil yield increase of 7-8% as the moisture content increases. Farsaie and Singh (1983) showed that the maximum oil recovery was obtained when sunflower seeds were expressed at 6% moisture content and increasing the moisture content to 14% decreased oil recovery by 16%. According to Bongiriwar *et al.* (1977), as the moisture content of groundnut increased up to 6%, the percentage oil removed increased and the yield decreased beyond 6% moisture content. Southwell *et al.* (1990) reported that a moisture content of 9% was found to be optimum for expression of oil from avocado fruit. In the case of canola seed, moisture content in excess of 9% adversely affected the oil yield (Blake, 1982); while 10% moisture content and 11% moisture content gave the maximum oil recovery for unsieved rice bran and sieved rice bran respectively (Sivala *et al.*, 1992). It was reported that increase in moisture content led to increase in yield of oil for sunflower kernels from 53.2% to 58.2% (Southwell and Harris, 1992); while maximum oil could be obtained from grated coconut if the moisture content of expression falls within 10.9% to 12.9% (Hammonds *et al.*, 1991). According to Fasina and Ajibola (1989), maximum oil yield was obtained from conophor nuts when conditioned to 11% moisture content. For melon seeds, Ajibola *et al.* (1990) found the maximum oil yield when the seeds were conditioned to a moisture content of 9.2%. Dedio and Dorrell (1977) observed that a moisture content of 8% (wet basis) was found to be the optimum for expression of oil from flaxseed. Williams and Rathod (1983) reported that a moisture content of 7-8% gave the best oil yield from soybean. For mechanical oil expression from mustard seeds, maximum oil yield was obtained when the seeds were conditioned to a moisture content of 8.7% (Reddy and Bohle, 1993). Akinoso *et al.* (2006) while working on sesame seeds observed that decreased moisture content caused increased oil yield. Maximum oil yield of 50.4% at an optimum moisture content of 4.6% wet basis was obtained.

2.4.2 Effects of Applied Pressure

The optimum pressure necessary for maximum oil expression from the different oilseeds have been determined as the application of more pressure than required reduces the pressing efficiencies, leads to a higher cost of expression and decreases oil yield. Ward (1976) reported that during the process of oil expression from oilseeds, increasing the pressure applied during screw pressing tends to decrease the size of the capillaries through which oil flows and further increase in pressure may eventually lead to the sealing of the capillaries. Bamgboye and Adejumo (2011a) observed a decrease in oil yield as the applied pressure increased from 30 to 37.5 MPa for roselle seeds. In their investigation, there were steady increases in the oil yield up to 30 MPa before the yields started decreasing. This was attributed to the fact that increasing the pressure applied on oilseeds during oil expression could narrow, shear, and may eventually seal the capillaries through which oil drains out during oil expression causing reduction in the oil yield despite the fact that there has been an increase in the applied pressure according to Ward (1976). According to Abidakun *et al.* (2012) on dika nut, it was observed that oil yield increased for all pressure levels ranging from 5-25 MPa with the highest at 25 MPa. This was also observed for soybean as reported by Mwthiga and Moriasi (2007). Reporting from studies conducted on oil expression from groundnut, Pominski *et al*. (1970) found out that the amount of oil expressed from the seed tends to level off at a pressure of 13.8 MPa. Adeeko and Ajibola (1990) equally observed that oil yield increase with increase in pressure up to 20 MPa beyond which the yield levelled off, but decrease in oil yield was observed at 25 MPa. Olajide (2000) observed significant increase in oil yield when applied pressure was increased from 5-15 MPa, but decreased when the pressure was increased to 25 MPa. A similar phenomenon was observed while working on sheanut kernels too. This decrease was attributed to the sealing of some inter-kernel voids at that increased pressure. Ajibola *et al*. (1990) observed that there was a significant increase in oil yield from melon seeds when applied pressure was increased from 5-18 MPa, but oil yield either levelled off or decreased slightly when the pressure was increased to 25 MPa. Sivala *et al*. (1992) observed that increase in applied pressure increased the oil yield up to 25.5 MPa beyond which there was a decrease in oil yield. For unsieved and sieved bran samples, maximum oil yields of 55.9% and 50.4% respectively were obtained at a pressure of 25.5 MPa. Adekola (1991) reported that oil yield increased with increase in applied pressure during oil expression from coconut. Fasina and Ajibola (1989) while working on oil expression from conophor nuts observed an increase in oil yield as pressure increased from 10 MPa to 25 MPa. Maximum oil yield of 39.6 % was obtained at an applied pressure of 25 MPa. For mustard seeds, Reddy and Bohle (1993) reported that the lowest and highest oil yields of 22.78% and 28.93% were obtained at 3.924 MPa and 7.848 MPa applied pressures respectively. Increased applied pressure resulted in increased oil yield.

2.4.3 Effects of Heating Temperature and Time

The optimum heating temperature and time for oil expression have been established for different oilseeds. Adekola (1991) reported that oil yield increase with increase in heating temperature subject to duration of heating for coconut. Highest oil yield was obtained at 120°C. However, at heating times longer than 15 mins at 120°C, oil yield reduced by 12.3%. This indicated an optimum heating time of 15 mins for maximum oil yield from coconut. Adeeko and Ajibola (1990) reported that oil yield increased by an increase in heating temperature and heating time for groundnut. An increase in heating temperature increased the oil yield of samples heated for 15 and 25 mins. For samples heated at 35 and 45 mins, there was no significant difference in the yield of oil samples heated at different temperatures. Oil yield from samples heated at 135°C was highest at 15 mins and further increase in heating time decreased the yield. Samples heated at 160°C increased in yield from 33% to 37% when heating time was increased from 15 to 25 mins. A further increase in time of heating led to a decrease in yield. Hammonds *et al.* (1991) reported that moderate heating of groundnut to about 60°C resulted in an improvement in oil yield as compared to expression without heating under room conditions. South-well and Harris (1992) observed that sunflower kernels which had been heated and conditioned gave a higher oil yield when compared with unheated sample. Reports from the investigation carried out on mechanical expression of conophor nut by Fasina and Ajibola (1989) showed that oil yield increased from 50-65°C, but decreased with increase in heating temperature to 110°C. It was observed that oil yield obtained from samples heated at 50°C were considerably lower than those obtained from the other heating temperatures. Oil yield increased with increased heating time for samples heated at 110°C. High oil yields were obtained at heating times of 20 and 28 mins for samples heated at 65, 80 and 95°C. Highest oil yield of 39.6% was obtained when sample was heated at 65°C for 28 mins. Ajibola *et al.* (1990) observed an increase in oil yield from melon seeds with increase in temperature and heating time for the range of variables considered in their study. Maximum oil yield of 41.6% was obtained when samples were heated at 130°C for 20 mins. Bamgboye and Adejumo (2011a) observed an increase in the oil yield as the heating temperature is increased to 100°C for roselle seeds. Increase in the heating temperature caused the protein to coagulate at a very fast rate, thus reducing the viscosity significantly and adjusting the moisture content which led to the release of the oil bound to them. Akinoso *et al.* (2006) while working on sesame seeds observed that increased heating temperature and time caused increased oil yield. Maximum oil yield of 50.4% at optimum heating temperature and time of 124.2°C and 13 mins respectively was obtained. Abidakun *et al.* (2012) while working on dika nut observed an increase in oil yield with increase in heating temperature and heating time.

However at higher heating temperatures, the oil yield decreased continuously with increase in heating time. Oil yield reached the maximum at 5 mins when it was heated at 150^{o}C and declined continuously thereafter. The highest oil yield was obtained from sample heated at 100^{o}C for 10 mins. The continuous decrease in oil yield at higher heating temperatures could be due to the fact that the moisture content decreased further as the heating increased according to Mwthiga and Moriasi (2007). Abidakun *et al.* (2012) observed that the combination of heating temperature and heating time is an integral factor affecting oil yield. This is explicable as it represented the quantity of heat energy added to the sample. Therefore, if the heat energy exceeded the latent heat of vaporisation, the moisture content of the meal is readjusted and if it falls below a threshold, the oil expression is obstructed.

2.5 Interaction between Process Variables and Oil Yield

Processing variables in oilseed expression affect the yield drastically, no matter how efficient the methods and machines employed. It has been established that there are interactions between process variables and oil yield from oilseeds.

Singh *et al.* (1984) reported that applied pressure, time, temperature and moisture content were the variables that affect oil yield from sunflower seeds. It was observed that at moisture content above 6%, the oil yield decreases. The highest oil yield of 83.3% was obtained at a seed moisture content of 6%, applied pressure of 42 MPa and temperature of 20^{o}C. Khan and Hanna (1984) observed that the oil yield from soybean was improved by increasing the temperature and pressure with a sample moisture content of 9.5-10%. Maximum oil yield of 85.71% was obtained when soybean flakes conditioned to 9% moisture was heated at 60^{o}C at a pressure of 45 MPa. Fasina and Ajibola (1989) observed that oil yield from conophor nut at any pressure was dependent on the moisture content of the sample, heating temperature and time. A maximum oil yield of 39.6% was obtained when milled sample, conditioned to 11% moisture was heated at 65^{o}C for 28 mins and expressed at a pressure of 25MPa. Ajibola *et al.* (1990) reported that oil yields from melon seeds were affected by the seed moisture content, heating temperature and time. From the range of variables considered in their study, a maximum oil yield of 41.6% was obtained when samples conditioned to a moisture content of 9.2% were heated at 130^{o}C for 20 mins and expressed at 25 MPa. Adekola (1991) reported that moisture content, applied pressure, heating temperature and time are factors affecting oil yield from coconut. Highest oil yield of 51.9% was obtained at an expression pressure of 25 MPa when samples were conditioned to moisture content of 7.31% wet basis and heated at 120^{o}C for 15 minutes. Reddy and Bohle (1993) observed that the oil yield from mustard seeds was significantly affected by moisture content of milled samples and applied pressure. For the range of variables considered in their study, a maximum oil yield of 28.93% was obtained when milled mustard seed was conditioned to a moisture content of 8.7% and a pressure of 7.848 MPa was applied. Olajide (2000) observed the combinations of process variables which are moisture content, applied pressure, heating temperature and time for maximum oil recovery from sheanut kernels. Optimum oil yield of 46.7% when samples were conditioned to a moisture content of 13% wet basis, heated at 120^{o}C for 50 minutes and expressed at 20 MPa was obtained. Tunde-Akintunde *et al.* (2001) investigated the effect of moisture content, heating temperature, heating time, applied pressure and pressing time on mechanically expressed soybean oil. Results showed that oil yield increased as moisture content was varied from 7.3 to 10.2%, heating temperature from 70 to 80^{o}C and heating time from 15 to 30 mins. The highest oil yield of 10.4% was obtained when sample at 10.2% moisture content was heated for 30 mins at a temperature of 80^{o}C. Akinoso *et al.* (2006) investigated the effects of moisture content, roasting duration and temperature on the oil yield from sesame seeds. The optimum moisture content, roasting duration and roasting temperature were 4.6 % wet basis, 13 mins and 124.2^{o}C respectively. These combinations gave 50.4 % oil yield. Bamgboye and Adejumo (2011a) investigated the effect of moisture content, applied pressure, heating temperature and time on roselle seed. The highest oil yield was obtained when sample was conditioned to a moisture content of 6.4%, heated at 100^{o}C for 20 mins at an applied pressure of 30 MPa. Abidakun *et al.* (2012) observed that the various factors responsible for proper oil expression from dika kernel include moisture content, applied pressure, heating temperature and time. Maximum oil yield of 72.2% was obtained at 6% moisture content, heating temperature of 100^{o}C, heating time of 10 mins and applied pressure of 25 MPa. Sivakumaran *et al.* (1985) revealed that moisture content, heating temperature and time were the interactive factors that influenced the expression of oil from runner type groundnut grown in the United States of America. Findings from the investigations showed that the maximum oil extraction of 92% was achieved at seed moisture content of 5.42%, heating temperature of 20^{o}C and heating time of 27.4 mins. Adeeko and Ajibola (1990) identified heating temperature, heating time and pressure as interactive factors that influenced oil expression from groundnut. Maximum oil yield of 37.8% was obtained when sample was heated to 100^{o}C for 25 mins and pressed at 25 MPa. Olajide (2000) investigated the combinations of process variables which are moisture content, applied pressure, heating temperature and time for maximum oil recovery from groundnut kernels. Optimum oil yield of 33.4% when samples were conditioned to a moisture content of 6.6% wet basis, heated at 95^{o}C for 30 minutes and expressed at 20 MPa was obtained. Ajav and Olatunde (2011) examined the influence of moisture content, heating time and heating temperature on the percentage oil yield of groundnut in order to establish the optimum process conditions. The optimum moisture content, heating duration and heating temperature were 6% wet basis, 25minutes and 100°C respectively which gave 41.6% oil yield.

2.6 Effects of Processing Factors on Oil Quality

Processing factors affect oil quality and vary with several conditions which include differences of environmental conditions, climate cultivation, soil composition, maturity level of oil bearing seeds and the harvesting time (Compaoré *et al.*, 2011). The method of extraction also has significant effect on the oil quality (Ogunsina *et al.*, 2011). Applied pressure, heating temperature, heating duration, moisture content, particle size, handling and storage are factors influencing yield and quality of vegetable oil expression (Weiss, 2000). The degree of influence varies with the type of oilseed and the method of oil expression used (Akinoso, 2006). Ohlson (1976) reported that processing conditions can have a rather negative effect on oil quality. In order to obtain high quality oils, it is very important to avoid deleterious effects such as long processing times, high temperatures, light and other catalysts. The effect of functional processing parameters on oil quality therefore becomes very important.

Pearson (1981) reported that for oil mechanically expressed from conophor nuts, the processing conditions considered did not have noticeable effect on the colour, specific gravity and iodine value. Ajibola *et al.* (1990) observed in their study on mechanical oil expression from melon seeds that processing conditions did not have significant effects on the colour and specific gravity of the expressed oil. The colour of the oil obtained was pale yellow. Adeeko and Ajibola (1990) while working on groundnut observed that increasing temperature and time of heating increased the colour intensity of the oils. This was attributed to the fact that with increase in temperature or time of heating, the quantity of moisture lost from the sample increased. Highest oil yield was obtained from samples heated at 160°C and 25 mins, but the colour of the oil was dark. According to Adeeko and Ajibola (1990), dark coloured oils require special refining, thereby increasing the cost of production. The colours of oils from samples heated at 135°C and 160°C for longer than 25 mins were dark and unattractive. Increasing the heating temperature and time increased the free fatty acid. This was attributed to the fact that increasing the temperature increased the lipase activity, thus leading to increase in free fatty acid. Saponification value, iodine value and specific gravity of the oil were not affected by variations in processing conditions. Olajide (2000) investigated the effect of processing conditions on the colour, specific gravity, melting point, peroxide value, iodine value and saponification value of expressed oil from groundnut kernel. The results of the investigation revealed that increase in heating temperature of groundnut kernel from 65 to 105°C increased the colour intensity of the expressed oil, while other properties were not significantly affected by processing conditions. Ajav and Olatunde (2011) in their study on groundnut oil expression observed that the colour of oil extracted was affected by the heating time and temperature. Increased heating temperature and time gave dark red oil whose intensity increased as the heating temperature and time increased. At 120°C, the oil extracted was of offensive burnt smell, with no increased oil yield observed. Adekola (1991) observed that the processing conditions studied on oil expression from coconut did not have noticeable effect on colour. Reddy and Bohle (1993) observed in their study of oil expression from mustard seed that processing conditions considered in the study did not have significant effects on the colour, specific gravity, free fatty acid and iodine value of oil. The mustard seed gave dirty yellow colour. Takeoka *et al.* (1997) investigated the effect of heating on the characteristics and chemical composition of seven commonly used frying oils and fats (beef tallow, canola oil, partially hydrogenated canola oil, corn oil, cottonseed oil, soybean oil, and partially hydrogenated soybean oil). It was observed that during heat treatment, a progressive decrease in unsaturation was observed in all oils by measurement of iodine value. This decrease was attributed to the destruction of double bonds by oxidation, scission, and polymerization (Cuesta *et al.*, 1991). It was also observed that oil colour darkens as heating or frying proceeds. Olajide (2000) observed the effect of processing conditions on the colour, specific gravity, melting point, peroxide value, iodine value and saponification value of expressed oil from sheanut kernel. It was found out that increase in heating temperature of sheanut kernel from 90 to 130°C increased the colour intensity of the expressed oil, while other properties were not significantly affected by processing conditions. Olayanju (2002) reported that the colour intensity of beniseed oil increased as the moisture content increased. This was attributed to the fact that colours are formed from carbohydrates in food where there is a loss of one or more molecules of water from the carbohydrate. Akinoso (2006) studied the effects of moisture content, roasting duration and time on the free fatty acid, colour and oil impurity of sesame seed oil. It was observed that free fatty acid increased with moisture content, decreased with roasting duration and temperature. Oil impurity increased with increased moisture content, decreased with roasting duration and temperature. Also, the colour intensity increased with all the processing conditions. Akinoso (2006) also investigated the effects of moisture content, roasting duration and time on the free fatty acid, colour and oil impurity of palm kernel oil. It was observed that free fatty acid increased with moisture content, decreased with roasting duration and temperature. Oil impurity increased with increased moisture content, decreased with roasting duration and temperature. Also, the colour intensity increased with all the processing conditions. Olaniyan (2010) while working on castor bean observed that an increase in the heating temperature increased the free fatty acid, saponification value, iodine value, total acid, peroxide value and the colour intensity of the oil expressed. However, increase in the heating temperature decreased the ester value. Specific gravity initially remained constant at 30^oC and 60^oC but later decreased at 90^oC, while refractive index remained constant at all temperatures. Viscosity decreased when the heating temperature was increased from 30 to 90^oC. The colour of the oil was golden yellow and light brown at 30 and 60^oC respectively, but changed to dark brown at 90^oC. Ogunsina *et al.* (2011) investigated the physicochemical characteristics of cold pressed and hexane extracted moringa seed oils namely iodine value, saponification value and unsaponifiable matter. Results of the findings showed 67.8 and 68.5 gI_2/100g oil, 190.4 and 191.2 mg KOH/g oil and 0.59 and 0.65% in that order for cold pressed and hexane extracted moringa seed oils respectively. Adejumo *et al.* (2013) studied the effect of heat treatment on the quality of moringa oil extracted by soxhlet method. It was discovered that an increase in the heating temperature decreased the saponification value, free fatty acid, acid value, peroxide value and iodine value; while heating temperature had no significant effect on the specific gravity of the oil. Orhevba *et al.* (2013) investigated the effect of moisture content on some quality parameters of mechanically expressed neem seed kernel oil. The quality parameters include saponification value, iodine value, fatty acid, acid value and colour. It was discovered that the highest saponification value of 262.46 mg/KOH/mol was obtained at moisture content of 8.1%, thereafter the saponification value decreased as the moisture content was increased. Iodine value increased as the moisture content increased from 6.1% to 8.1%, decreased sharply at 13.2% and then increased sharply at 16.6%. Moisture content had increasing, decreasing and then increasing effects on the values of the free fatty acid. Moisture content had an upward and downward effect on acid value. It was also observed that moisture contents at higher levels affected the colour of the oil, which changed from brown to dark brown.

2.7 Process Optimisation by Response Surface Methodology (RSM)

Response Surface Methodology (RSM), based on the combination of statistical and mathematical tools, is considered to be a valuable technique for the development, modification and optimisation of various processes (Montgomery, 2005; Raymond and Douglas, 2002). RSM has proven to be a useful tool for the analysis of problems during which a certain response of concern is usually influenced by different reaction variables with the purpose of optimising a defined response of interest. Modeling of experimental response was the main objective of using RSM, but later on, applications of RSM were extended to develop models for the optimisation of numerical experiments (Box and Norman, 1987). When treatments are based on continuous array of values, then RSM can be used for the improvement, development and optimisation of response variables mathematically expressed as:

$$y = f\ (x_1\ x_2) + e \qquad \dots (1)$$

Central Composite Design (CCD) has gained much attention in the recent years as the most acceptable second order design for the comprehensive estimation of response surfaces based upon second order models. Box and Wilson first introduced CCD in 1951 for response surface optimisation (Box and Wilson, 1951). CCD uses either a full factorial design with two levels (2^k) or fractional factorial designs (2^{k-f}) fabricated with numerous design points. CCD is comprised of three types of design points including; factorial points n_f, axial points n_a and central points n_c. The following expression can be used for the cumulative design points:

$$n = 2^{\mathrm{k}}\,(n_{\mathrm{f}}) + 2k(n_{\mathrm{a}}) + k(n_c) \qquad \dots (2)$$

RSM is aimed at topographical understanding of response surfaces and region finding where we can find optimal responses (Montgomery, 2005).

Olajide (2000) used RSM to optimise the applied pressure, pressing time, heating temperature, heating time and moisture content for groundnut kernels and sheanut kernels oil expression processes. Optimum oil yield of 33.4% was obtained when coarsely ground groundnut kernels conditioned to a moisture content of 6.6% (wet basis) were heated at 95^{o}C for 30 minutes and expressed at 20 MPa for 6 minutes. For sheanut kernels, optimum yield of 46.7% was obtained when finely ground sheanut kernels conditioned to a moisture content of 13% (wet basis) were heated at 120^{o}C for 50 minutes and expressed at 20 MPa for 6 minutes. Shridhar *et al.* (2010) used RSM to optimise the dilution level and agitation time for castor oil extraction. The percentage recovery of oil was investigated with respect to two variables including dilution level and agitation time. Optimal dilution level and agitation time of 7.3 and 2.38 hr respectively were obtained and the maximum extraction was found to be 48.75%. Cvjetko *et al.* (2012) optimised three operating parameters namely pressure, temperature and extraction time of supercritical CO_2 extraction of oil from rapeseed using RSM to obtain high yield of oil. Optimal conditions for oil yield within the experimental range of their studied variables were 29.7 MPa, 52.14^{o}C and 3.36 h, and oil yield was predicted to be 28.27%. Results showed that data were adequately fitted into the second-order polynomial model. The linear and quadratic terms of independent variables of temperature, pressure and extraction time had a significant effect on the oil yield. Awolu *et al.* (2013) optimised neem oil production and its characterization using RSM. They studied the effects of three factors viz sample mass, particle size and extraction time on the neem oil volume. 49% (47 ml) of neem oil was obtained at 45 g mass of sample, 1.39 mm particle size and 2 h extraction time. The Analysis Of Variance (ANOVA) results of the RSM showed that all the linear coefficients and the quadratic coefficients were significant ($p = 0.05$). R^2 and adjusted R^2 values of 0.9966 and 0.9935 were obtained respectively.

2.8 Model Equations for Oil Expression Processes

Hamzat and Clarke (1993) stated that it is necessary to have a clear understanding of the mechanisms of oil expression and the important process variables in order to be able to design an oilseed press in an optimal manner and also to have efficient process. This can be achieved by modelling the oil recovery from oil-crops by using both theoretical and experimental methods. Mathematical models are also useful in predicting process efficiencies for a wide range of processing conditions. Several investigations have been carried out to obtain predictions of oil yield in terms of process variables.

Singh *et al.* (1984) developed mathematical models to predict oil yield from sunflower in terms of process variables such as moisture content, applied pressure, pressing duration, heating temperature and pressing time. Mathematical models were developed for different types of seeds and are presented as follows:

For whole seed:

$$R_0 = -77 + 13.8M + 0.25P + 0.47T - 0.35M^2 - 0.0038P^2 + 0.002T^2 - 0.056MT \quad \dots (3)$$

$R = 0.93$, s.e. = 1.00

Where,

R_o = residual oil left in the cake, %

M = moisture content of the seed, % wet basis

P = pressure applied during the pressing, MPa

T = seed temperature before pressing, ^oC

The multiple correlation coefficient R was 0.97 and the standard error of estimate was 2.07. The model revealed that moisture content was the most important factor affecting cake residual oil content. The duration of pressing had no effect on cake residual oil content, thus it did not appear in the model. At 6% moisture content and 20^oC, the least amount of residual oil was obtained.

For dehulled seed:

$$R_0 = 23 + 4.6M - 2.3t + 0.17T - 0.180M^2 - 0.0008P^2 + 0.10t^2 + 0.0060MP + 0.09Mt - 0.013MT \quad \dots (4)$$

$R = 0.93$, s.e. = 1.00

Where,

t = duration of pressing, mins

For finely ground seed:

$$R_0 = -10 + 4.5M + 0.29P - 1.7t + 0.13T - 0.130M^2 - 0.001\mathrm{T}^2 + 0.0011\mathrm{MP} + 0.11\mathrm{Mt} - 0.012\mathrm{MT} - 0.012\mathrm{Pt} - 0.012\mathrm{PT} + -0.012\mathrm{tT} \quad \ldots (5)$$

R = 0.98, s.e. = 0.68

The above model revealed that all the independent variables and their interactions were significant in the case of finely ground seed.

For coarsely ground seed:

$$R_0 = -70 + 11.5M + 0.26P + 1.5t + 0.53T - 0.347M^2 - 0.0025\mathrm{P}^2 - 0.13\mathrm{t}^2 - 0.0014\mathrm{T}^2 - 0.038\mathrm{MT} - 0.014\mathrm{P}T \quad \ldots (6)$$

R = 0.99, s.e. = 0.76

Sivakumarran *et al.* (1985) carried out a study on expeller optimisation for peanut oil production and the operating conditions of a small expeller for maximum expression of oil from U.S. runner type peanuts were determined. The moisture content, temperature, period of pre-heating and pressure applied were interactive factors that influenced the oil expression when the pressure of expression was kept at a maximum. Functional relationships between these variables and the meal oil content were established from experimental data. The response surface equation was:

$$\mathrm{Y} = 376.661 - 8.214X_1 + 7.449X_2 - 29.072X_3 - 0.118X_1X_2 + 0.271X_1X_3 - 0.302X_2X_3 + 0.0052{X_1}^2 + 0.100{X_2}^2 + 1.056{X_3}^2 \quad \ldots (7)$$

Where,

X_1 = peanut temperature, °C

X_2 = pre-heat time, min

X_3 = moisture content, %

Y = meal oil content, %

The best oil expression achieved was 92% and conditions for this were 95.6°C, 5.42% moisture content and 27.4 mins preheat time respectively.

Khan and Hanna (1984) also obtained oil yield prediction models for different samples of soybean.

For ground soybean (with hulls):

$$\mathrm{Y} = 6.78 + 1.68\mathrm{T} - 0.004\mathrm{T}^2 - 3.83\mathrm{M} + 0.422\mathrm{M}^2 + 0.3917\mathrm{P} + 1.39\mathrm{t} - 0.1335\mathrm{TM} + 0.007\mathrm{TP} - 0.0017\mathrm{MPt} \quad \ldots (8)$$

For flakes with hulls (Brady crop cooker):

$$Y = 199.16 + 2.81T - 0.0077T^2 + 32.26M - 1.20M^2 + 1.399P + 1.23t - 0.1243TM - 0.013TP + 0.005Tt - 0.076MP \quad \dots (9)$$

For ADM soybean flakes (without hulls):

$$Y = 62.89 + 0.45T - 0.002T^2 - 0.04251P + 1.318t \quad \dots (10)$$

Where,

T = temperature, °C

P = applied pressure, MPa

t = pressing time, mins

M = moisture content, % wb

Y = predicted percent oil expressed

In general, the trends of the experiment showed that the best oil yield results were achieved by increasing the temperature, pressure and pressing time with a moisture content of 9.5-10%.

Fasina and Ajibola (1990) also developed some equations to predict the yield of oil expressed from conophor nuts. Empirical equations relating oil yield to processing variables such as pre-heating moisture content, heating temperature, heating time, applied pressure and post heating moisture content and duration of pressing. An equation was developed which relates the post-heating moisture content to the pre-heating moisture content, heating temperature and heating time as:

$$M_f = M_i - aM_i^b \; T_p^c \; t_i^d \quad \dots (11)$$

Where,

M_f = post heating moisture content, % db

M_i = pre heating moisture content, % db

T_p = heating temperature, °C

t = heating time, mins

a, b, c and d are equation parameters and their values were determined. Another equation relating the oil yield to the post heating moisture content at each of the pressure levels considered in the study was also developed. The equation was of the form:

$$Y = 40 \, M_f^b \, e^{-cm_f^3} \quad \dots (12)$$

Where,

Y = oil yield, %

M_f = post heating moisture content, % db

An equation relating the oil yield to post heating moisture content and applied pressure was developed. The equation was of the form:

$Y = a\, M_f^{b}\, P^{c}\, e^{dM_f}$ … (13)

Where,

Y = oil yield, %

M_f = post-heating moisture content, % db

P = applied pressure, MPa

Equation (12) below was also developed to relate the applied pressure at each of the pre-pressing conditions.

$\log\left(1 - \frac{y}{40}\right) = m - kp$ … (14)

Where,

Y = oil yield, %

P = applied pressure, MPa

m and k are equation parameters.

A relationship between the volumetric oil yield and time of pressing was also presented in the form of equation and given as:

$Y = 100\left(1 - e^{-kt_f^{n}}\right)$ … (15)

Where,

Y_v = volumetric oil yield, %

t_p = pressing time, mins

k and n are equation parameters.

Low standard error of estimates was obtained for all the equations and this shows that there was a good fit between fitted curves and the experimental points.

Hamzat and Clarke (1993) obtained the following equations to predict oil yield from groundnuts using the concept of quasi-equilibrium oil yield.

For whole seed,

$y = 40.45M^{-0.0063}\, P^{0.014}\, H^{-0.005}\, (1 - 0.270e^{-0.004t})$ … (16)

s.e. = 0.90

For coarse sample,

$y = 39.65M^{-0.31}\, P^{0.004}\, H^{-0.003}\, (1 - 0.483e^{-0.004t})$ … (17)

s.e. = 0.87

For fine sample,

$y = 40.45M^{-0.067}\, P^{0.011}\, H^{-0.001}\, (1 - 0.346e^{-0.004t})$ … (18)

s.e. = 0.89

Where,

y = oil yield, %

M = seed moisture content, % wb

t_p = pressing pressure, MPa

H = thickness (bed depth) of pressed seed, mm

a, b, c, d, f are constants.

Reddy and Bohle (1993) developed oil yield prediction equation for mustard seed. The equation is of the form:

$$Y = 19.85214 - 1.74831M + 7.33665P + 0.024707T + 0.08542M^2 - 0.29723P^2 + 0.00136T^2 - 0.35917MP - 0.01391MT + 0.005708PT \quad \ldots (19)$$

Where,

Y = oil yield, %

M = moisture content, % wb

P = applied pressure, MPa

T = Pressing time, mins

Akinoso *et al.* (2006) developed oil yield prediction equation for sesame seed. The equation is of the form:

$$Y = 38.485 - 4.944X_1 + 0.446X_2 + 0.207X_3 + 0.118X_1^2 - 0.01722X_2^2 - 0.00009972X_3^2 + 0.03032X_1X_2 + 0.005413X_1X_3 + 0.0007251X_2X_3 \quad \ldots (20)$$

Where,

Y = oil yield, %

X_1 = moisture content, % wb

X_2 = roasting duration, mins

X_3 = roasting temperature, ^oC

Shridhar *et al.* (2010) obtained the following equation in terms of coded factors for the oil yield of castor seed:

$$Y = 47.50 + 7.41X_1 + 2.08X_2 + 0.63X_1X_2 - 16.62X_1^2 - 2.87X_2^2 \quad \ldots (21)$$

Where,

X_1 = dilution level

X_2 = agitation time, hr

Awolu *et al.* (2013) obtained the following equation in terms of coded factors for the oil yield of neem seed:

$$Y = 47.30 + 10.75X_1 + 1.58X_2 + 3.50X_3 + 2.50X_1X_2 + 2.00X_1X_3 - 0.50X_2X_3 - 14.47X_1^2 - 12.33X_2^2 - 11.32X_3^2 \quad \ldots (22)$$

Where,

Y = oil yield, %

X_1 = mass of sample, g

X_2 = particle size, mm

X_3 = extraction period, hr

Jazie *et al.* (2013) obtained model equation based on the coded values for the biodiesel yield from rapeseed oil as given below:

$$Y = 95.85 + 1.089X_1 - 9.15X_1^2 + 2.64X_2 - 9.87X_2^2 - 0.63X_3 - 8.9X_3^2 + 0.81X_1X_2 + 2.07X_1X_3 + 3.2X_2X_3 \quad \ldots (23)$$

Where,

Y = oil yield (%)

X_1 = catalyst concentration (% wt)

X_2 = methanol/oil molar ratio

X_3 = reaction temperature (^oC)

The empirical equations and models that have been developed thus far are usually crop specific because different oil crops respond differently to changes in process parameters. At present, no model is known to relate the yield of mechanically expressed moringa seed oil to process parameters using Response Surface Methodology, hence the need for this research work.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Determination of the Engineering Properties of Moringa

The engineering properties (physical and mechanical) of moringa seeds were determined using ASABE standards and used as design parameters for the development of an oil expeller.

3.1.1 Determination of Physical Properties of Moringa

Physical properties namely length, width, thickness, arithmetic mean diameter, geometrical mean diameter, surface area, sphericity, aspect ratio, moisture content, true and bulk densities, porosity, one thousand seed weight, coefficient of static friction and angle of repose of moringa seeds were determined following standard procedures.

3.1.1.1 Dimensional Properties

One hundred moringa seeds were randomly selected and the length, width and thickness were measured using a digital caliper with an accuracy of 0.01 mm. The arithmetic mean diameter (D_a), geometric mean diameter (D_g), surface area (S) and sphericity (Φ) were calculated from equations (24-27) respectively as given by Mohsenin (1986), while the aspect ratio (R_a) was calculated from equation (28) as given by Maduako and Faborode (1990).

$$D_{\mathrm{a}} = \frac{(\mathrm{L+W+T})}{3} \quad \ldots (24)$$

$$D_{\mathrm{g}} = (LWT)^{\frac{1}{3}} \quad \ldots (25)$$

$$\mathrm{S} = \pi {D_{\mathrm{g}}}^2 \quad \ldots (26)$$

$$\Phi = (D_{\mathrm{g}}/\mathrm{L}) \times 100 \quad \ldots (27)$$

$$R_{\mathrm{a}} = (\mathrm{W/L}) \times 100 \quad \ldots (28)$$

Where; L= length, W= width, T= thickness.

3.1.1.2 Gravimetric Properties

The initial moisture content of the moringa seeds was determined in the laboratory using the oven-dried method. 50 g of moringa seeds were oven-dried at a constant temperature of 130°C for 6 hrs. The moisture content was calculated using equation (29) below:

$$\text{Moisture Content (\% wet basis)} = \frac{Initial\ weight\ of\ product - Final\ weight\ of\ product}{Initial\ weight\ of\ product} \times 100 \quad \ldots (29)$$

The true density of moringa seeds was determined by the water displacement method. A known weight of samples was poured into a 500 cm^3 fractionally graduated measuring cylinder containing 250 cm^3 distilled water. The rise in water indicated the true volume of the seeds. The true density was calculated as:

$$\text{True Density} = \frac{Weight\ of\ the\ sample}{Volume\ of\ \ water\ displaced} \quad \ldots (30)$$

The bulk density of samples was determined by using a regular container of known mass. The container was filled to the brim with the samples and was gently tapped ten times for the samples to consolidate. The weight of the samples were noted and the volume of the container was estimated by filling with water, which was then poured into a 500 cm^3 fractionally graduated measuring cylinder to determine the volume. The bulk density was calculated as:

$$\text{Bulk Density} = \frac{Weight\ of\ sample}{Volume\ occupied} \qquad \ldots (31)$$

The porosity was calculated from the bulk and true densities as given by Mohsenin (1986).

$$Porosity = \frac{True\ Density - Bulk\ Density}{True\ Density} \times 100 \qquad \ldots (32)$$

The one thousand seed weight was determined using a digital electronic balance having an accuracy of 0.001 g. One hundred moringa seeds were weighed and multiplied by 10 as adopted by Tarighi *et al.* (2011).

3.1.1.3 Frictional Properties

The coefficients of static friction of moringa seeds were determined with respect to six different surfaces namely glass, stainless steel, mild steel, galvanized steel, rubber and plywood using an inclined plane apparatus as described by Dutta *et al.* (1988). The inclined plane was gently raised and the angle of inclination at which the samples started sliding was measured. By measuring the angle of surface (ϕ) at this point, the static coefficient of friction (μ) is determined as the tangent of the angle (Dutta *et al.*, 1988).

$$\mu = \tan\phi \qquad \ldots (33)$$

For the dynamic angle of repose determination, the method described by Taser *et al.* (2005) and Garnayak *et al.* (2008) was adopted. A bottomless cylinder was used, the cylinder was placed over a plain surface and the seeds were filled in. The cylinder was raised slowly allowing the sample to flow down and form a natural slope. The dynamic angle of repose was calculated from the height and diameter of the pile as:

$$\theta = \tan^{-1}\left(\frac{2h}{d}\right) \qquad \ldots (34)$$

Where θ = angle of repose, h = height of the pile (mm) and d = diameter of the pile (mm).

3.1.2 Determination of Mechanical Properties of Moringa

Mechanical properties namely force at peak, deformation at peak, stress at peak, energy to peak, force at break, deformation at break, stress at break, energy to break, force at yield, stress at yield, energy to yield and the Young’s modulus were determined following standard procedures.

An Instron Universal Testing Machine (Plate 3.1) equipped with a 25 kg compression load cell and integrator was used to determine the various mechanical properties of the moringa seeds. The measurement accuracy was 0.001 N in force and 0.001 mm in deformation as given by Mohsenin, 1970. The height of the seed when loaded in the machine was taken as the thickness of the seed as measured with a digital caliper. The individual seed was compressed by the machine until rupture occurred as is denoted by a bio-yield point in the force-deformation curve. The rupture point is a point on the force-deformation curve at which the loaded specimen shows a visible or invisible failure in the form of break or crack. This point was detected by a continuous decrease of the load in the force-deformation diagram. Once the bio-yield was detected, the loading was stopped. The various parameters were measured at a speed of 20 mm/min.

3.2 Design Considerations for the Moringa Oil Expeller

In designing the oil expeller for moringa, some design considerations which would increase the performance level of the machine were made. In the design, simple manufacturing and engineering techniques were adopted to produce a machine which is relatively cheap, easy to operate and maintain, spare parts available and a machine that will not fail. In the material selection, considerations were given to the techno-economic status of the small scale vegetable oil processors who are the intended users of the machine. Other important considerations included:

(i) Ready availability of the materials of construction for the design of the various components in the local markets to facilitate easy fabrication and purchase of spare parts.

(ii) Since the expeller is a food processing equipment, the parts that will get in contact with the oil were made of simple iron to prevent contamination of the oil. Chromium and nickel in steel may react with the oil at high temperatures and lower the oil quality.

(iii) For the expeller to work efficiently and to prevent avoidable failures, the selection of materials for fabrication considered the appropriate material strength properties and sizes. This was achieved by using established standard data and calculations.

(iv) The design took into consideration the easy transportation of the machine where necessary. Based on this, the design made it possible to be able to dismantle some parts of the machine.

Plate 3.1. The Universal Instron Testing Machine

3.3 Theoretical Considerations for the Moringa Oil Expeller

The following assumptions were made for design considerations as given by Olayanju (2002):

(i) No pressure development would take place in the feed section. The pressure development and the expression of oil start at the beginning of the press section.

(ii) The maceration of oilseed was complete in the press section leaving the homogenous mixture of oil and solids in the discharge section.

(iii) The temperature of oilseed mass remained constant in the ram section. In reality, the temperature would increase along the ram section due to shearing action of the shaft.

(iv) As the oil-solid mixture passes through the section, it is subjected to radial pressure exerted by the wormshaft. The pressure causes flow of oil in the radial direction through the solid matrix and out through the barrel slots. The oil-flow in turn changes the flow rate of mixture in the axial direction.

3.4 Design Calculations

Several calculations were made based on the results of the measured physical and mechanical properties of the moringa seeds.

3.4.1 Determination of the Mass of Oil extracted per batch

Assuming 2 kg of oil is extracted per hour. The oil content of moringa seed is between 30-40% (Mohammed *et al.*, 2003; Anwar *et al.*, 2006; Anwar and Rashid, 2007; Nzikou *et al.*, 2009; Uzama *et al.*, 2011; Adejumo *et al.*, 2013; Ogunsina *et al.*, 2011, Goja, 2013 and Orhevba, 2013); assuming oil content of 35%

$$\frac{Mass\ of\ oil}{Mass\ of\ moringa} = 0.35 \qquad \ldots (35)$$

$$Mass\ of\ moringa = \frac{Mass\ of\ oil}{0.35} = \frac{2}{0.35} = 5.71\ kg$$

Therefore, about 6 kg of moringa is required.

3.4.2 Determination of the Roaster Volume

In order to estimate the roaster volume, the volume of moringa (v) with bulk density (ρ) $662\ kgm^{-3}$ (as determined by the physical properties of moringa) and mass (m) $6\ kg$ is calculated as;

$$volume, v = \frac{m}{\rho} \qquad \ldots (36)$$

$$volume, v = \frac{6}{662} = 0.0091\ m^3$$

The volume of the cylindrical roaster, V_R is given by

$$V_R = \pi r^2 h \qquad \ldots (37)$$

Where,

r = radius of roasting cylinder, m

h = height of roasting cylinder, m

$$\pi r^2 h = 0.0091\ m^3$$

Assuming a height of $0.5m$, the radius of the roasting cylinder is,

$$r^2 = \frac{0.0091}{\pi h}$$

$$r^2 = \frac{0.0091}{3.142 \times 0.5}$$

$$r = \sqrt{0.00579}$$

$$r = 0.08\ m$$

The diameter of the roasting chamber is calculated as

$$d = 2r = 2 \times 0.08m = 0.16\ m$$

3.4.3 Stirring Clearance

The roaster volume should be 1.5 times greater than the calculated volume V_R to allow for stirring clearance. Hence the total volume of the roasting chamber will be $1.5 \times 0.0091\ m^3 = 0.0137\ m^3$.

3.4.4 Determination of Heater Capacity

To determine the heater capacity of the roasting chamber, the average moisture content of the seeds and moisture content of roasted seeds will be used (about 2-3 % wb) in evaluating the quantity of heat needed to properly roast moringa seeds for oil expression.

Mass of Moringa = 6 kg

The amount of initial water content at 7.31% moisture content $= 0.0731 \times 6\ kg = 0.439\ kg$

Amount of dry matter and oil $= 6 - 0.439 = 5.56\ kg$

Initial moisture content (db) = $\frac{0.0731}{1-0.0731} \times 100 = 7.89\%$ … (38)

Final moisture content (db) $= \frac{0.02}{1-0.02} \times 100 = 2.04\%$ … (39)

The amount of water removed equal to product of initial dry matter and difference in dry basis moisture content i.e.

The amount of water removed $= 5.56 \times \frac{7.89 - 2.04}{100} = 0.325\ kg$ … (40)

The quantity of heat required, Q $= \frac{amount\ of\ water \times specific\ heat\ of\ air}{roaster\ \ efficiency}$ … (41)

$$\frac{0.49 \times 1.005\ x\ 10^3}{0.8} = 408.28\ kcal/hr$$

1 kcal/hr = 1.622 watts

$408.28\ \text{kcal/hr} = 662.23\ \text{W} = 0.662\ \text{kW}$

For adequate supply of heat, a heating element of 1.0 kW was chosen.

3.4.5 Roasting Time

The time needed for the roasting is computed from Newton's law as;

$$\frac{d\omega}{d\theta} = ka_r(T_2 - T_1) \qquad \ldots (42)$$

Where,

$d\omega$ = Amount of water removed, kg

$d\theta$ = Time needed for roasting, min

k = Constant = 0.2

a_r = Area of Roaster, m^2

T_1 = Initial temperature, ^oC

T_2 = Final temperature, ^oC

$$d\theta = \frac{d\omega}{ka_r(T_2 - T_1)} = \frac{0.325kg}{0.2 \times 320\ x\ 10^{-3} \times 250\ x\ 10^{-3} \times (100-40)}$$

$$d\theta = 0.34\ hr \sim 20\ mins$$

3.4.6 Determination of Expeller Volume

In determining volume of expeller, consideration was given for volume of hollow cylindrical barrel and the volume of the tapered screw shaft. Assuming a 40% decrease in volume as oil is processed, the volume of expeller is calculated as:

Volume of expeller (V_E) $= \frac{60}{100} \times 0.0137\ m^3$ … (43)

$= 0.00822\ m^3$

3.4.7 Determination of Barrel Volume

The barrel volume is calculated using equation (44) below:

The volume of cylindrical barrel (V_B) = $\pi r^2 l$ … (44)

$= 3.142 \times 0.08^2\ x\ 0.97 = 0.0195\ m^3$

Where,

r = radius of cylinder

l = length of cylinder

3.4.8 Determination of Shaft Volume

The shaft volume is calculated using equation (45) below:

The volume of desired tapered screw shaft, $V_S = V_B - V_E$ … (45)

$V_S = 0.0195 - 0.00822 = 0.01128\ m^3$

The volume of tapered shaft, (V_S)

$$V_S = \frac{\pi l}{3}\left(R^2 + Rr + r^2\right) \qquad \dots (46)$$

Where,

r = minimum radius of tapered shaft.

R = maximum radius of tapered shaft.

$$R^2 + Rr + r^2 = \frac{3 \times V_s}{\pi \times l} \qquad \dots (47)$$

$$= \frac{3 \times 0.01128}{3.142 \times 0.97}$$

$$R^2 + Rr + r^2 = 0.0111\, m^3$$

Using Goal Seek;

Minimum radius r, = 0.015 m

Maximum radius R, = 0.098 m

	Barrel	Shaft	Active volume
Length (m)	0.40	0.97	
Radius (m)	0.08	0. 015 - 0.098	
Volume (m^3)	0.0195	0.01128	0.00822

3.4.9 Design Capacity of the Expeller

The capacity of an expeller is controlled by the drag flow, pressure flow and leak flow in the barrel assembly. Varma (1998) gave the theoretical capacity of an expeller with single flight in feed section as:

$$Q = \pi DNH \cos\alpha \,(P\cos\alpha - e) \qquad \dots (48)$$

Where,

Q = Theoretical capacity of the expeller, kg/hr

D = Mean diameter of screw, mm

N = Speed of rotation, rpm

H = Depth of worm, mm

P = Worm Pitch, mm

e = Thickness of worm, mm

α = Helix angle, ^{o}

Using measured data for moringa seeds as input values,

$Q = 3.142 \times 50 \times 45 \times 6.25 \times \cos 10\ (50\cos 10 – 6.25)$

$= 1.87 \times 10^6\ mm^3/min$

$= 0.1122\ \text{m}^3/\text{hr}$

For an average bulk density of 662 kg/m^3

$Q = 0.1122\ \text{m}^3/\text{hr} \times 662\ \text{kg/m}^3 = 74.30\ \text{kg/hr}$

3.4.10 Forces acting on Screw Thread

The two main forces acting on the screw thread are the frictional force required to translate and compress the moringa seeds as well as the frictional force resulting from the screw's motion. According to Olayanju (2002), by taking equilibrium of forces; the following equations (49) and (50) will be solved simultaneously

$$W = K\cos(\alpha + \phi) \qquad \dots (49)$$

$$F = K\cos(\alpha + \phi) \qquad \dots (50)$$

Therefore, $\frac{F}{W} = \frac{K\sin(\alpha + \phi)}{K\cos(\alpha + \phi)} = \tan(\alpha + \phi)$ … (51)

$$F = W\tan(\alpha + \phi) \qquad \dots (52)$$

But the friction angle, $\phi = \tan^{-1}\mu$

Where μ = coefficient of static friction = 1.376 (as determined by the physical properties of moringa)

$\phi = \tan^{-1}(1.376) = 53.99 \sim 54^{o}$

W = 67 N (maximum force at peak as determined from the mechanical properties of moringa)

$F = 67\tan(10 + 54) = 137.37$ N

At a point in time, a minimum of 50 moringa seeds are crushed at the feed end portion of the machine. Therefore, a minimum average force of 6.87 kN will be required to express the oil.

3.4.11 Torque on Screw Thread

Torque (T) and axial load are related to each other by equation (53) as given by Hall *et al.*, (1980):

$$T = W[r_m\tan(\alpha + \phi) + f_c r_c] \qquad \dots (53)$$

With the use of a well lubricated bearing, the frictional force at the collar will be neglected. Thus, the quantity $f_c r_c$ becomes zero. Hence, the equation becomes

$$T = Wr_m\tan(\alpha + \phi) \qquad \dots (54)$$

But from equation (52), $F = W\tan(\alpha + \phi)$

Therefore, the torque transmitted by worm action is given by

$$T = Fr_m \qquad \dots (55)$$

Where,

T = Torque on screw thread, Nm

F = Axial force required to expel oil, N

r_m = Radius screw, mm

$r_m = \frac{D_m}{2} = \frac{54}{2} = 27$ mm

Where, D_m = Mean diameter of screw, mm

$T = 6.87 \times 10^3 \times 27 \times 10^{-3}$

$T = 185.5$ Nm

3.4.12 Power Requirements

The power drive mechanism incorporates the use of a reduction gear motor coupled to the expeller shaft by pulley and belts arrangement. The chosen speed for the expeller N_c is 45 rpm.

The angular speed $w_e = \frac{2\pi N}{60}$ … (56)

$w_e = \frac{2 \times 3.142 \times 45}{60} = 4.71\ \mathrm{rad/s}$

The power input to the expeller is computed from equation (57)

$P_e = Tw_e$ … (57)

$= 185.5 \times 4.71 = 873.7$ W = 0.874 kW

The power of the electric motor to drive the expeller was estimated using the equation (58) below as given by Onwualu *et al.* (2006):

$P_m = \frac{P_e}{\eta}$ … (58)

Where,

P_m = Power of the electric motor

P_e = Power requirement of the expeller

η = Drive efficiency

Assuming a drive efficiency of 75% = 0.75

$P_m = \frac{873.7}{0.75} = 1165$ W = 1.165 kW = 1.55 hp

To give allowance for power used in driving pulleys and the shaft, a 2.0 hp (1.50 kW) electric reduction gear motor with a speed of about 180 rpm is chosen.

3.4.13 Belt Design

For the chosen 1.50 kW, 180 rpm electric gear motor, the belt type is a B-section (Figure 3.1). Diameter, d = 75 mm is used at the gear motor shaft. The pulley is designed by considering the power to be transmitted between the electric motor and the screw expellant shaft. The ratio of the pulley for the electric motor to that of the expellant shaft would be 1:2 (Ajao *et al.*, 2009) and the allowable diameter of the pulleys is calculated as given by Olaomi (2008) in equation (59) as:

$N_1 D_1 = N_2 D_2$ … (59)

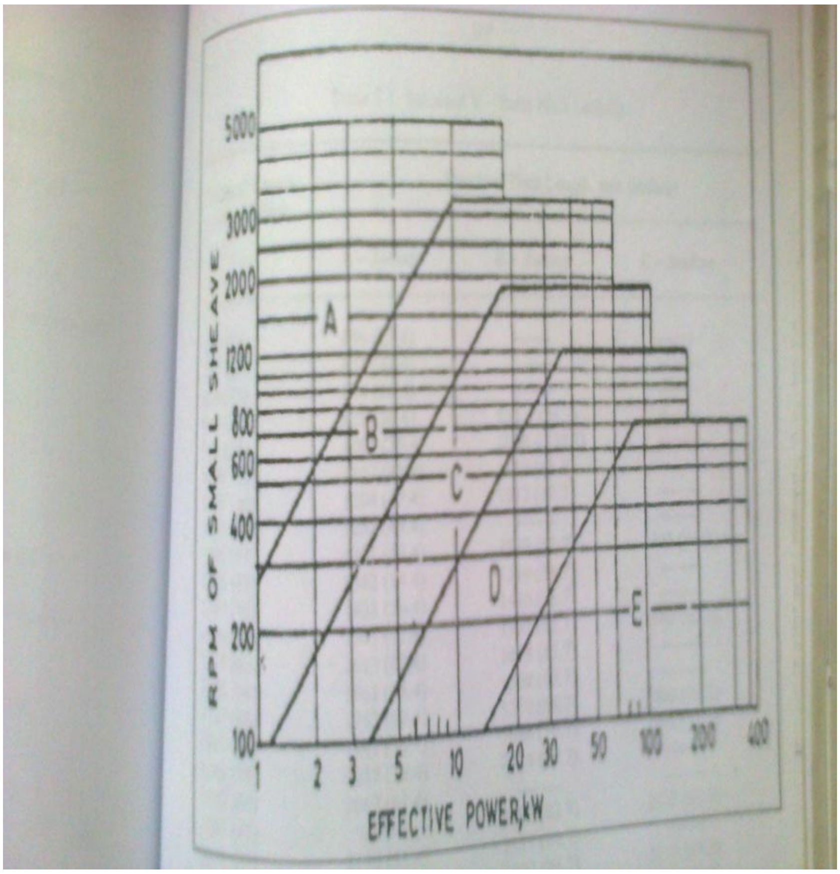

Figure 3.1. Effective Power of Belts as a function of rpm of small Sheaves

Source: Mubeen (1998)

Where,

N_1 = Speed of the driving motor, rev/min

N_2 = Speed of the expellant shaft, rev/min

D_1 = Diameter of driving pulley, m

D_2 = Diameter of driven pulley, m

The expeller pulley's diameter is calculated as:

$$D_2 = \frac{N_1 D_1}{N_2} \qquad \ldots (60)$$

$$D_2 = \frac{180 \text{ x } 75}{45} = 300\ mm$$

The total length of the belt is calculated as given by Khurmi and Gupta (2004) in equation (61):

$$L = 2C + \frac{\pi}{2}(D_1 + D_2) + \frac{(D_2 - D_1)^2}{4C} \qquad \ldots (61)$$

Where,

L = Total length of belt, mm

C = Minimum centre distance, mm

The minimum centre distance is calculated as given by Ajao *et al.* (2009) in equation (62):

$$C = \frac{D_1 + D_2}{2} + D_1 \qquad \ldots (62)$$

$$C = \frac{75 + 330}{2} + 75 = 262.5\ mm$$

From equation (61), the total length of the belt is calculated as:

$$L = 2 \text{ x } 262.5 + \frac{3.142}{2}(75 + 300) + \frac{(300 - 75)^2}{4 \text{ x } 262.5} = 1162 \text{ mm}$$

From Table 3.1, the nearest standard pitch is 1110 mm for which the nominal length is 1067 mm. A 2 B42- synchronous (toothed) belt arrangement which combines the characteristics of belts and chains will be used. This will guard against slippage, hence maintaining a constant speed ratio between the driving and the driven shafts.

3.4.14 Determination of Belt Tensions

The angle of wrap is calculated using equation (63) as given by Hall *et al.* (1980):

$$\alpha = 180 + 2\sin^{-1}[(R_2 - R_1)/C] \qquad \ldots (63)$$

R_1 = Radius of the smaller pulley = 37.5 mm

R_2 = Radius of the larger pulley = 150 mm

C = Centre distance = 262.5 mm

$$\alpha = 180 + 2\sin^{-1}[(150 - 37.5)/262.5] = 230.8^{o} = 4.03 \text{ rad}$$

$$\alpha = 180 - 2\sin^{-1}[(150 - 37.5)/262.5] = 129.2^{o} = 3.86 \text{ rad}$$

Table 3.1. Standard V-Belts Pitch Lengths

Nominal Length mm (inches)	**Standard Pitch Length, mm (inches)**		
	A – Section	**B – Section**	**C – Section**
660 (26)	696 (27.4)	-------	-------
787 (31)	823 (32.4)	-------	-------
838 (33)	874 (34.4)	-------	-------
889 (35)	925 (36.4)	932.2 (39.7)	-------
965 (38)	1001 (39.4)	1008.4 (39.7)	-------
1067 (42)	1102 (43.4)	1110 (43.7)	--------
1168 (46)	1204 (47.4)	1212 (47.7)	--------
1219 (48)	1252 (49.4)	--------	--------
1295 (51)	1331 (52.4)	1339 (52.7)	1351 (53.2)
1295 (53)	1382 (54.4)	1389 (54.7)	--------
1397 (55)	1433 (56.4)	1440 (56.7)	--------
1524 (60)	1561 (61.4)	1567 (61.7)	1580 (62.2)
1575 (62)	1610 (63.4)	1618 (63.7)	--------
1625 (64)	1661 (65.4)	1669 (65.7)	--------
1727 (68)	1762 (69.4)	1770 (69.7)	1783 (70.2)
1905 (75)	1941 (76.4)	1948 (76.7)	1961 (77.2)
1981 (78)	2017 (79.4)	2024 (79.7)	--------
2032 (80)	2067 (81.4)	--------	--------
2057 (81)	--------	2101 (82.7)	2113 (83.2)
2108 (83)	2144 (84.4)	2151 (84.7)	--------
2159 (85)	2195 (86.4)	2202 (86.7)	2215 (87.2)
2286 (90)	2322 (91.4)	2329 (91.7)	2342 (92.2)
2438 (96)	2474 (97.4)	--------	2499 (98.2)
2464 (97)	2499 (98.4)	2507 (98.7)	--------
2667 (105)	2702 (106.4)	2710 (106.7)	2723 (107.2)
2845 (112)	2880 (113.4)	2888 (113.7)	2901 (114.2)
3048 (120)	3084 (121.4)	3091 (121.7)	3104 (122.2)

Source: Mubeen (1998).

To obtain the tensions in the tight and slack sides, the following equations (64) and (65) are solved simultaneously

$(T_1 - T_2)\ V = P$ … (64)

and $\frac{T_1 - mv^2}{T_2 - mv^2} = e^{\mu\alpha/\sin\theta}/2$ … (65)

P = Power transmitted (kW)

T_1 = Tension in the tight side (kN)

T_2 = Tension in the slack side (kN)

But $m = bte$ … (66)

b = belt width = 17 mm

t = belt thickness = 11 mm

e = belt density = 970 kg/m^3 for leather belt

m = 17 × 11 × 10^{-3} × 970 = 0.18 kg/m

μ = coefficient of friction between belt = 0.15 for leather belt on steel

v = belt velocity

$v = rw_e$ … (67)

But $w_e = \frac{2\pi N}{60}$ from equation (56)

Therefore, $v = rw_e = \frac{2\pi rN}{60} = \frac{2 \times 3.142 \times 37.5 \times 0.001 \times 180}{60} = 0.71\ \mathrm{m/s}$

θ = 40^o (most common angle of groove)

For small pulley, $e^{\mu_1\alpha_1/\sin\theta}/2$ … (68)

$$e^{0.15 \times 3.86/\sin 20} = 5.44$$

For big pulley, $e^{\mu_2\alpha_2/\sin\theta}/2$ … (69)

$$e^{0.15 \times 4.03/\sin 20} = 5.86$$

According to Olayanju (2002), the pulley with the smaller value governs the design. Therefore, the smaller value (5.44) will be used in the design. Equation (65) then becomes

$$\frac{T_1 - mv^2}{T_2 - mv^2} = 5.44$$

$$\frac{T_1 - 0.18 \times 0.71 \times 0.71}{T_2 - 0.18 \times 0.71 \times 0.71} = 3.27$$

$$\frac{T_1 - 0.0907}{T_2 - 0.0907} = 3.27$$

$$T_1 - 0.0907 = 3.27T_2 - 0.297$$

$$3.27T_2 - T_1 = 0.297 - 0.0907$$

$3.27T_2 - T_1 = 0.2063$ … (70)

But from equation (58),

$(T_1 - T_2)\ V = P$

$P = 1$ hp $= 0.746$ kW

$V = 0.71\ m/s$

Therefore, $T_1 - T_2 = \frac{P}{V}$ … (71)

$T_1 - T_2 = \frac{0.746}{0.71} = 1.05$

$T_1 = 1.05 + T_2$ … (72)

By substituting equation (72) into equation (70), equation (70) becomes

$3.27T_2 - (1.05 + T_2) = 0.2063$

$3.27T_2 - T_2 = 0.2063 + 1.05$

$2.27T_2 = 1.2563$

$T_2 = \frac{1.2563}{2.27} = 0.553$ kN

By substituting the value of T_2 into equation (66),

$T_1 = 1.05 + 0.553 = 1.603$ kN

The bending load on the wormshaft is due to the weight of the pulley, the summation of tensions on the belts acting vertically downward and the weight of the threaded shaft as shown in Figure 3.2. The shaft will be supported at the two ends A and B by two bearings. The reactions R_A and R_B at the two supports are determined by equation (73)

$R_A + R_B = W_s + (T_1 + T_2) + W_p$ ... (73)

W = Weight of threaded shaft = 50 N

$T_1 + T_2$ = Sum of tensions on vertical belts = 2156 N

W_p = Weight of pulley = 50 N

$R_A + R_B = 50 + 2156 + 50$

$R_A + R_B = 2256$ … (74)

Taking moment about B,

$R_A\ (0.605) - 50\ (0.3025) - 2206(0.545) = 0$

$0.605R_A = 1217.395$

$R_A = 2012.22\ \mathrm{N}$

Taking moment about A,

$R_B\ (0.605) - 50\ (0.3025) - 2206(0.06) = 0$

$0.605R_A = 147.485$

$R_B = 243.78\ \mathrm{N}$

The shear force and bending moment diagrams are shown in Figure 3.3.

3.4.15 The Power Transmission Shaft

The power transmission shaft is designed to satisfy the strength criterion.

The required diameter for a solid shaft having combined bending and torsional loads is obtained from ASME code equation as adopted by (Hall *et al.* 1980) as:

$$D^3 = \frac{16}{\pi S_s}\sqrt{(K_b M_b)^2 + (K_t M_t)^2} \qquad \ldots (75)$$

Where,

D = Diameter of solid shaft, mm

S_s = Allowable combined shear stress for bending and torsion = 40 MPa for steel shaft with keyway

K_b = Combined shock and fatigue factor applied to bending moment = 1.5 to 2.0 for minor shock

K_t = Combined shock and fatigue factor applied to torsional moment = 1.0 to 2.0 for minor Shock

M_b = Bending moment, Nm = 147.5 Nm

M_t = Torsional moment, Nm = 185.5 Nm

$$D^3 = \frac{16}{40\ x\ 10^6 \pi}\sqrt{(2.0\ x\ 147.5)^2 + (2.0\ x\ 185.5)^2}$$

$D^3 = 6.04 \times 10^{-5}$ m

$D = 0.0392\ \mathrm{m} = 39.2\ \mathrm{mm}$

The calculated diameter is less than the chosen diameter of 40 mm. Therefore, strength criterion is satisfied.

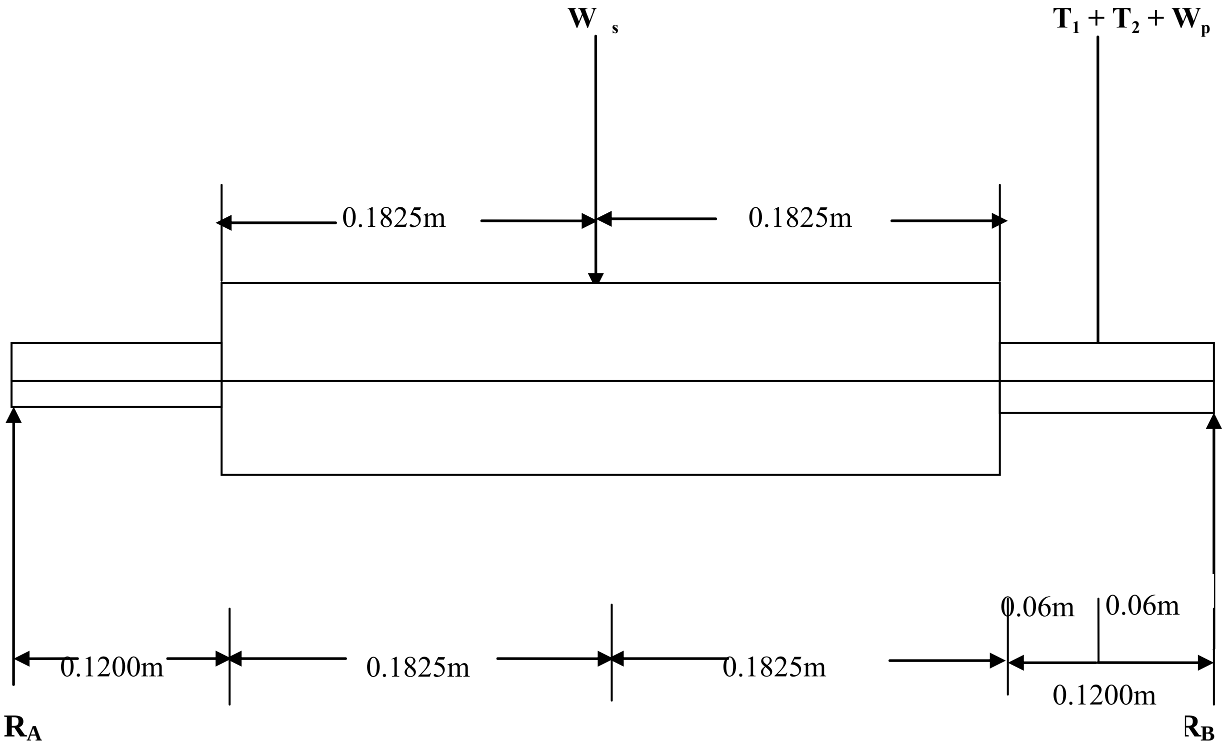

Figure 3.2. Bending Loads on the Wormshaft

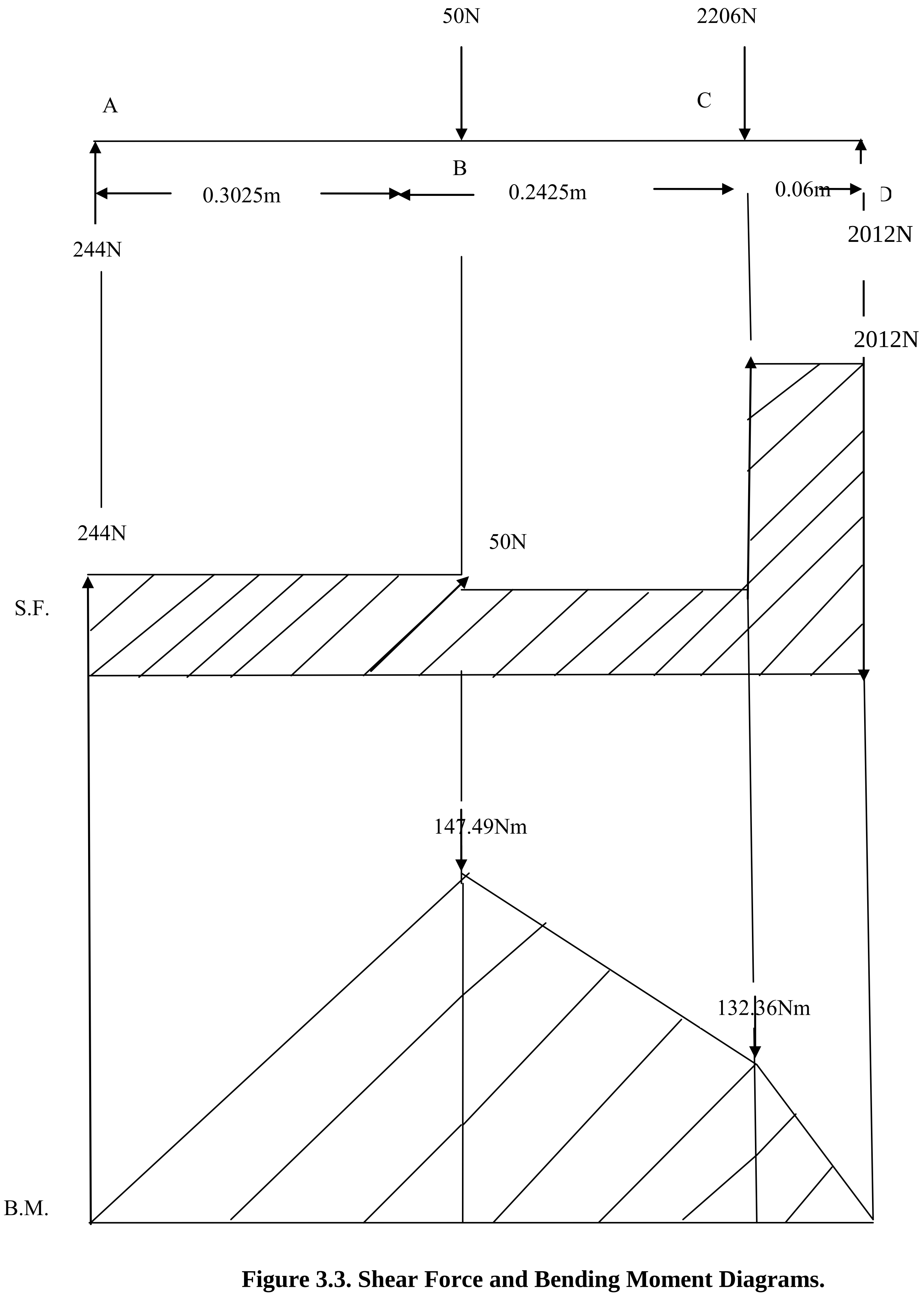

Figure 3.3. Shear Force and Bending Moment Diagrams.

3.5 Description of the Moringa Oil Expeller

The moringa oil expeller is shown in Plate 3.2. It consists of an electric gear motor [5], feed hopper [4], roasting chamber [3], expression chamber, stirrer, heater, wormshaft [8], shaft housing, oil barrel, oil barrel cover [7], belts and pulleys [6], bevel gears [1], bearings [9], temperature regulator [2], oil outlet [10], cake outlet and machine frame [11].

3.5.1 The Roasting Chamber

This is the unit where the seeds are being heated. It consists of a roasting drum with dimensions 320 mm × 250 mm, 1 kW rated capacity heater which will supply the energy to vapourize moisture from the wet products in the roasting drum and a temperature regulator which controls the temperature of the air inside the drying chamber. The heater normally causes a difference in relative humidity and temperature of the inlet air and that of the air in the drying chamber and if not controlled, it leads to overheating and subsequent burning of products. The temperature regulator therefore controls the heater.

3.5.2 The Feeding Assembly

This consists of a hopper which is directly located under the roasting chamber. It is made of mild steel. The hopper has dimensions of 200 mm × 220 mm × 225 mm. The roasted seeds flow down from the roasting chamber into the feed hopper from where they enter the expelling chamber.

3.5.3 The Expression Chamber

This was made of 90 mm diameter, 790 mm long and 12.7 mm thick stainless steel pipe. This was split into two equal halves (top and bottom parts). Perforations were provided on the bottom part of the barrel so that the expressed oil can drain through them. The two halves were bolted together using bolts and nuts. The expression chamber is enclosed in a cover to prevent expressed oil from coming in contact with dust and foreign materials.

3.5.4 The Worms and Wormshaft Assembly

The wormshaft assembly consists of a special wormshaft fitted with six worms of different pitches. The worm flight design along pressure and discharge section is such that the materials do not wrap around more than 320^o. This leaves an axial gap in the flight that enables the compressed material to slide in either direction relative to velocity generated by worm pitch. This balances the pressure over a group of worm section and reduces the tendency of material to lock in individual section and rotate with the shaft. The configuration of the worm section is such that the volume displacement at the feed end of the press is greater than the discharge end. The whole assembly rotates in the barrel. The wormshaft was made from a mild steel solid rod of diameter 80 mm and length 970 mm, which was machined on the lathe at a decreasing screw

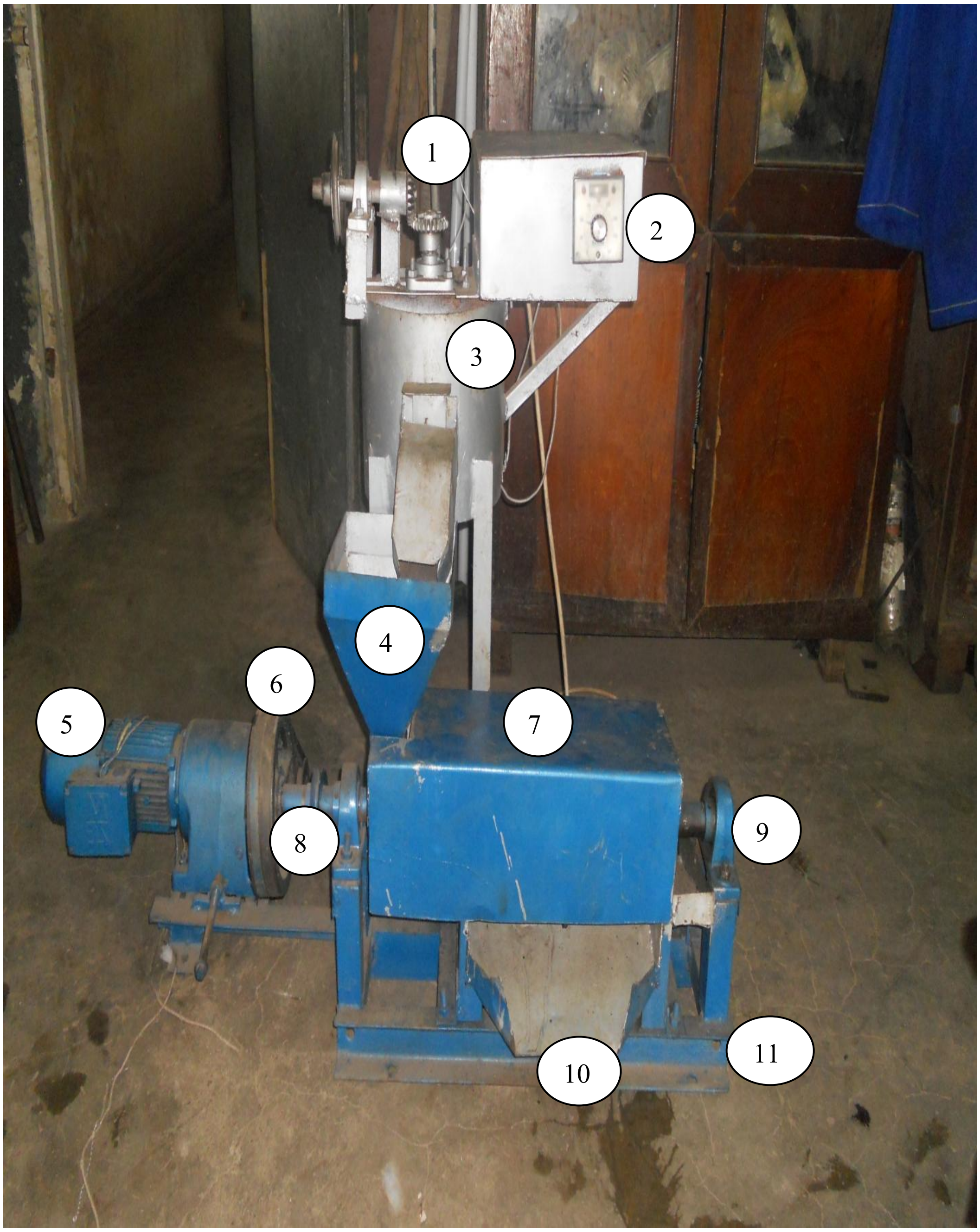

Plate 3.2. The Moringa Oil Expeller

1: Bevel Gear
2: Temperature Regulator
3: Roasting Chamber
4: Hopper
5: Electric Gear Motor
6: Belt and Pulley Arrangement
7: Oil Barrel Cover
8: Wormshaft
9: Pillow Bearing
10: Oil Trough
11: Machine Frame

pitch and decreasing screw depth. The wormshaft is housed in the cylindrical barrel at a clearance of 1.5 mm between the screw diameter and inside diameter of the barrel. Two pillow bearings (90 mm diameter) are elevated to a height where the wormshaft can rotate concentrically. The worms have a dual role of conveying the oilseeds through the barrel and at the same time exerting pressure on the material. Besides increasing the pressure in the barrel, the shear action on the barrel breaks the oilseeds into smaller particles. Due to pressure created by the worms and choke, the oil flows out of the oil-solid matrix through the holes in the oil barrel.

3.5.5 The Power Unit

This consists of a 1.8 hp, 180 rpm, 3-phase AC electric gear motor, a set of belts and pulleys (one connected from the electric gear motor to the main shaft and the other from the main shaft to the roaster).

3.5.6 The Oil and Cake Troughs

These are made of mild steel. They are inclined at an angle of 60^o to the horizontal to allow for the free flow of oil and cake. The oil trough is located at the front of the machine for oil collection, while the cake trough is located at the back of the machine for cake collection.

3.5.7 The Machine Frame

This supports all the other components and units of the oil expeller. It consists of a base and supports which are made from mild steel.

The AUTOCAD drawings of the various component parts showing the orthographic, isometric, schematic, wireframe, exploded and main views of the expeller are shown in Appendix H.

3.6 Working Principles of the Moringa Oil Expeller

The seeds are introduced into the machine through the roasting drum where they are heated. Thereafter, the seeds flow down to the feed hopper through a sliding gate provided on the roasting drum. The machine conveys, grinds and presses the seeds inside the cylindrical barrel with the aid of the wormshaft until oil is squeezed out of the seed. The oil extracted is drained though the oil barrel into the oil trough where it is collected, while the residual cake is discharged to the cake trough at the cake outlet where it is collected. The machine is powered by a 1.8 hp three-phase electric motor.

3.7 Experimental Design

The effects of the processing variables namely moisture content, heating temperature, heating time and applied pressure on the oil yield were investigated. The four independent variables considered are very important factors affecting the yield and quality of oil expression from oilseeds using oil expellers. The experimental design adopted was 4 factors, 5 levels, factorial Central Composite Rotatable Design (CCRD) of Response Surface Methodology (Box *et al.*, 1978) as adopted by Olajide (2000) while working on groundnut and sheanut kernels; Shridhar *et al.* (2010) while working on castor seed oil, Narayana (2012) while working on coconut and Awolu *et al.* (2013) while working on neem seed.

Central Composite Rotatable Design is comprised of three types of design points namely factorial points (n_f), axial points (n_a) and central points (n_c). According to the Central Composite Rotatable Design, the total number of treatment combinations is $n = 2^{k}\,(n_{f}) + 2k(n_{a}) + k(n_{c})$ where 'k' is the number of independent variables and n is the number of repetition of experiments at the center point. The total number of design points is thus $N = 2^{k} + 2k + (n_{o})$. Therefore, the CCRD involved 30 experiments consisting of 2^4 factorial CCD, with 8 axial points ($\alpha = 2$) and 6 replications at the center points. For each independent variable, the levels were chosen with respect to moisture content of moringa seeds at harvest, preliminary experiments, observations and previous reports by various researchers on various oilseeds since there is no information as regards the optimization of the various process parameters that influence oil expression from moringa using oil expeller. Five levels of applied pressures (5, 10, 15, 20 and 25 MPa) and moisture content levels of (8, 9, 10, 11 and 12 %wet basis) were chosen. Five heating temperature levels (50, 60, 70, 80 and 90°C) for heating times of (15, 20, 25, 30 and 35 minutes) were also chosen. Coded values of the independent variables (-2, -1, 0, 1, 2) were used; where -2, 0 and 2 represent the lowest, medium and highest levels respectively. The coded values are set out in Tables 3.2 and 3.3.

$$Coded\ value = \frac{Natural\ value - Base\ level\ (level\ 0)}{Interval\ of\ variation} \qquad \ldots (76)$$

The relationships between the coded and natural values in the RSM design for the experiments are given below:

$$X_1 = \frac{(M_{\mathrm{c}} - 10)}{1} \qquad \ldots (77)$$

$$X_2 = \frac{(H_{\mathrm{T}} - 70)}{10} \qquad \ldots (78)$$

$$X_3 = \frac{(H_{\mathrm{t}} - 25)}{5} \qquad \ldots (79)$$

$$X_4 = \frac{(A_{\mathrm{p}} - 15)}{5} \qquad \ldots (80)$$

X_1 = Coded value for moisture content

M_c = Natural value for moisture content

X_2 = Coded value for heating temperature

H_T = Natural value for heating temperature

X_3 = Coded value for heating time

H_t = Natural value for heating time

X_4 = Coded value for applied pressure

A_p = Natural value for applied pressure

3.8 Response Surface Methodology (RSM)

A Design Expert (version 6.0.6) software package for design of experiments was used to analyze and generate model equations for the expression process. Data obtained through the experimental matrix were computed for the determination of regression coefficient of the second order multiple regression models. The analysis of regression and variance was performed by the Design Expert. To validate the optimal parameters, the experiment was repeated at the optimal conditions as suggested by Islau *et al.* (2002). The obtained results were compared with predicted values.

3.9 Statistical Analysis

The data obtained in the experiments were analyzed using Response Surface Methodology so as to fit the quadratic polynomial equation generated by the Design-Expert software version 6.0.6 (Stat-Ease Inc., Minneapolis, USA). In order to correlate the response variable to the independent variables, multiple regression was used to fit the coefficient of the polynomial model of the response. The quality of the fit of the model was evaluated using Analysis Of Variance (ANOVA). ANOVA was carried out to determine the significance and fitness of the model as well as the effect of significant individual terms and their interaction on the chosen responses. The P-value (probability of error value) was used as a tool to check the significance of each regression coeffiecient which also indicated the interaction effect of each cross product. Data obtained from the experiments were also statistically analyzed to determine the significant difference in the process conditions and their interactions at 5% probability level using SPSS window 20.0 software package.

3.10 Experimental Tests of the Moringa Oil Expeller

Moringa seeds were procured from the market, dehulled and thereafter, manually cleaned to remove foreign materials. A factorial experimental design (4 × 5) was used in the test at various moisture contents, heating temperatures, heating times and applied pressures. Initial moisture content of the sample was determined using the standard method as described in section 3.1.1.2. One kg each of moringa seeds was conditioned to desired levels of moisture contents (8, 9, 10, 11 and 12 %wet basis) using equation (58) as adopted by Olajide (2000):

Table 3.2. Levels, Codes and Intervals of Independent Variables for the Experiment

Factors	Codes	-2	-1	0	1	2	Interval of Variation
Moisture Content (%wet basis)	X_1	8	9	10	11	12	1
Heating Temperature (^oC)	X_2	50	60	70	80	90	10
Heating Time (min)	X_3	15	20	25	30	35	5
Applied Pressure (MPa)	X_4	5	10	15	20	25	5

Table 3.3. Experimental Design (Second Order Design in the Four Variables)

	X_1	X_2	X_3	X_4	M_c	H_T	H_t	A_p
1	0.000	0.000	0.000	0.000	10.00	70.00	25.00	15.00
2	1.000	-1.000	-1.000	1.000	11.00	60.00	20.00	20.00
3	1.000	1.000	1.000	-1.000	11.00	80.00	30.00	10.00
4	-1.000	1.000	1.000	-1.000	9.00	80.00	30.00	10.00
5	0.000	0.000	2.000	0.000	10.00	70.00	35.00	15.00
6	0.000	0.000	0.000	0.000	10.00	70.00	25.00	15.00
7	1.000	1.000	-1.000	-1.000	11.00	80.00	20.00	10.00
8	2.000	0.000	0.000	0.000	12.00	70.00	25.00	15.00
9	1.000	1.000	-1.000	1.000	11.00	80.00	20.00	20.00
10	-1.000	-1.000	-1.000	1.000	9.00	60.00	20.00	20.00
11	0.000	0.000	0.000	2.000	10.00	70.00	25.00	25.00
12	1.000	-1.000	1.000	1.000	11.00	60.00	30.00	20.00
13	-1.000	1.000	1.000	1.000	9.00	80.00	30.00	20.00
14	-1.000	-1.000	1.000	1.000	9.00	60.00	30.00	20.00
15	-2.000	0.000	0.000	0.000	8.00	70.00	25.00	15.00
16	1.000	-1.000	-1.000	-1.000	11.00	60.00	20.00	10.00
17	0.000	0.000	0.000	0.000	10.00	70.00	25.00	15.00
18	0.000	0.000	0.000	-2.000	10.00	70.00	25.00	5.00
19	1.000	1.000	1.000	1.000	11.00	80.00	30.00	20.00
20	0.000	0.000	-2.000	0.000	10.00	70.00	15.00	15.00
21	0.000	0.000	0.000	0.000	10.00	70.00	25.00	15.00
22	0.000	0.000	0.000	0.000	10.00	70.00	25.00	15.00
23	1.000	-1.000	1.000	-1.000	11.00	60.00	30.00	10.00
24	-1.000	-1.000	-1.000	-1.000	9.00	60.00	20.00	10.00
25	0.000	0.000	0.000	0.000	10.00	70.00	25.00	15.00
26	0.000	-2.000	0.000	0.000	10.00	50.00	25.00	15.00
27	-1.000	1.000	-1.000	1.000	9.00	80.00	20.00	20.00
28	0.000	2.000	0.000	0.000	10.00	90.00	25.00	15.00
29	-1.000	1.000	-1.000	-1.000	9.00	80.00	20.00	10.00
30	-1.000	-1.000	1.000	-1.000	9.00	60.00	30.00	10.00

$$Q = \left(\frac{100-\mathrm{Mi}}{100-Mf} - 1\right) \times W_s \qquad \ldots (81)$$

Where,

Q = Volume of water to be added, ml.

M_i = Initial moisture content of the sample, % wet basis

M_f = Final (desired) moisture content of sample % wet basis

W_s = Weight of the sample, g

The conditioned samples were kept in cloth wrapped with polythene bags and stored in a refrigerator set at a temperature of $(4 \pm 1)\,^{o}$C for a period of 15 hrs to allow for even distribution of moisture. The samples to be expressed were removed from the refrigerator and kept in a desiccator to prevent moisture loss prior to heating. They were then heated at 50, 60, 70, 80 and 90^{o}C for 15, 20, 25, 30 and 35 mins duration. Applied pressures of 5, 10, 15, 20 and 25 MPa were used in the experiment. Experiments were done in triplicates. The expressed oil (Plate 3.3) was collected and left to stand for 96 hours after which it was weighed (Weiss, 2000). The cake output was also weighed.

3.11 Determination of the Total Oil Content of Moringa Seeds

In order to determine the initial total oil content of the moringa seeds, the method as described by Orhevba *et al.* (2013) was adopted. The samples collected were washed with distilled water. They were then air-dried and ground. 10 g of the ground sample was weighed and placed on a filter paper which was folded carefully. The filter paper containing the sample was then inserted into the Soxhlet apparatus (Plate 3.4). The weights of the filter paper and sample were recorded. 200 ml of the solvent (hexane) was measured using a measuring cylinder and then poured into a 500 ml round bottom flask with the sample and heated at 60^{o}C for 5 hours after which the sample was removed and transferred into the air oven to dry at 105^{o}C for 15 minutes. The sample was then weighed and the difference was calculated using equation (82) below. The oil was recovered by solvent evaporation. It was heated at a low temperature until the solvent finally evaporated leaving behind the oil extracted.

$$Oil\ Yield = \frac{\text{Weight of sample before extraction} - \text{Weight of sample after extraction}}{\text{Weight of sample before extraction}} \times 100 \qquad \ldots (82)$$

This was taken as the total oil content of the moringa seeds and was used in the calculation of the percentage extraction efficiency in terms of oil yield.

The oil yield was determined from equation (83) below as adopted by Ajav and Olatunde (2011):

Plate 3.3. Expressed Moringa Oil Samples

Plate 3.4. Soxhlet Apparatus

$$Y = \frac{W_o}{W_g} \times 100 \qquad \text{... (83)}$$

Where,

Y = Oil yield, %

W_g = Weight of Moringa, kg

W_o = Weight of oil expressed, kg

The extraction efficiency was determined from equation (84) as adopted by Ajav and Olatunde (2011). The expressed oil was weighed and results were expressed as a percentage of the total weight of sample used for the expression. Results obtained for each experiment at different processing conditions were used to calculate the percent oil yield in comparison with the initial oil in the sample estimated by the Soxhlet method.

$$\eta = \frac{O_Y}{O_T} \times 100 \qquad \text{... (84)}$$

Where,

η = Extraction efficiency, %

O_Y = Oil yield, %

O_T = Total oil content, %

The material balance efficiency in terms of the oil and cake output was determined from equation (85) below:

$$\varphi = \frac{W_o + W_c}{W_T} \times 100 \qquad \text{... (85)}$$

Where,

φ = Material balance efficiency, %

W_o = Weight of oil, g

W_c = Weight of cake, g

W_T = Total weight of moringa seeds used for the experiment, g

3.12 Physico-chemical Analysis of the Moringa Oil

The Free Fatty Acid (FFA) content, oil impurity and colour were used as criteria for assessing oil quality using AOAC standard methods.

3.12.1 Free Fatty Acid

10 g of the oil sample was accurately weighed into a 250 ml stopper flask. In a second flask, 50 ml of ethanol was heated to the boiling point and while still over 70^{o}C, it was neutralized with 0.1 KOH using phenolphthalein indicator. The neutralized ethanol was poured in the first flask containing the oil and the content of the flask mixed. They were boiled, and while still hot, titrated with 0.1 KOH, shaking vigorously during the titration. The end point of

the titration was reached when the addition of a single drop of 0.1 KOH produced a slight, but definite colour change persisting for at least 15 seconds.

The FFA was then calculated as:

$$\text{FFA} = \frac{(5.61 \times \text{V} \times \text{N})}{W} \qquad \ldots (86)$$

V = Volume in ml of 0.1 KOH used

N = Normality of the ethanolic KOH (0.1)

W = Weight of the oil sample

3.12.2 Colour

The oil was filtered through a filter paper to remove any impurity. A glass cell was cleaned with carbon tetrachloride and dried. The glass cell was filled with the oil and placed in position in the tintometer. The colours were matched with sliding red, yellow and blue colours. The colour was reported in terms of Lovibond units.

$$\text{Colour} = Y + 5R \qquad \ldots (87)$$

Y = Sum total of yellow slides used

R = Sum total of red slides used

3.12.3 Oil Impurity

A filter paper and a beaker were dried in the oven between 103-105°C to constant weight. The filter paper was cooled in the dessicator for 30 mins and weighed (W_1). The filter paper was then folded and placed in the beaker. 10 ml of oil sample was accurately measured and spread on the filter paper. Small quantity of petroleum ether was added to the filter paper containing the oil to enhance filtration. When the filtration was complete, the filter paper was removed and dried in an oven till all the oil evaporated. The filter paper was quickly transferred to the dessicator and cooled for 30 minutes. The filter paper was weighed (W_2) and the oil impurity calculated as:

$$\text{Oil Impurity} = \frac{\text{W}_2 - \text{W}_1}{\text{ml of oil}} \times 100 \qquad \ldots (88)$$

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Physical Properties of Moringa

The values of the physical properties of moringa seeds measured are presented in Tables A1 to A7 in Appendix A, while a summary of the results is shown in Tables 4.1-4.3.

The average moisture content was 7.31% wet basis and all the other experiments were conducted at this moisture content. The moisture content is very important as it influences the size, shape and angle of repose of the seeds; which in turn determines the hopper capacity and the free flow of seeds.

The average seed length, width and thickness were 8.45±0.976 mm, 7.82±0.922 mm and 6.41±1.092 mm respectively. Reported values for the length, width and thickness (respectively) of other oil-bearing crops revealed 56.18±8.64 mm, 37.89±3.82 mm and 12.01±1.66 mm for oil bean seeds (Asoegwu, 2006); 10.63-11.09 mm, 7.27-7.99 mm and 6.02-7.41 mm for castor bean seeds (Shafiee *et al.*, 2009); 12.81-14.50 mm, 7.02-8.42 mm, 2.22-2.49 mm for melon seeds (Davies, 2009); 2.5 mm, 1.6 mm and 0.94 mm for sesame seeds (Arafa, 2007); 11.21±1.60 mm, 7.56±0.94 mm, 6.93±0.77 mm for groundnut kernels (Olajide, 2000); 31.50±0.28 mm, 23.70±0.20 mm and 22.00±0.24 mm for sheanut kernels (Olajide, 2000); 3.34 mm, 2.13 mm and 0.80 mm for beniseeds (Olayanju, 2002); 58.87 mm, 18.96 mm and 15.64 mm for fennel seeds (Ahmadi *et al.*, 2009); 12.14-12.57 mm, 5.79-6.38 mm, 3.86-4.09 mm for sunflower seeds (Seifi and Alimardani, 2010); 7.27-7.81 mm, 3.50-3.79 mm and 2.80-3.50 mm for safflower seeds (Aktas *et al.*, 2006); 7.27-8.25 mm, 6.48-6.97 mm, 5.41-5.94 mm for soybean grains (Tavakoli *et al.*, 2009) and 17.01-17.71 mm, 10.74-11.23 mm, 8.19-8.16 mm for jatropha seeds (Bamgboye and Adebayo, 2012). Comparatively, it would be observed that moringa seeds are smaller in length to all the above mentioned seeds except sesame, safflower, soybean and beniseeds. Also, the width is in the same range as that of castor bean and melon seeds, but slightly wider than groundnut kernels. Furthermore, the thickness is in the same range as that of castor bean seeds, but slighty lower than groundnut kernels. The thickness is also lower than sheanut kernels, fennel, jatropha and oil bean seeds, but higher than melon, sesame, sunflower, safflower, soybean and beniseeds. The oil bean seeds are approximately seven times longer, five times wider and two times thicker than moringa seeds. The sheanut kernels are approximately four times longer, three times wider and three times thicker than moringa seeds, while the fennel seeds are approximately seven times longer, two times wider and thicker than moringa seeds. The values of the linear dimension of the moringa seeds were used in the calculation of the

Table 4.1. Dimensional Properties of Moringa Seeds

Physical Properties	No of observations	Unit of measurements	Minimum Value	Maximum Value	Mean Value	Standard Deviation	Coefficient of Variation
Length	100	mm	6.44	10.68	8.45	0.976	11.55
Width	100	mm	5.98	9.91	7.82	0.922	11.79
Thickness	100	mm	4.11	7.97	6.41	1.092	17.04
Arithmetic Mean Diameter	100	mm	5.813	8.963	7.560	0.866	11.46
Geometric Mean Diameter	100	mm	5.668	8.782	7.490	0.880	11.75
Surface Area	100	mm^2	100.93	242.29	177.47	40.08	22.58
Sphericity	100	-	0.750	0.969	0.888	0.052	5.86
Aspect Ratio	100	-	0.735	0.986	0.927	0.050	5.39

Table 4.2. Gravimetric Properties of Moringa Seeds

Physical Properties	No of observations	Unit of measurements	Minimum Value	Maximum Value	Mean Value	Standard Deviation	Coefficient of Variation
Moisture Content	3	% wet basis	6.97	7.58	7.31	0.312	23.43
True Density	10	g/cm^3	0.721	1.071	0.971	0.105	9.25
Bulk Density	10	g/cm^3	0.630	0.692	0.662	0.026	25.46
Porosity	-	%	-	-	68.18	-	-
One Thousand Seed Weight	10	g	234.00	246.00	239.20	3.084	1.29

Table 4.3. Frictional Properties of Moringa Seeds

Physical Properties	No of observations	Unit of measurements	Minimum Value	Maximum Value	Mean Value	Standard Deviation	Coefficient of Variation
Coefficients of Static Friction [Glass]	10	°	0.932	1.192	1.027	0.072	14.26
Coefficients of Static Friction [Stainless steel]	10	°	1.036	1.150	1.111	0.036	30.86
Coefficients of Static Friction [Mild steel]	10	°	1.235	1.600	1.376	0.111	12.40
Coefficients of Static Friction [Galvanized steel]	10	°	1.000	1.428	1.234	0.174	7.09
Coefficients of Static Friction [Rubber]	10	°	1.881	2.605	2.199	0.265	8.30
Coefficients of Static Friction [Plywood]	10	°	1.327	1.963	1.607	0.257	6.25
Angle of Repose	10	°	20.46	22.66	21.44	0.745	28.78

amount of seeds that will be crushed at the feed end portion of the machine. It also assisted in determining the force that will be required to express the oil based on the number of seeds to be processed per batch.

The arithmetic mean diameter and geometric mean diameter of the moringa seeds were 7.560±0.866 mm and 7.51±0.880 mm respectively. The surface area was 177.19±40.08 mm^2; while the sphericity and aspect ratio were 0.889±0.052 (88.9%) and 0.9257±0.050 (92.57) respectively. Garnayak *et al.* (2008) considered any grain, fruit or seed as spherical when the sphericity value is above 70%, thus, the high sphericity of the moringa seeds is indicative of the shape towards being a sphere. This value is higher than those reported for other oil-bearing crops; 0.523±0.065 for oil bean seeds (Asoegwu, 2006); 0.69-0.73 for castor bean seeds (Shafiee *et al.*, 2009); 0.47-0.53 for melon seeds (Davies, 2009); 0.63 for sesame seeds (Arafa, 2007); 0.76 for groundnut kernels (Olajide, 2000); 0.80 for sheanut kernels (Olajide, 2000); 0.52-0.55 for beniseeds (Olayanju, 2002); 0.45 for fennel seeds (Ahmadi *et al.*, 2009); 0.53-0.55 for sunflower seeds (Seifi and Alimardani, 2010); 0.47-0.49 for safflower seeds (Aktas *et al.*, 2006) and 0.672-0.684 for jatropha seeds (Bamgboye and Adebayo, 2012). However, it is in the same range as soybean grains (0.847-0.873) and canola seeds (0.82-0.93) as reported by Tavakoli *et al.*, (2009) and Razavi *et al.* (2009) respectively.

Figures 4.1-4.8 show the frequency distribution of the dimensional properties for the hundred samples of moringa seeds measured.

The average true and bulk densities were 0.971 gcm^{-3} (971 kgm^{-3}) and 0.662 gcm^{-3} (662 kgm^{-3}) respectively; while the porosity was computed from the values of the true density and bulk density using equation (26) and was found to be 68.18%. The true density of the moringa seeds showed that the seeds are slightly less dense than water and therefore will float on water. Comparatively, the true density is in the same range as those reported for sunflower seeds, (740-980 kgm^{-3}) and jatropha seeds (863-1035 kgm^{-3}) (Seifi and Alimardani, 2010; and Bamgboye and Adebayo, 2012). It is higher than the values reported for castor bean seeds (704.75-761.74 kgm^{-3}), melon seeds (816.09-847.47 kgm^{-3}), sesame seeds (542.1-607.3 kgm^{-3}), fennel seeds (889.08-937.98 kgm^{-3}) and safflower seeds (776-780 kgm^{-3}) (Aktas *et al.*, 2006; Shafiee *et al.*, 2009; Davies, 2009; Darvishi, 2012 and Ahmadi *et al.*, 2009). Also, it is lower than those reported for groundnut kernels (1010 kgm^{-3}), beniseeds (981-1042 kgm^{-3}), sheanut kernels (1170 kgm^{-3}) and soybean grains (1126.43-1147.86 kgm^{-3}) (Olajide, 2000; Olayanju, 2002; Olajide, 2000 and Tavakoli *et al.*, 2009). The bulk density is higher than those reported for oil bean seeds (588 kgm^{-3}), castor bean seeds (434.75-447.50 kgm^{-3}), soybean (625.36-650.95 kgm^{-3}), melon

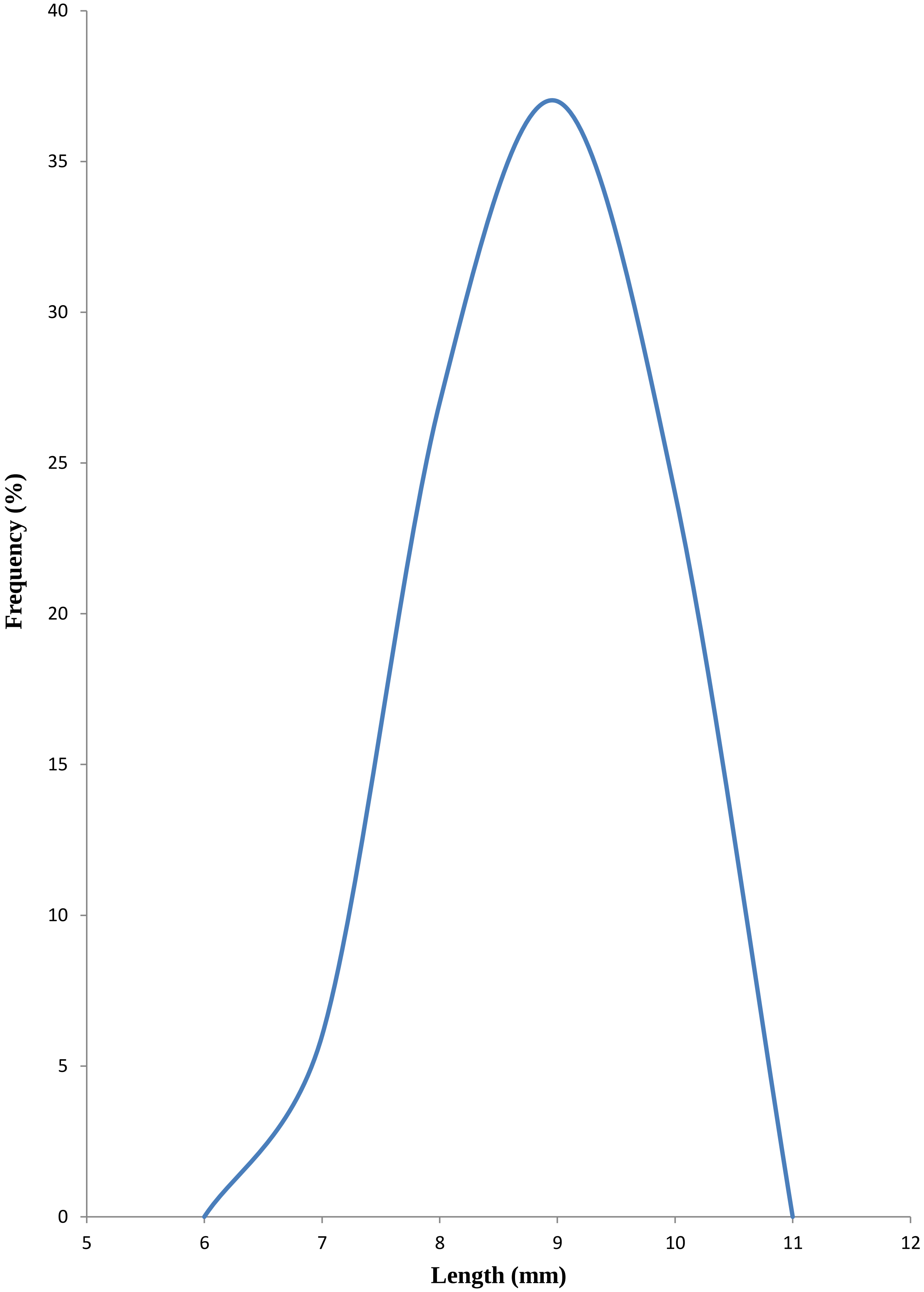

Figure 4.1. Frequency Distribution of the Length of Moringa Seeds

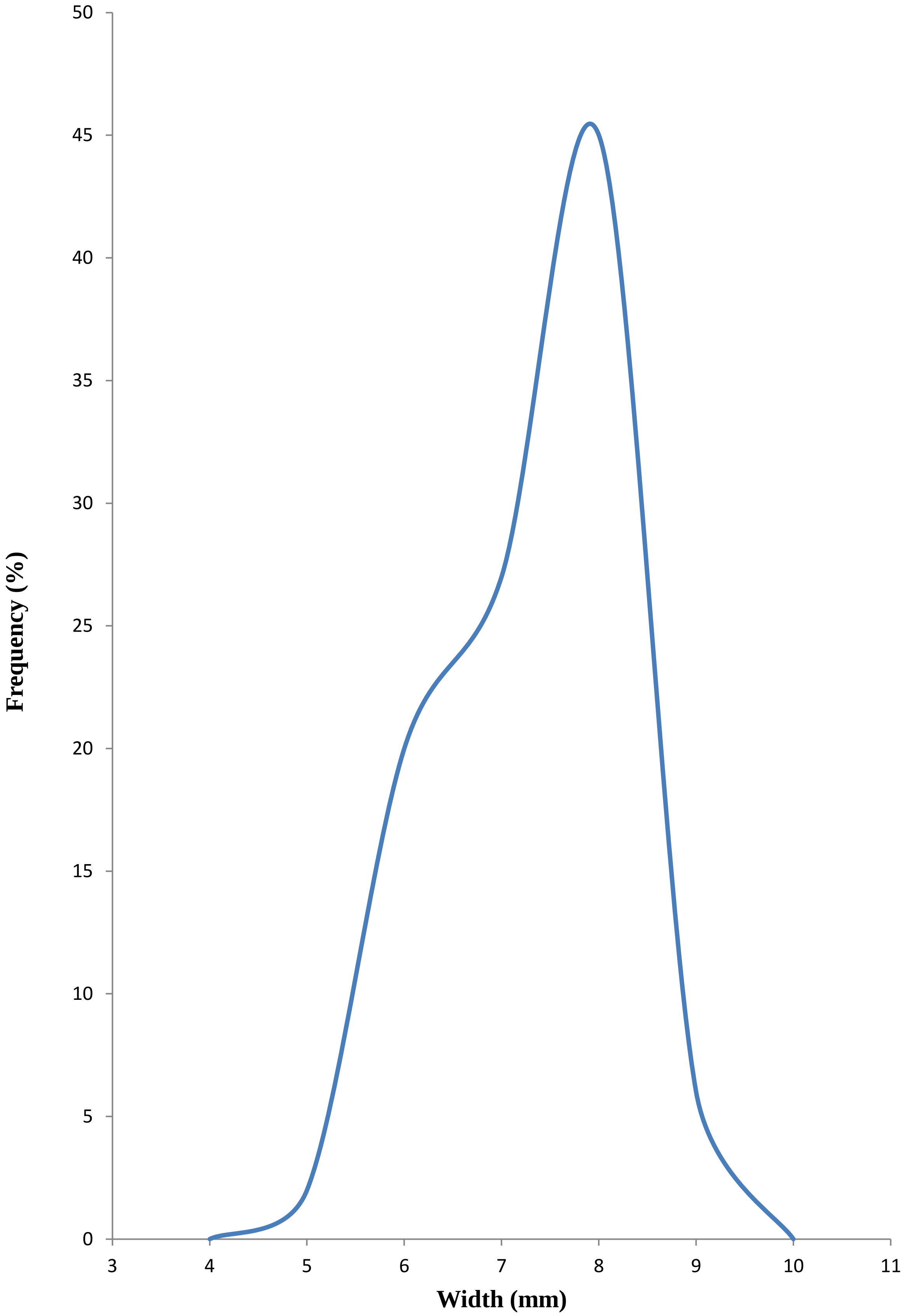

Figure 4.2. Frequency Distribution of the Width of Moringa Seed

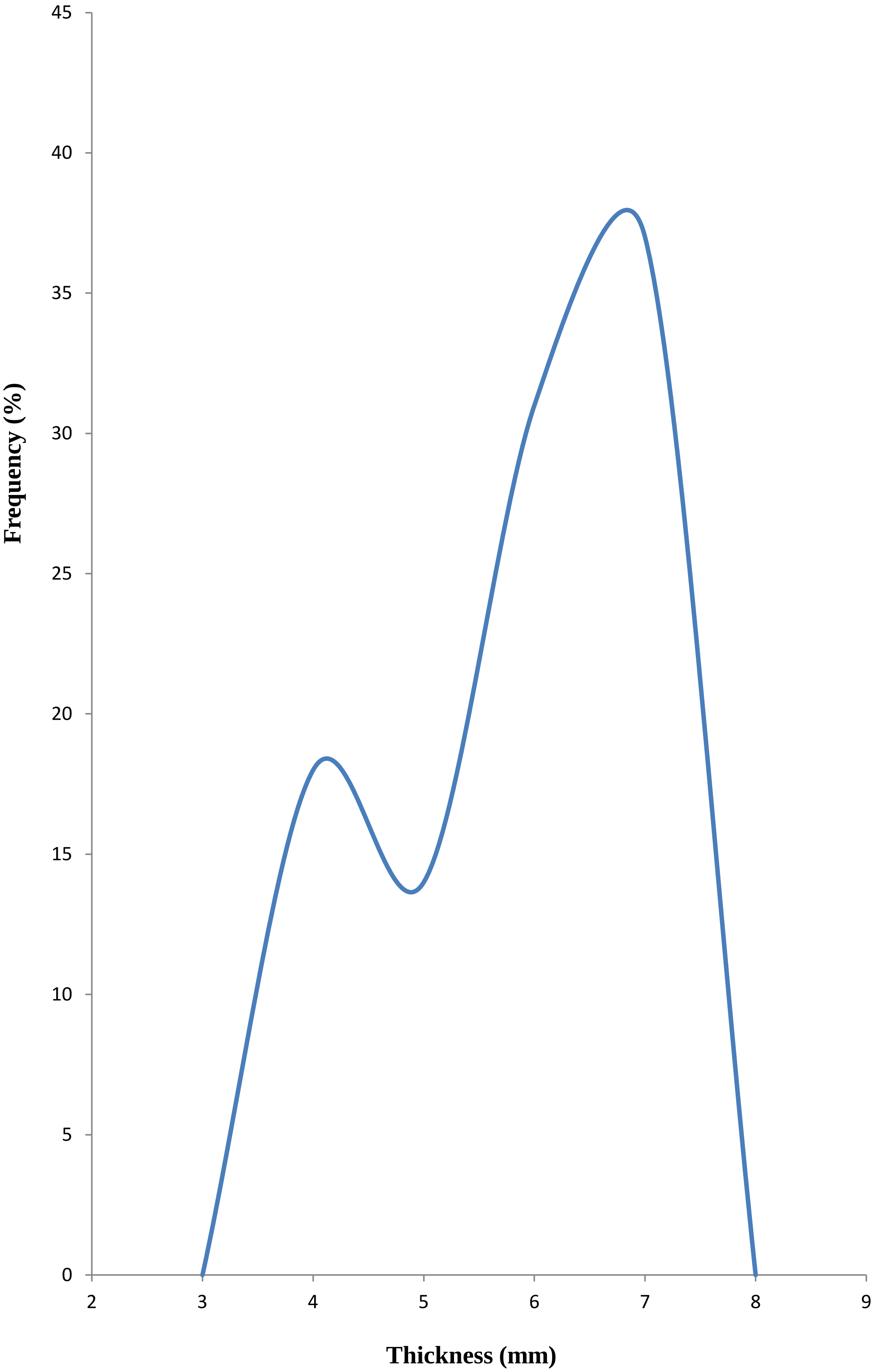

Figure 4.3. Frequency Distribution of the Thickness of Moringa Seeds

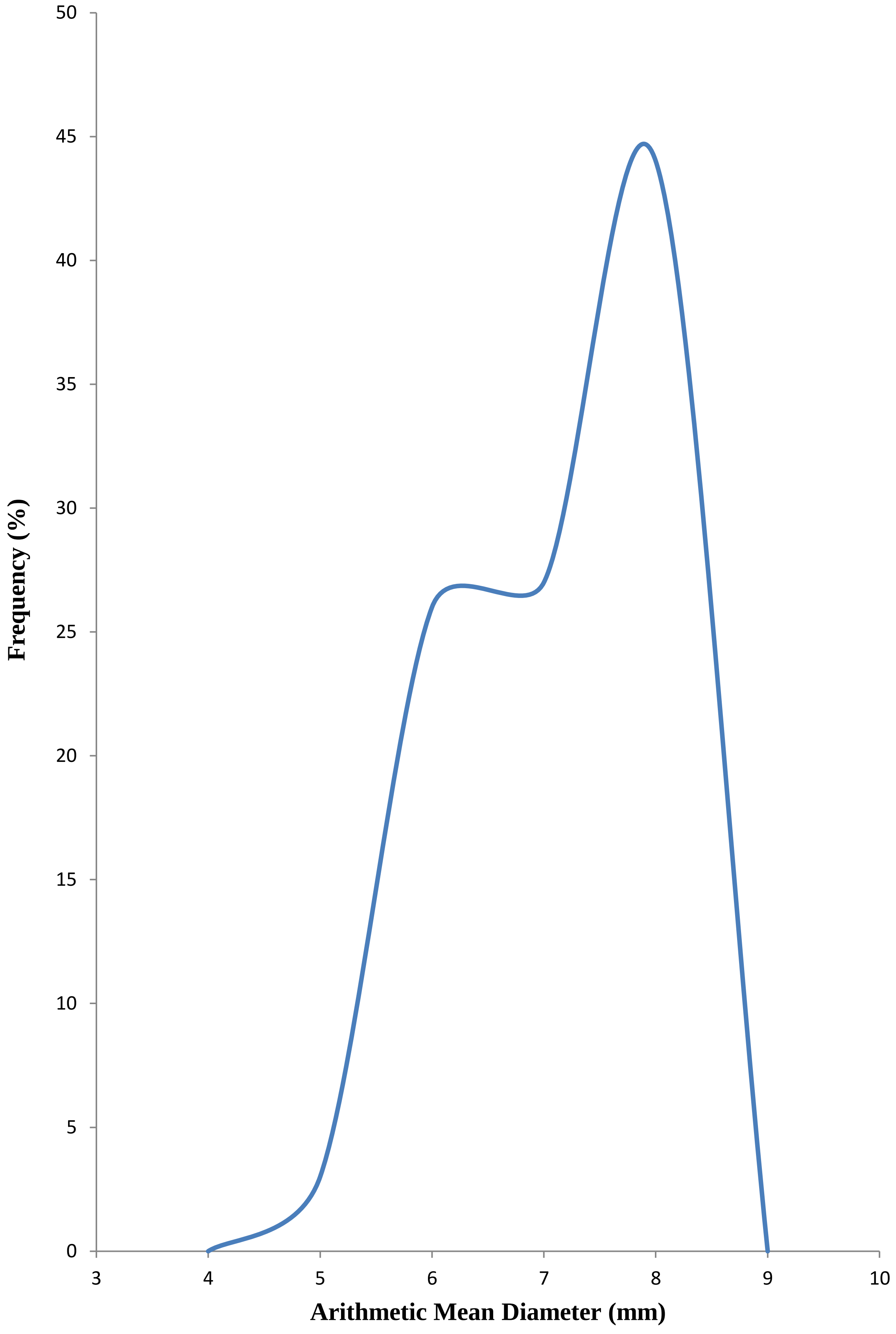

Figure 4.4. Frequency Distribution of the Arithmetic Mean Diameter of Moringa Seeds

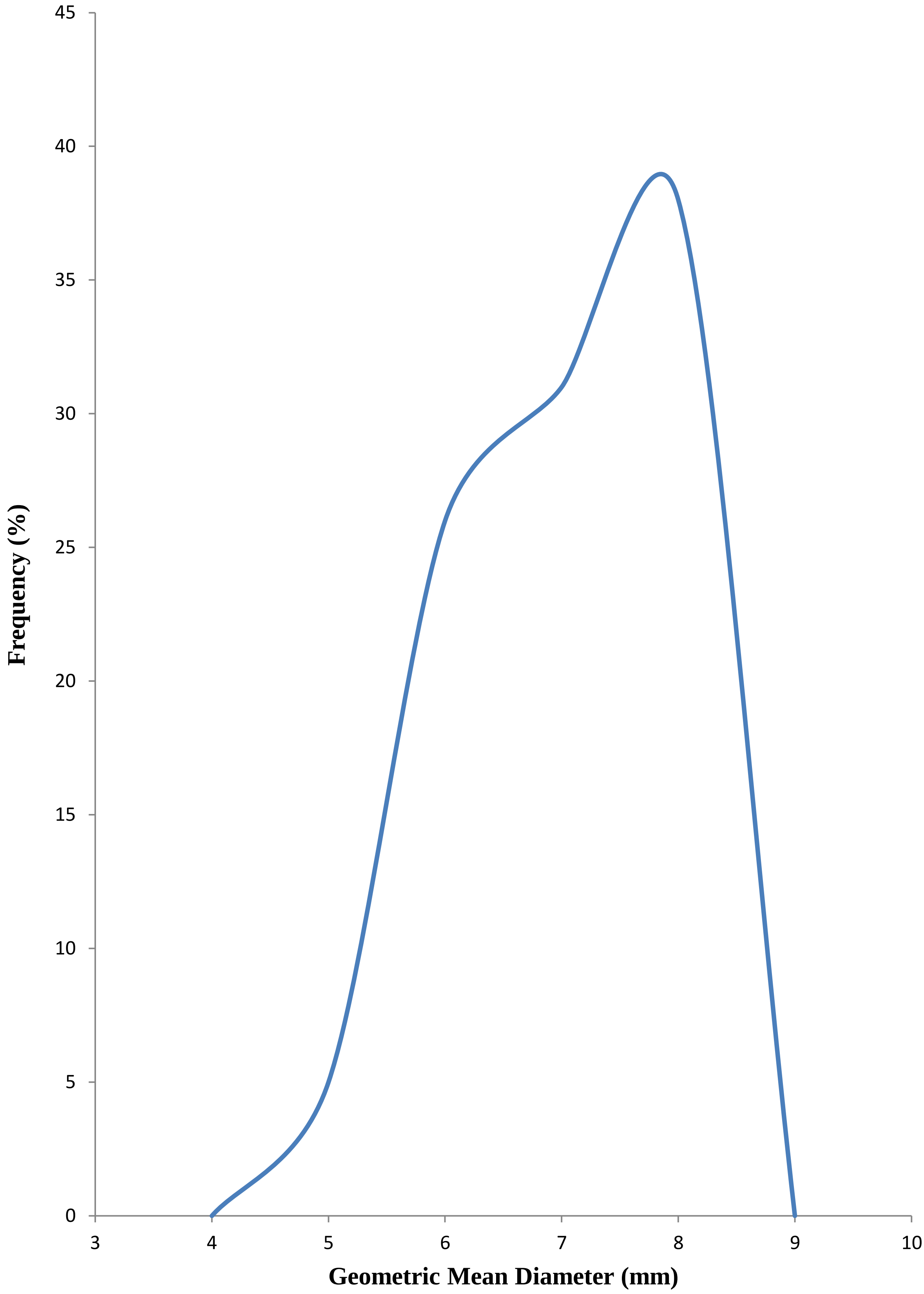

Figure 4.5. Frequency Distribution of the Geometric Mean Diameter of Moringa Seeds

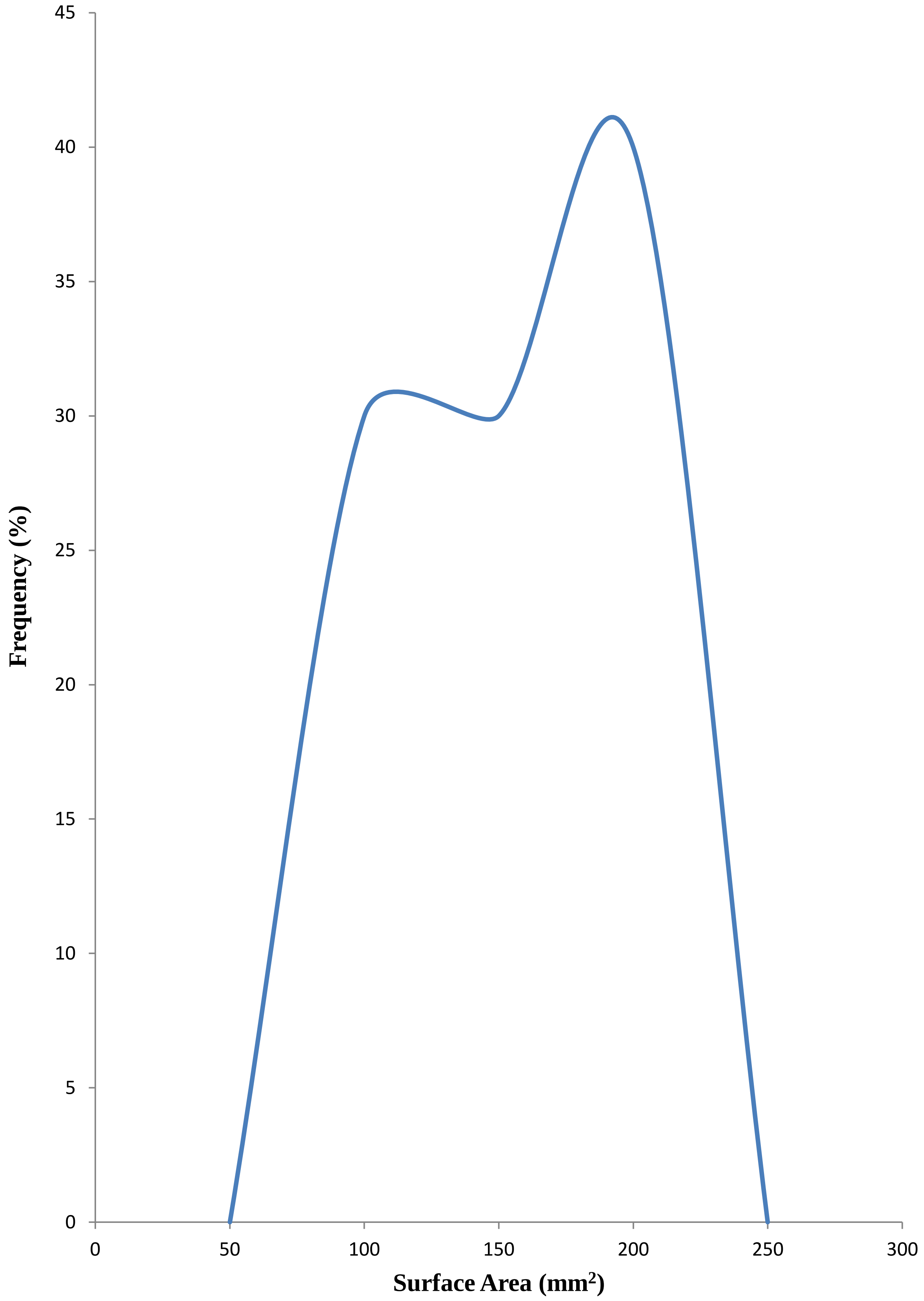

Figure 4.6. Frequency Distribution of the Surface Area of Moringa Seeds

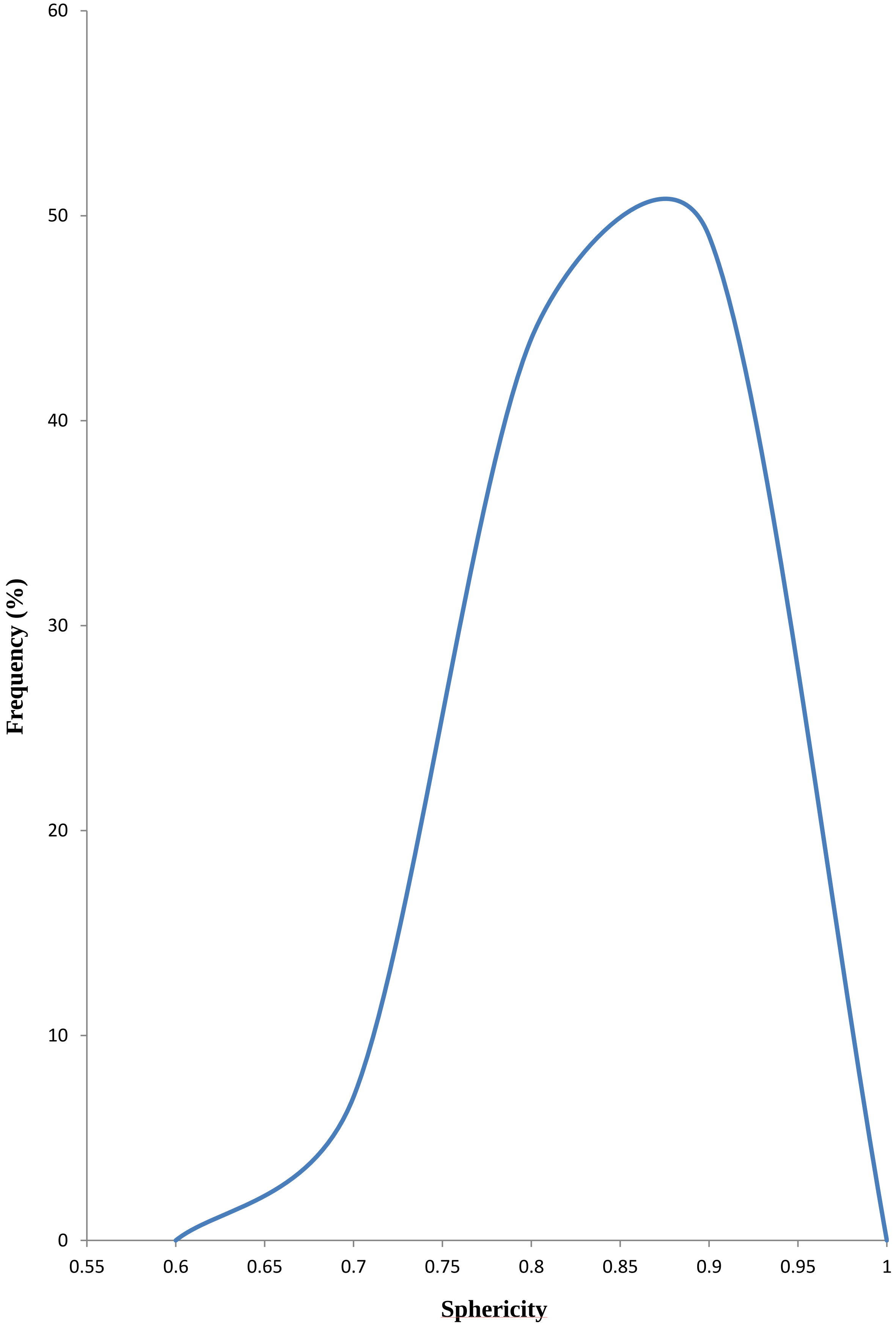

Figure 4.7. Frequency Distribution of the Sphericity of Moringa Seeds

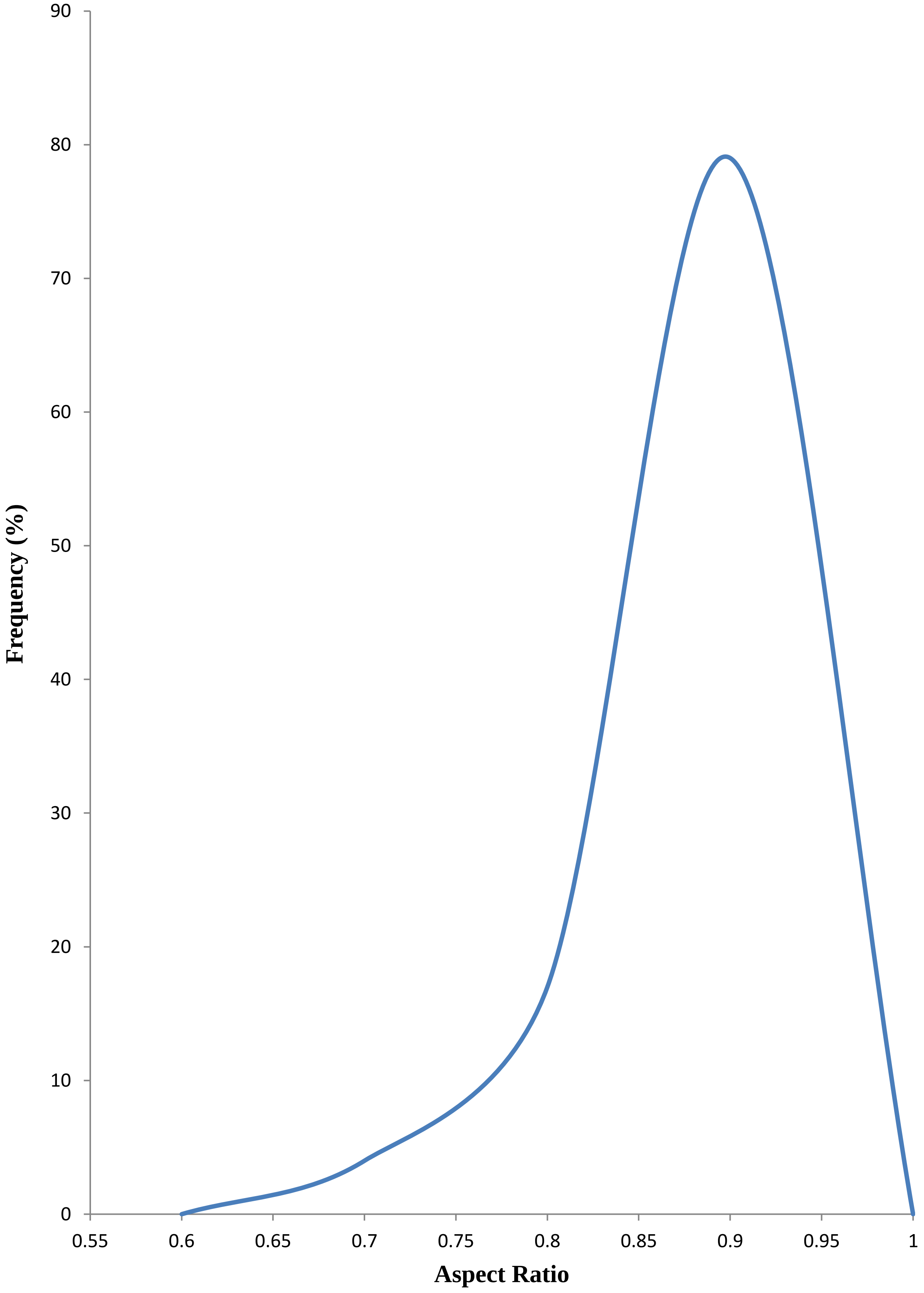

Figure 4.8. Frequency Distribution of the Aspect Ratio of Moringa Seeds

seeds (405-543 kgm^{-3}); sesame seeds (640 kgm^{-3}), groundnut kernels (479.28 kgm^{-3}), beniseeds (613-688 kgm^{-3}), fennel seeds (413.51-352.39 kgm^{-3}), sunflower seeds (380-410 kgm^{-3}), safflower seeds (520-547 kgm^{-3}), and jatropha seeds (428-474 kgm^{-3}) (Asoegwu, 2006; Shafiee *et al.*, 2009; Tavakoli *et al.*, 2009; Davies, 2009; Arafa, 2007; Davies, 2009; Olayanju, 2002; Ahmadi *et al.*, 2009; Seifi and Alimardani, 2010; Seifi *et al.*, 2010; and Bamgboye and Adebayo, 2012). The densities were utilized in the estimation of the capacity of the expeller in feed section.

The average one thousand seed weight was 239.20 g. Corresponding values reported for other oil bearing seeds showed that moringa seeds weigh more than soybean grains (171.50-219.04 g), sunflower seeds (80.3-96.8 g), safflower seeds (52.68-68.8 g) and melon seeds (94.0-110.0 g) (Tavakoli *et al.*, 2009; Seifi and Alimardani, 2010; Aktas *et al.*, 2006; and Davies, 2009). However, other oil bearing seeds which weigh more than moringa seeds include castor bean seeds (401.0-468.8 g) and jatropha seeds (515.4-692.6 g) (Shafiee *et al.*, 2009; and Bamgboye and Adebayo, 2012). One point worthy of note however is that the one thousand seed weight is a function of the individual mass (weight) of the seed/kernel/grain.

The average coefficients of friction on six different surfaces namely glass, stainless steel, mild steel, galvanized steel, rubber and plywood were 1.027, 1.111, 1.376, 1.234, 2.199 and 1.607 respectively. It was observed that the static coefficient of friction was highest on rubber and lowest on glass. This was in agreement with earlier reports on other oil bearing seeds by Shafiee *et al.* (2009) on castor bean seeds, Davies (2009) on groundnut kernels, Davies (2010) on melon, Olayanju (2002) on beniseeds, Tavakoli *et al.* (2009) on soybean grains and Karaj and Müller (2010) as well as Bamgboye and Adebayo (2012) on jatropha seeds. It was observed that the smoother the structural surface, the lower the coefficient of friction of the moringa seeds on the surface. The knowledge of the coefficient of friction was utilized during the calculations of the force required to translate and compress the moringa seeds and the frictional force resulting from the expeller screw’s motion.

The mean angle of repose was $21.44^{o} \pm 0.745$. Comparatively, it is in the range of sesame seeds, 20.16-28.67º ((Darvishi, 2012). Also, it is higher than the values reported for groundnut kernels, 17.0º (Olajide, 2000); and lower than those values reported for castor bean seeds (30.2-34.8º), fennel seeds (36.33-48.66º), melon seeds (29.7-36º), sheanut kernels (34.0º), soybean grains (24.56-29.93º), sunflower seeds (41-57º), safflower seeds (47-56º) and jatropha seeds (28-36º) (Shafiee *et al.*, 2009; Shafiee *et al.*, 2010; Davies, 2009; Olajide, 2000; Tavakoli *et al.*, 2009; Seifi and Alimardani, 2010; Seifi *et al.*, 2010; and Bamgboye and Adebayo, 2012). The lower angle of repose was due to the high sphericity value obtained for moringa seeds compared to the other oil bearing seeds, making them to flow more easily than most oil bearing crops. The angle of repose determined the angle at which chutes were positioned in order to achieve consistent flow of materials through the chute. To ensure free flow, an angle of repose which was modestly higher than the average angle of repose (21.44°±0.745) obtained for the moringa seeds was used.

4.2 Mechanical Properties of Moringa

The values of the mechanical properties of moringa seeds measured are illustrated in Tables B1 to B3 in Appendix B, while a summary of the results is shown in Table 4.4.

The force-deflection curves are shown in Figures 4.10 and 4.11, while Figures 4.12 and 4.13 show the force-strain curves for the samples tested. The force-deflection curves obtained in this investigation were similar to those obtained by previous researchers on different oil bearing crops viz: Ozumba and Obiakor (2011) on palm-kernel seed, Manuwa and Muhammad (2010) on shea kernel and Bamgboye and Adejumo (2011b) on roselle seeds. The average force to rupture the seed was obtained as 58.535 N varying from 49.9 N to 67.0 N, while the average rupture energy of the seed was 0.1344 N.m ranging from 0.1043 N.m to 0.1708 N.m. The average deformation was 5.099 mm varying from 4.85 mm to 5.354 mm. Maximum strain of 85% was recorded for the moringa seeds. The force was used in the calculation of the main forces acting on the screw thread of the expeller.

The bio-yield point in the force-deformation curves indicates the seed rupture point and this point was determined by a visual decrease in force as deformation increased. This point reflects the sensitivity of the moringa seeds to damage. The rupture point indicates failure over a significant volume of the material. Beyond the rupture point, the stress decreases rapidly with increasing deformation. The amount of energy required to bring about rupture in the seeds indicates its toughness. It is the area under the force-deformation curve before the rupture point. The Young's Modulus is the gradient of the initial straight line portion of the stress-strain curve and has been found to be 195.32±17.85 N/mm^2. The yield is the point at which the initial straight line portion of load/deformation curve dips (drops off). The mean value for the deformation at peak was found to be 5.0990±0.0974 mm and it represents the distance travelled at point of yield. The energy to peak is the workdone to the point of yield and was found to be 0.1344±0.0185 N.m. The force at break is the force at which maximum deformation was reached and was found to be 58.420±5.479 N. The deformation at break represents the maximum deformation and was found to be 5.1241±0.0779 mm. The energy to break is the energy at the point of maximum deflection and was obtained to be 0.1708± 0.0184 N.m.

In comparison with other oil bearing crops, Manuwa and Muhammad (2010) obtained maximum values of 588.55 N, 8.822 mm and 1.9999 N.m for small size shea kernel and

Table 4.4. Mechanical Properties of Moringa Seeds

Physical Properties	**No of observations**	**Unit of measurements**	**Minimum Value**	**Maximum Value**	**Mean Value**	**Standard Deviation**	**Coefficient of Variation**
Force at Peak	20	N	48.900	67.000	58.535	5.472	10.70
Deformation at Peak	20	mm	4.8500	5.3540	5.0990	0.0974	52.57
Stress at Peak	20	N/mm^2	42.500	55.800	49.26	4.403	11.19
Energy to Peak	20	N.m	0.1043	0.1708	0.1344	0.0185	7.26
Force at Break	20	N	48.900	67.000	58.420	5.479	10.66
Deformation at Break	20	mm	5.0530	5.3540	5.1241	0.0779	65.78
Stress at Break	20	N/mm^2	42.500	55.800	49.12	4.412	11.13
Energy to Break	20	N.m	0.1056	0.1708	0.1357	0.0184	7.38
Force at Yield	20	N	19.800	54.300	39.000	7.1700	5.44
Stress at Yield	20	N/mm^2	27.300	38.900	33.66	4.011	8.39
Energy to Yield	20	N.m	0.0277	0.1215	0.0584	0.0224	2.61
Young Modulus	20	N/mm^2	66.65	147.95	195.32	17.85	10.94

940.61 N, 10.086 mm and 2.8946 N.m for large size shea kernel; for the applied force, deformation and rupture energy of shea kernel respectively. Olayanju (2002) obtained values of 8.7 N and 18.6 N for the force required to rupture and express oil from Yandev-55 variety of beniseeds at rupture and oil points respectively, and 9.0 N and 20.8 N for the force required to rupture and express oil from E-8 variety of beniseeds at rupture and oil points respectively. The corresponding deformations ranged between 0.123-0.494 mm and 0.46-0.54 mm for rupture and oil point respectively. Karaj and Müller (2010) obtained maximum values of 0.96±0.25 mm, 1.11±0.30 mm and 0.92±0.26 mm for the deformation at rupture point in horizontal (x), transverse (y) and vertical (z) directions respectively for a fraction size greater than 0.69 for jatropha seeds. Bamgboye and Adejumo (2011b) while working on roselle seeds obtained 23.45-49.05 N, 23.38-35.48 Nmm^{-2} and 0.41-0.50 mm for the compressive force, rupture stress and deformation respectively. Also, 27.0-38.15 Nmm^{-2}, 33.3-52.56 N and 216.03-374.11 Nmm^{-2} were obtained for the yield stress, rupture force and Young's Modulus respectively. Gupta and Das (2000) found that the compressive force required to cause the rupture of sunflower kernel ranges from 26.86-33.94 N. The sunflower seeds loaded in a vertical orientation absorbed more energy (144.7-222.9 J/m^3) prior to rupture than those loaded in the horizontal (95.21-84.2 J/m^3) orientation; while the sunflower kernels loaded in a vertical orientation required less energy (18.1-54.3 J/m^3) to rupture than those loaded in the horizontal (38.9-65.8 J/m^3) orientation.

Figures 4.9 and 4.10 show typical examples of force-deflection and force-strain curves for moringa seeds under compressive loading.

4.3 Effects of Processing Conditions on Oil Yield of Moringa

The average summary of the oil yield results at the various processing conditions combinations using 4 factors, 5 levels, factorial Central Composite Rotatable Design (CCRD) of Response Surface Methodology is presented in Table 4.5 below:

For the range of variables considered in this study, the highest oil yield of 28.58% was obtained when moringa seeds were conditioned to a moisture content of 11% wet basis and heated at 80^{o}C for 30 mins at an applied pressure of 20 MPa. In comparison, Adejumo *et al.* (2013) obtained an optimum oil yield of 33.7% at a heating temperature of 100^{o}C and a heating time of 30 mins using soxhlet extraction method. Mohammed *et al.* (2003) obtained a yield of 31% using organic solvent for extraction. Anwar *et al.* (2006) obtained an oil yield of 30.36, 35.26 and 38.37% respectively from one drought (Layyah) and two irrigated regions (Rahim Yar Khan, Jhang) of Punjab, Pakistan using hexane as solvent for extraction. Anwar and Rashid

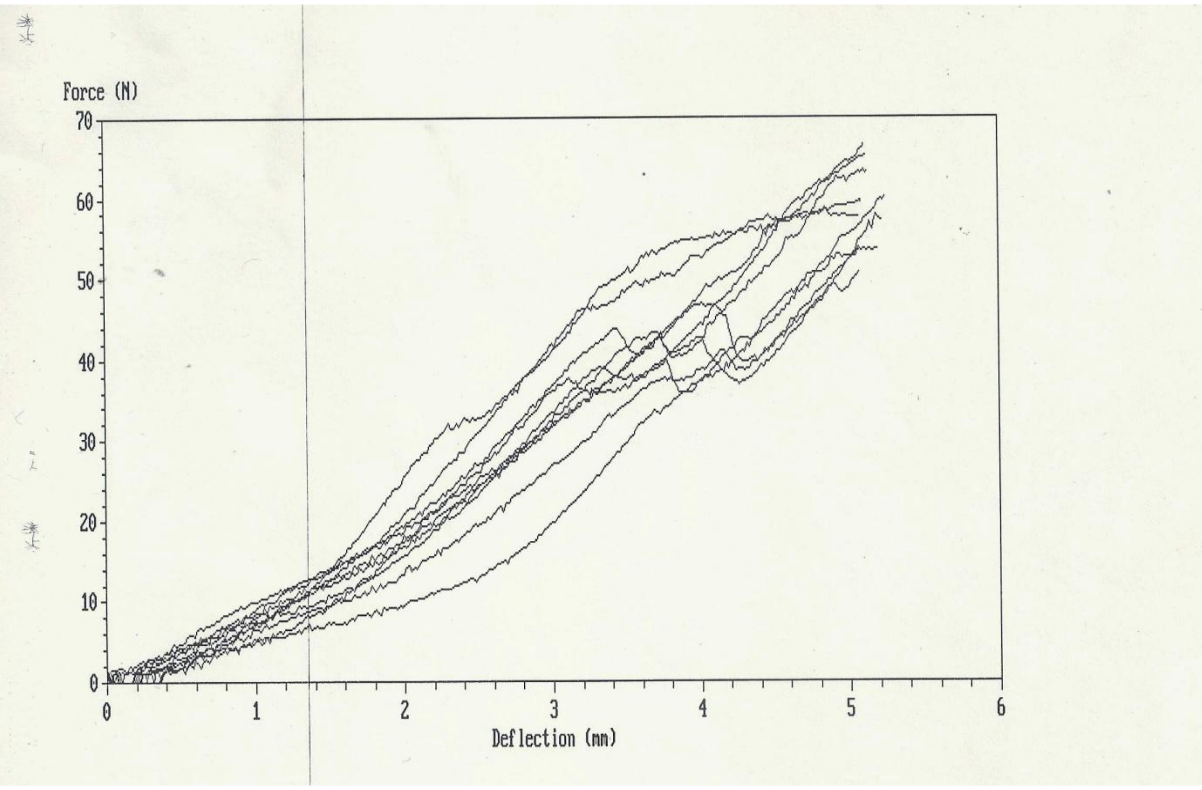

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Figure 4.9. Typical Example of Force-Deflection Curves for Moringa Seeds under Compressive Loading

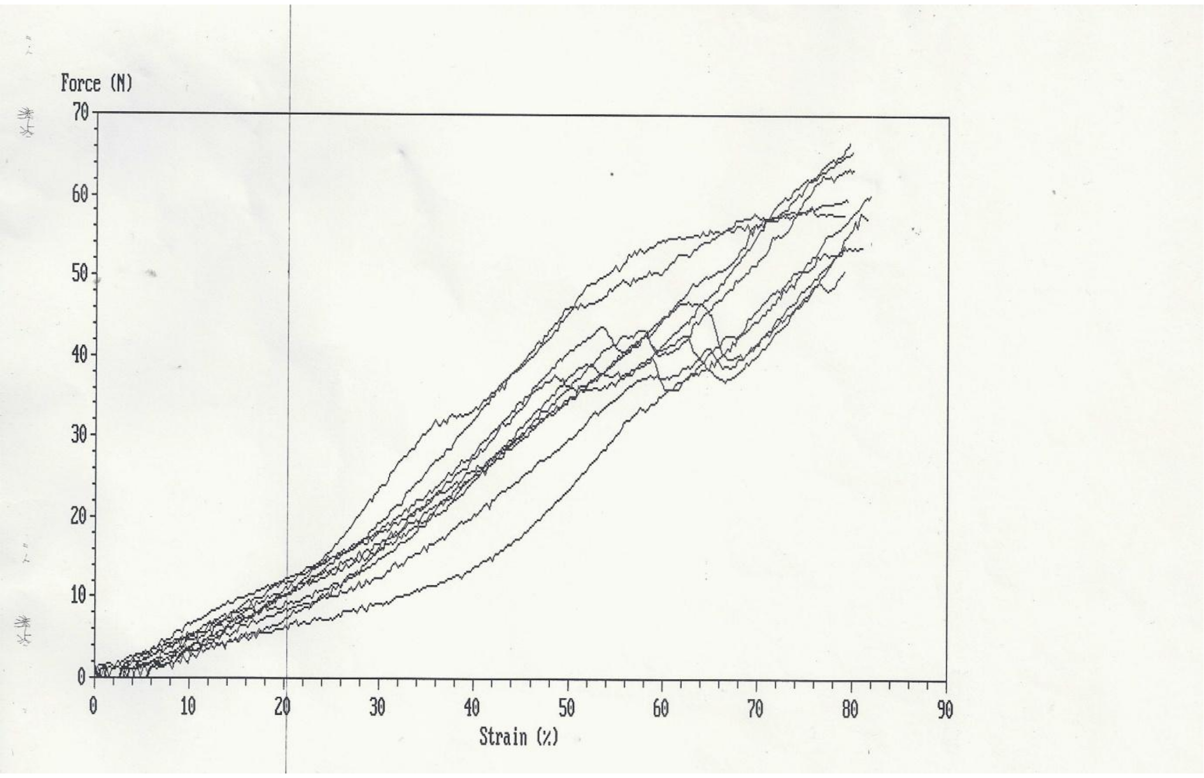

Figure 4.10. Typical Example of Force-Strain Curves for Moringa Seeds under Compressive Loading

Table 4.5. Oil Yield of Moringa at various Processing Conditions

S/No	MC (% wb)	HT (^{o}C)	Ht (mins)	AP (MPa)	Oil Yield (%)
1	10.00	70.00	25.00	15.00	24.34
2	11.00	60.00	20.00	20.00	23.26
3	11.00	80.00	30.00	10.00	26.16
4	9.00	80.00	30.00	10.00	18.88
5	10.00	70.00	35.00	15.00	18.23
6	10.00	70.00	25.00	15.00	24.09
7	11.00	80.00	20.00	10.00	25.33
8	12.00	70.00	25.00	15.00	17.27
9	11.00	80.00	20.00	20.00	27.79
10	9.00	60.00	20.00	20.00	16.32
11	10.00	70.00	25.00	25.00	23.66
12	11.00	60.00	30.00	20.00	24.55
13	9.00	80.00	30.00	20.00	20.68
14	9.00	60.00	30.00	20.00	17.20
15	8.00	70.00	25.00	15.00	13.68
16	11.00	60.00	20.00	10.00	19.36
17	10.00	70.00	25.00	15.00	24.08
18	10.00	70.00	25.00	5.00	11.42
19	11.00	80.00	30.00	20.00	28.58
20	10.00	70.00	15.00	15.00	14.23
21	10.00	70.00	25.00	15.00	24.20
22	10.00	70.00	25.00	15.00	24.24
23	11.00	60.00	30.00	10.00	20.20
24	9.00	60.00	20.00	10.00	14.91
25	10.00	70.00	25.00	15.00	24.30
26	10.00	50.00	25.00	15.00	17.46
27	9.00	80.00	20.00	20.00	17.00
28	10.00	90.00	25.00	15.00	20.34
29	9.00	80.00	20.00	10.00	16.10
30	9.00	60.00	30.00	10.00	14.46

MC = Moisture content of moringa seed

HT = Heating temperature of moringa seed

Ht = Heating time of moringa seed

AP = Applied pressure on moringa seed

(2007) found out that the moringa seeds harvested from the forests of Kohat district of North West Frontier Province exhibited an oil yield of 34.80%. Nzikou *et al.* (2009) reported an oil yield of 38.5% and 40% using two oil extraction methods viz extraction with petroleum ether (soxlhet) and extraction with a mixture of chloroform:methanol (1:1) (blye and dyer) respectively. Goja (2013) reported the hexane-extracted oil yield of moringa to be 34.5%. This suggested that method of extraction has significant effect on oil yield as observed by Orhevba (2006). Also, Anwar *et al.* (2006) observed that genetic and environmental factors can affect the oil yield and quality of a vegetable oilseed crop.

Increase in moisture content showed a substantial improvement in oil recovery up to 11% wet basis. However, further increase in moisture content up to 12% led to a decline in the oil yield. Sivala *et al.* (1992) explained that any oil bearing material subjected to compression is not completely saturated with oil at the beginning. The oil emanates from the interior of particles and within a short time, if drainage is not permitted, it saturates the system. If at this stage an opening is provided, oil drains from the system. Addition of moisture helps to reach saturation point early. Following initial compression when the entrapped air is pushed out, the liquid, if present in optimum quantity, transmits the applied pressure in all directions and more oil cells are formed, thereby releasing a greater quantity of oil. As compression progresses and the oil drains out from the system, the load is slowly transferred to the rigid structure of the solid cake. Even if some oil is entrapped in the cake matrix, it cannot be expelled because the particles form a solid skeleton and prevent the load from being transferred to the oil. When excess moisture is present, the liquid phase takes the entire load; itself being incompressible and does not exert any pressure on the oil bearing particles, thus showing a decrease in oil yield. At higher moisture level, mucilage is developed in the outer cell and the addition of more water causes swelling of the mucilage; and this produces a cushioning effect which prevents the rupturing of the oil cells. Therefore, the optimum moisture content for moringa was found to be 11% wet basis for which an increase in moisture content causes a decline in oil yield. This conformed to earlier reports by Farsaie and Singh (1983) on sunflower, Bongiriwar (1977) on groundnut, Blake (1982) on canola seed, Olajide (2000) on groundnut and sheanut, Bamgboye and Adejumo (2011a) on roselle and Abidakun *et al.* (2012) on dika nut amongst others.

Increase in temperature from 50-80^{o}C increased oil yield, but oil yield decreased with increase in heating temperature up to 90^{o}C. Increase in heat treatment leads to hardening of samples, thereby offering increased resistance to pressure application during expression, leading to decrease in oil yield of samples. Oil yield obtained from samples heated at 50^{o}C were considerably lower than those obtained from the other heating temperatures. This could be attributed to insufficient heat treatment given to samples during heating. Oil yield increased with increasing time for samples up to 30 mins after which further increase in time caused a decline in oil yield. Samples heated at 50°C needed more time to allow for the coagulation of protein, increasing fluidity of the oil, breakdown of oil-cells and adjustment of moisture content to the optimum level, while samples heated at 80°C needed a relatively shorter time to achieve all these and further heat treatment decreases the oil yield. Increase in heating time increased the oil yield up to 80°C, beyond which further increase in heating time decreased the yield. This was due to the heat coagulation of the proteins which leads to the reduction of the viscosity of the oil being expressed while moisture loss takes place simultaneously. At higher temperatures, protein coagulation and viscosity reduction take place at a faster rate leading to increased yield at short durations; while extending the heating duration at higher temperatures caused substantial moisture loss leading to hardening of samples which consequently leads to a decrease in oil yield. Oil flow was found to be inversely proportional to the kinematic viscosity which decreases with increase in heating temperature, thus increase in the ability of the oil to flow (Kagwacie and Anozie, 1995). The highest oil yield of 28.58% was obtained when sample was heated at 80°C for 30 mins. This agrees with the findings of Adekola (1991) on coconut, Adeeko and Ajibola (1990) on groundnut, Olajide (2000) on groundnut and sheanut, Tunde-Akintunde *et al.* (2001) on soybean, Ajav and Olatunde (2011) on groundnut, Bamgboye and Adejumo (2011a) on roselle and Abidakun *et al.* (2012) on dika nut amongst others. It was observed that moringa seeds do not require a very high temperature during expression process as compared to some other oil bearing seeds like groundnut, melon, soybean, sheanut, coconut, roselle, cashew, dika nut amongst others which were reported by other researchers. At high temperatures, oil recovery becomes extremely low due to hardening of samples.

There was a significant increase in oil yield when applied pressure was increased up to 20 MPa, but oil yield decreased when the pressure increased to 25 MPa. This was due to the sealing of some inter kernel voids at this higher pressure. According to Ward (1976), increasing the pressure applied on oilseeds during pressing tend to narrow, shear and may eventually seal the capillaries through which oil is expressed. This observation is in agreement with oil expression from other oilseeds as reported by various researchers viz Adeeko and Ajibola (1990) on groundnut, Sivala *et al.* (1992) on rice bran, Ajibola *et al.* (1990) on melon seeds, Reddy and Bohle (1993) on mustard seeds, Olajide (2000) on groundnut and sheanut, Abidakun *et al.* (2012) on dika nut, Bamgboye and Adejumo (2011a) on roselle amongst others.

The interactions between the process variables namely moisture content, heating temperature, heating time and applied pressure on the yield of moringa oil during expression process are shown in Figures 4.11-4.16.

4.3.1 Moisture Content

Increase in moisture content from 9-11% wb at a heating temperature of 60^{o}C, heating time of 30 mins and applied pressure of 20 MPa increases oil yield by 30%; while increase in moisture content from 9-11% wb at a heating temperature of 60^{o}C, heating time of 20 mins and applied pressure of 10 MPa increases oil yield by 23%. Also, increase in moisture content from 9-11% wb at a heating temperature of 80^{o}C, heating time of 20 mins and applied pressure of 10 MPa increases oil yield by 36.4%, while increase in moisture content from 9-11% wb at a heating temperature of 80^{o}C, heating time of 30 mins and applied pressure of 10 MPa increases oil yield by 28%. Similarly, increase in moisture content from 9-11% wb at a heating temperature of 80^{o}C, heating time of 30mins and applied pressure of 20 MPa increases oil yield by 27.6%. Finally, oil yield increases from a moisture content of 8-10% wb at a heating temperature of 70^{o}C, heating time of 25 mins and applied pressure of 15 MPa by 30%, while it decreases by 29% by increasing the moisture content from 10-12% wb. This shows that the optimum moisture content for oil expression from moringa is 11%, above which there is a decline in the oil yield of moringa oil.

4.3.2 Heating Temperature

Increase in heating temperature from 60-80^{o}C at a moisture content of 9% wb, heating time of 20 mins and applied pressure of 10 MPa increases oil yield by 7.4%; while increase in heating temperature from 60-80^{o}C at a moisture content of 9% wb, heating time of 20 mins and applied pressure of 20 MPa increases oil yield by 4%. Similarly, increase in heating temperature from 60-80^{o}C at a moisture content of 9% wb, heating time of 30 mins and applied pressure of 20 MPa increases oil yield by 16.8%. Also, increase in heating temperature from 60-80^{o}C at a moisture content of 11% wb, heating time of 20 mins and applied pressure of 20 MPa increases oil yield by 16.3%; while increase in heating temperature from 60-80^{o}C at a moisture content of 11% wb, heating time of 30 mins and applied pressure of 20 MPa increases oil yield by 14%. Finally, oil yied increases from a heating temperature of 50-70^{o}C at a moisture content of 10% wb, heating time of 25 mins and applied pressure of 15 MPa by 28.3%, while it decreases by 16.4% by increasing the heating temperature from 70-90^{o}C. This shows that the optimum heating temperature for oil expression from moringa is 80^{o}C, above which there is a decline in the oil yield of moringa oil.

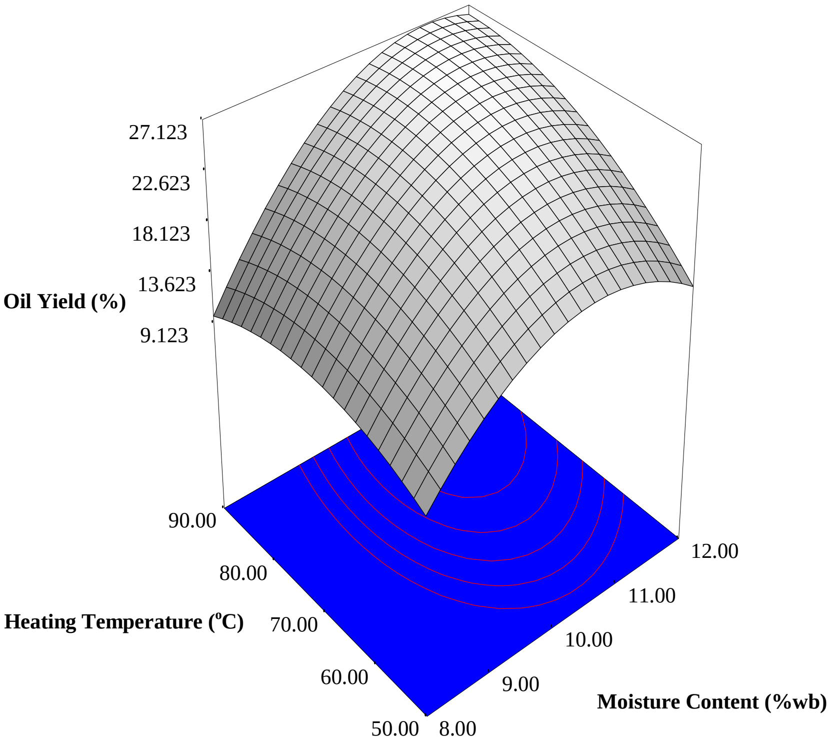

Figure 4.11. Effect of Moisture Content and Heating Temperature on Oil Yield

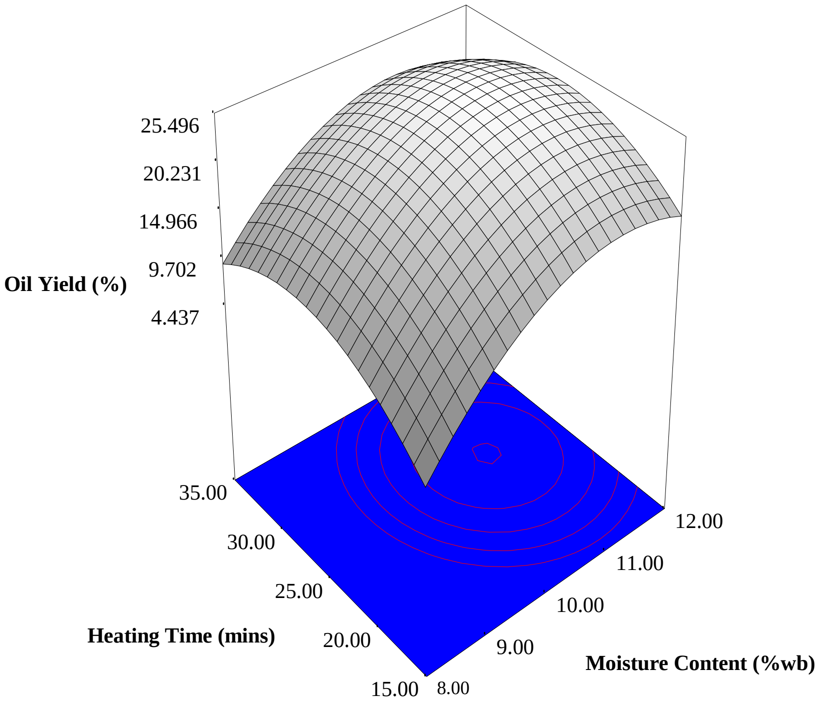

Figure 4.12. Effect of Moisture Content and Heating Time on Oil Yield

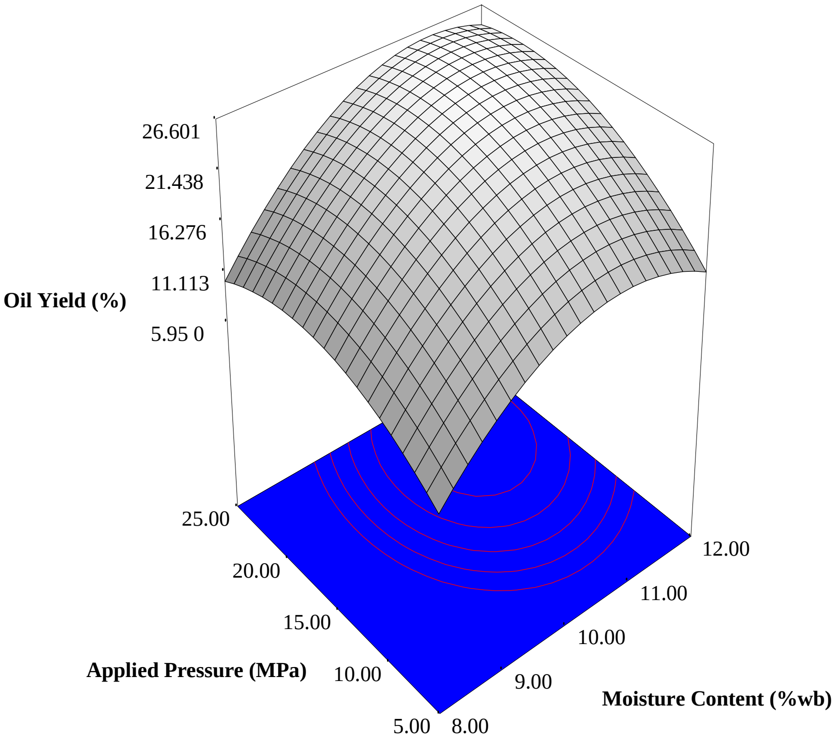

Figure 4.13. Effect of Moisture Content and Applied Pressure on Oil Yield

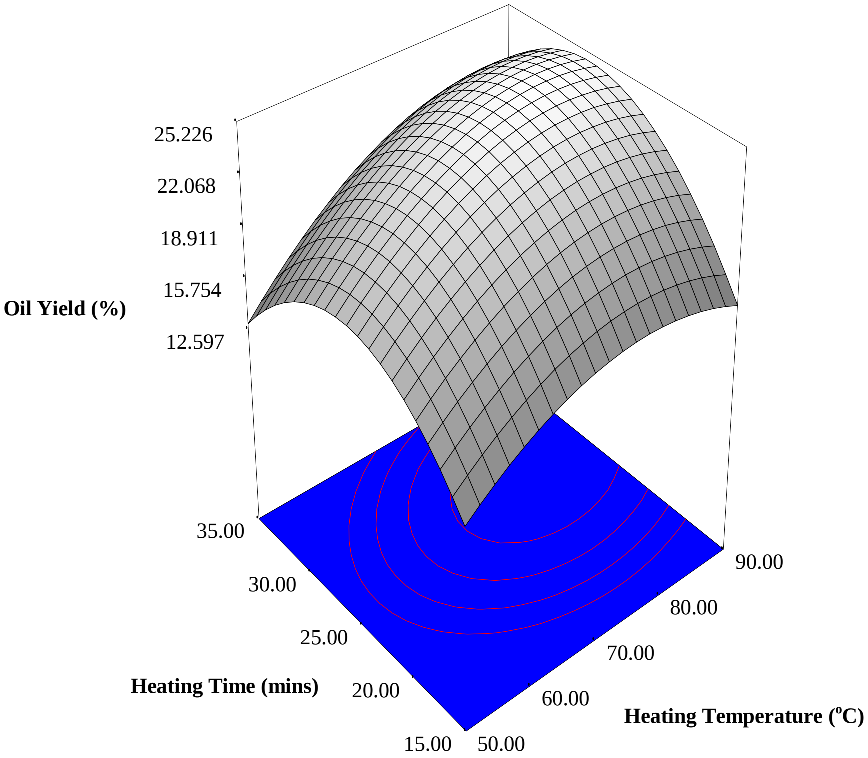

Figure 4.14. Effect of Heating Temperature and Heating Time on Oil Yield

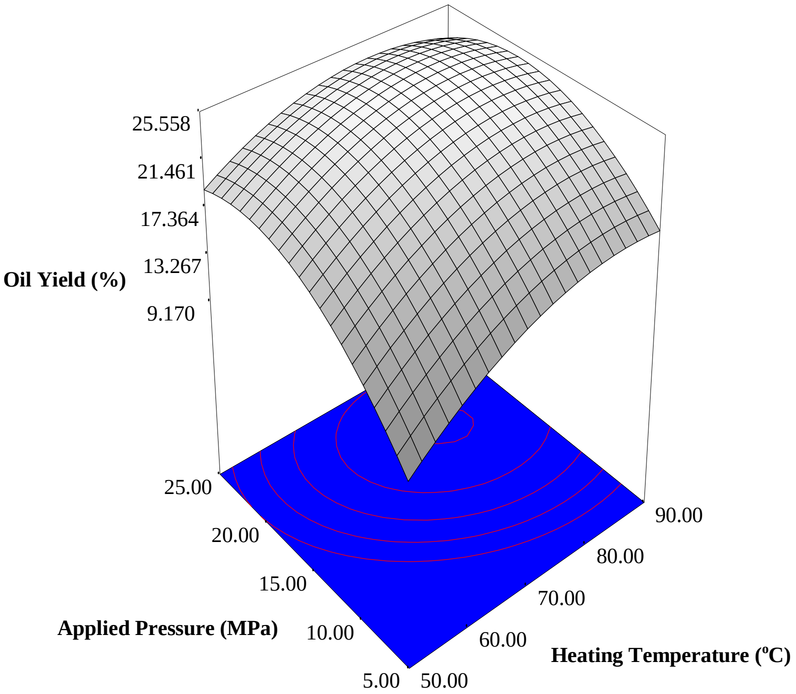

Figure 4.15. Effect of Heating Temperature and Applied Pressure on Oil Yield

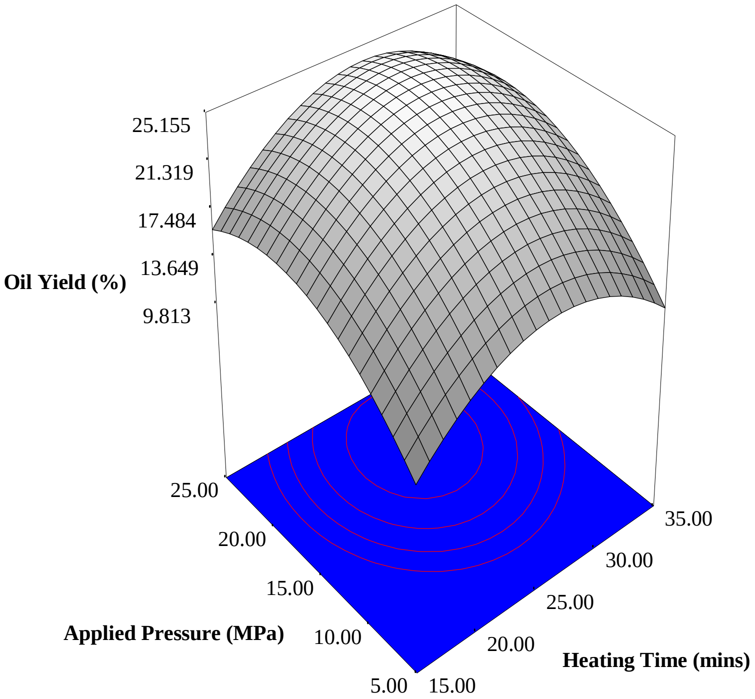

Figure 4.16. Effect of Heating Time and Applied Pressure on Oil Yield

4.3.3 Heating Time

Increase in heating time from 20-30 mins at a moisture content of 9% wb, heating temperature of 60^oC and applied pressure of 20 MPa increases oil yield by 5%; while increase in heating time from 20-30 mins at a moisture content of 9% wb, heating temperature of 80^oC and applied pressure of 20 MPa increases oil yield by 17.8%. Also, increase in heating time from 20-30 mins at a moisture content of 11% wb, heating temperature of 60^oC and applied pressure of 10 MPa increases oil yield by 4.2%; while increase in heating time from 20-30 mins at a moisture content of 11% wb, heating temperature of 60^oC and applied pressure of 20 MPa increases oil yield by 5.3%. Similarly, increase in heating time from 20-30 mins at a moisture content of 11% wb, heating temperature of 80^oC and applied pressure of 10 MPa increases oil yield by 3.2%. Finally, oil yied increases from a heating time of 15-25 mins at a moisture content of 10% wb, heating temperature of 70^oC and applied pressure of 15 MPa by as high as 41.5%, while it decreases by 25% by increasing the heating time from 25-35 mins. This shows that the optimum heating time for oil expression from moringa is 30 mins, above which there is a decline in the oil yield of moringa oil.

4.3.4 Applied Pressure

Increase in applied pressure from 10-20 MPa at a moisture content of 9% wb, heating temperature of 60^oC and heating time of 20 mins increases oil yield by 8.6%; while increase in applied pressure from 10-20 MPa at a moisture content of 9% wb, heating temperature of 80^oC and heating time of 20 mins increases oil yield by 5.3%. Similarly, increase in applied pressure from 10-20 MPa at a moisture content of 9% wb, heating temperature of 80^oC and heating time of 30 mins increases oil yield by 8.7%. Also, increase in applied pressure from 10-20 MPa at a moisture content of 11% wb, heating temperature of 60^oC and heating time of 30 mins increases oil yield by 17.7%; while increase in applied pressure from 10-20 MPa at a moisture content of 11% wb, heating temperature of 60^oC and heating time of 20 mins increases oil yield by 8.9%. Finally, oil yied increases from an applied pressure of 5-15 MPa at a moisture content of 10% wb, heating temperature of 70^oC and heating time of 25 mins by as high as 53%, while it decreases by 2.8% by increasing the applied pressure from 15-25 MPa. This shows that the optimum applied pressure for oil expression from moringa is 20 MPa, above which there is a decline in the oil yield of moringa oil.

4.4 Optimization of the Expression Process of Moringa Seeds using Yield as Response

Four different models namely linear, two factorial interaction (2FI), quadratic and cubic were used to analyze the expression process for moringa seeds and the models were fitted to the experimental data using Design Expert software. The appropriate model was chosen based on the selection of the highest order polynomial where the additional terms are significant and the model is not aliased, insignificant lack-of-fit and the maximization of the "Adjusted R-Squared" and the "Predicted R-Squared". Considering these, the linear and quadratic models were suggested. In terms of higher coefficient of determination (R^2) and lower standard deviation values, the quadratic model was finally chosen ahead of the linear model to predict the oil expression process for moringa seeds. The final equation is given below:

$$Y = -203.79542 + 29.44125M_c + 0.40712H_T + 2.74250H_t + 1.11525A_p - 1.57708\,M_c^2 - 0.007208H_T^2 - 0.055533H_t^2 - 0.042433A_p^2 + 0.067000M_cH_T - 0.039250M_cH_t + 0.078500M_cA_p + 0.006900H_TH_t - 0.006025H_TA_p + 0.006600H_tA_p \qquad \ldots (89)$$

(Std. Dev. = 3.08, R-Squared = 0.7691, Mean = 20.41, Adj R-Squared = 0.5536, C.V. = 15.07, Pred R-Squared = -0.3294, PRESS = 817.61, Adeq Precision = 6.952).

Where,

Y = Oil yield, %

M_c = Moisture content, %wb

H_T = Heating temperature, ^oC

H_t = Heating time, mins

A_p = Applied pressure, MPa

The positive terms in the equation represent a direct relationship between processing conditions and interactions with yield, while the negative terms represent an inverse relationship between them. It was observed that moisture content, heating temperature, heating time and applied pressure all have a direct relationship with oil yield. Increase in moisture content, heating temperature, heating time and applied pressure leads to increase in oil yield. Also, it was found that moisture content is the most important factor affecting oil yield from moringa seeds. This conforms with the findings of Khan and Hanna (1984) on soybean, Sivakumarran (1985) on peanut, Olajide (2000) on groundnut and sheanut and Akinoso (2006) on sesame seeds.

The Model F-value of 3.57 implies that the model is significant. Values of "Prob > F" less than 0.0500 indicate model terms are significant. In this case A, B, D, A^2, C^2 are significant model terms (Appendix G). This implies that the moisture content, heating temperature, heating time and applied pressure all have significant effects on oil yield with the moisture content having the greatest influence on oil yield. Therefore, the four procesing conditions influenced the quantity of oil recovery from moringa seeds using expeller. Values of "Prob > F" greater than 0.1000 indicate the model terms are not significant. The "Lack of Fit F-value" of 1238.86 implies the lack of fit is significant. It was found that the model was significant with a very low probability value (< 0.0001) and a satisfactory coefficient of determination (R^2 = 0.7691). The high coefficient of determination showed excellent correlations between the independent variables. This value indicates that the response model can explain 76.91% of the total variability in the responses.

The statistical analysis of the oil yield showed that all the factors were significant except the interaction among the heating temperature, heating time and applied pressure. This shows that all the processing variables have significant effects on the yield of moringa oil during expression process. It has a mean of 19.651, standard error of 0.021 and lower and upper bounds of 19.597 and 19.705 respectively. The results of the statistical analysis are presented in Appendix H.

4.5 Validation of Model

An excellent agreement between the observed and predicted values for oil yield from moringa was obtained from the parity plot between the predicted and the actual values as shown in Figure 4.17. There is a high correlation (R^2 = 0.7691) between the predicted and experimental values for moringa oil yield which indicated that the predicted values and experimental values are in reasonable agreement. It means that the data fitted well with the model and gave a convincingly good estimate of response for the expression process in the range studied. In the range of 8-12% wet basis for moisture content, 50-90^{o}C for heating temperature, 15-35 mins for heating time and 5-25 MPa for applied pressure, predicted optimum oil yield of 28.2% at moisture content of 11.30%, temperature of 85.57^{o}C, duration of 27.17 mins and pressure of 19.63 MPa was obtained. Under these optimal conditions, the experimental value was 28.22% which was in agreement with those predicted by computation. Deviations between experimental and predicted values were low and ranged from 0.01-6.20. This shows that the model chosen predicted the oil yield adequately.

4.6 Effects of Processing Conditions on the Physico-chemical Properties of Moringa Oil

The results of the Free Fatty Acid (FFA), colour and oil impurities of moringa oil at various processing conditions are presented in Table 4.6.

4.6.1 Free Fatty Acid

The free fatty acid value measures the extent to which the glycerides in the oil have been decomposed by lipase action. This decomposition is accelerated by light and heat, hence, rancidity is usually accompanied by free fatty acid formation. The FFA of the expressed moringa oil ranged between 2.42-7.40 mg/KOH/g for all the processing conditions. It was observed that

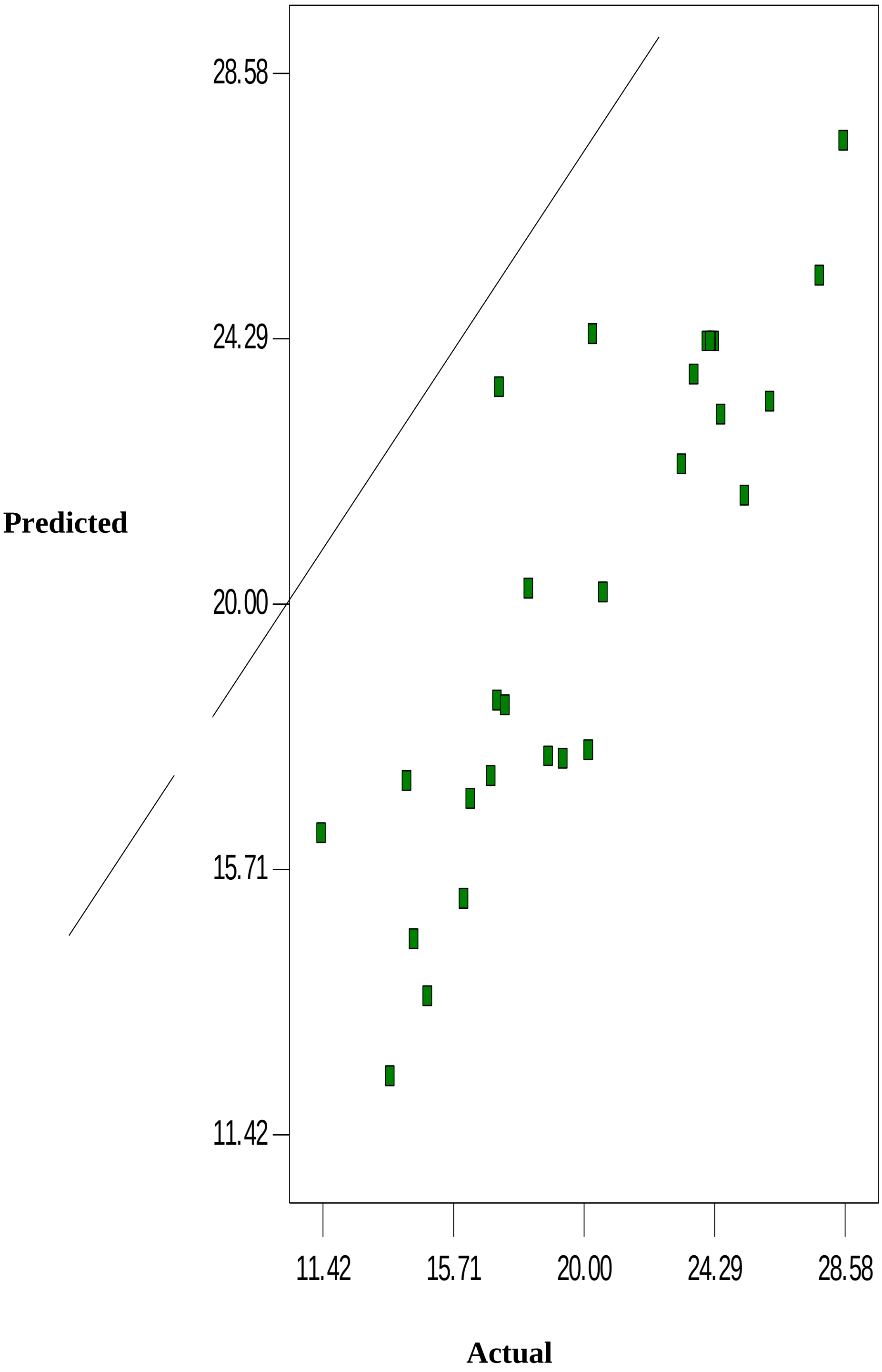

Figure 4.17. Predicted and Actual values for Moringa Oil Yield

Table 4.6. Physico-chemical Properties of Moringa Oil

S/No	MC	HT	Ht	AP	FFA	CL	OI
1	10.00	70.00	25.00	15.00	5.61	6.6	2.74
2	11.00	60.00	20.00	20.00	7.16	6.1	3.07
3	11.00	80.00	30.00	10.00	2.93	7.3	2.32
4	9.00	80.00	30.00	10.00	2.76	7.2	2.26
5	10.00	70.00	35.00	15.00	4.16	6.8	2.61
6	10.00	70.00	25.00	15.00	5.67	6.6	2.72
7	11.00	80.00	20.00	10.00	3.88	7.0	2.57
8	12.00	70.00	25.00	15.00	6.07	6.7	2.81
9	11.00	80.00	20.00	20.00	3.65	7.0	2.52
10	9.00	60.00	20.00	20.00	7.03	5.9	2.94
11	10.00	70.00	25.00	25.00	4.83	6.6	2.66
12	11.00	60.00	30.00	20.00	6.93	6.2	2.89
13	9.00	80.00	30.00	20.00	2.64	7.2	2.21
14	9.00	60.00	30.00	20.00	6.74	6.1	2.85
15	8.00	70.00	25.00	15.00	4.66	6.4	2.64
16	11.00	60.00	20.00	10.00	7.21	6.0	3.11
17	10.00	70.00	25.00	15.00	5.55	6.6	2.71
18	10.00	70.00	25.00	5.00	5.98	6.5	2.76
19	11.00	80.00	30.00	20.00	2.82	7.4	2.30
20	10.00	70.00	15.00	15.00	6.41	6.3	2.83
21	10.00	70.00	25.00	15.00	5.45	6.5	2.75
22	10.00	70.00	25.00	15.00	5.36	6.6	2.72
23	11.00	60.00	30.00	10.00	7.05	6.2	2.91
24	9.00	60.00	20.00	10.00	7.06	5.9	2.98
25	10.00	70.00	25.00	15.00	5.27	6.5	2.74
26	10.00	50.00	25.00	15.00	7.40	5.7	3.20
27	9.00	80.00	20.00	20.00	3.34	6.9	2.44
28	10.00	90.00	25.00	15.00	2.42	7.6	2.12
29	9.00	80.00	20.00	10.00	3.45	6.9	2.46
30	9.00	60.00	30.00	10.00	6.84	6.1	2.86

FFA = Free Fatty Acid, mg/KOH/g

CL = Colour, LUY

OI = Oil Impurity, %

the FFA increased with increase in moisture content. This as explained by Akinhanmi and Akintokun (2008) and Suganya *et al.* (2000) was due to the fact that during extraction of oil from oilseeds, water inside the seed bed flows out along with the oil and reacts with triglycerides to form free fatty acids and glycerols. Conversely, the FFA decreases with other processing conditions. This conforms to earlier reports by Olayanju (2002), Akinoso (2006) and Adejumo *et al.* (2013). Orhevba (2013) obtained values of 8.27±0.19 mg/KOH/g at a heating temperature of 60^oC for 5 hrs after which the moringa sample was removed and transferred into the air oven to dry at 105^oC for 15 minutes using solvent (hexane) extraction. Adejumo *et al.* (2013) obtained values of 2.74, 2.71 and 2.70 mgKOH/g for moringa samples heated at 100, 130, 150^oC respectively for 30 mins using soxhlet extraction; and 5.80 mgKOH/g for unheated sample. Ojiako and Okeke (2013) obtained a value of 2.51 mg/KOH/g for moringa seeds using soxhlet extraction. These showed that FFA of moringa decreases with increase temperature. Increase in temperature inactivates lipolytic enzymes which could cause rapid degradation of oil, hence, leading to a low FFA. The interactions between the process variables namely moisture content, heating temperature, heating time and applied pressure on the FFA of moringa oil during expression process are shown in Figures 4.18-4.23.

4.6.2 Colour

One of the key determinants of quality is the colour of the moringa oil. Colour is an indirect measure of product quality or processing performance. Though appearance properties have only aesthetic value with little influence on performance, it is the most obvious product characteristic evaluated by any consumer of vegetable oil. Dark coloured oils require special refining, thereby increasing the cost of production. The colour of the moringa oil was found to be pale yellow at all the processing conditions. Weiss (1983) stated that high quality oils must be pale or colourless and therefore, dark coloured oils are undesirable. This is because they will need to be specially refined and this invariably will increase the cost of production. This conforms to earlier reports by Mohammed *et al.* (2003) and Anwar and Rashid (2007) who observed a pale yellow colour for moringa oil. Akinoso (2006) reported that in practice, most consumers are attracted to a colour range of between 5.4-7.7 LU. The colour intensity of the expressed moringa oil ranged between 5.7-7.6 LU for all the processing conditions. Even though the colour at all processing conditions are within tolerable range, it was observed that colour intensity increased with increase in all the process variables. This conforms to earlier findings of

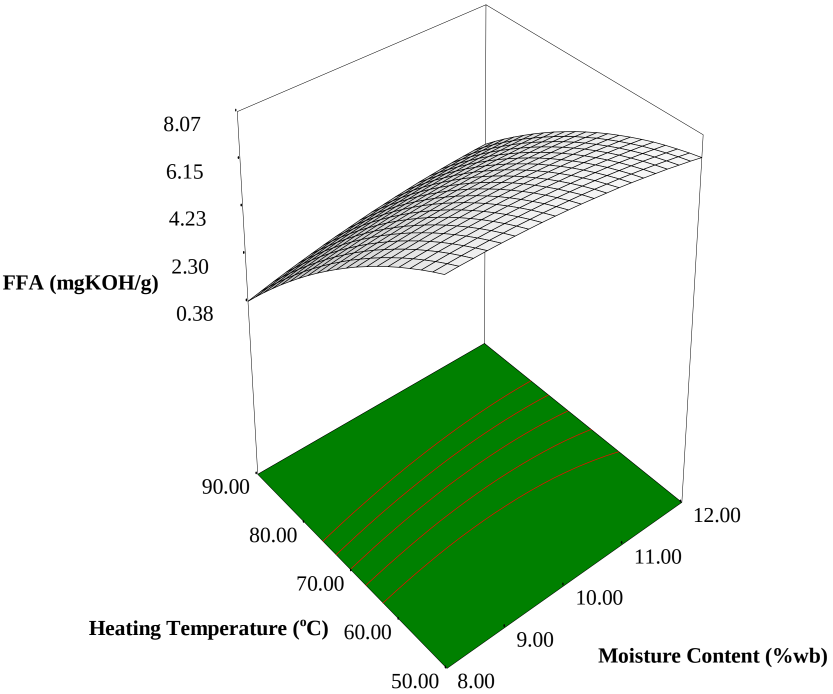

Figure 4.18. Effect of Moisture Content and Heating Temperature on Oil FFA

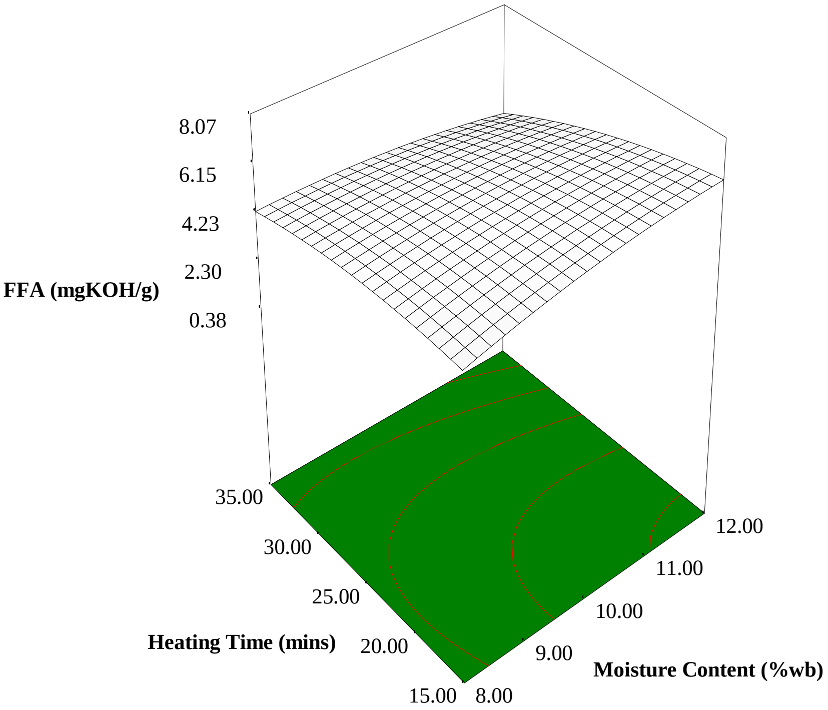

Figure 4.19. Effect of Moisture Content and Heating Time on Oil FFA.

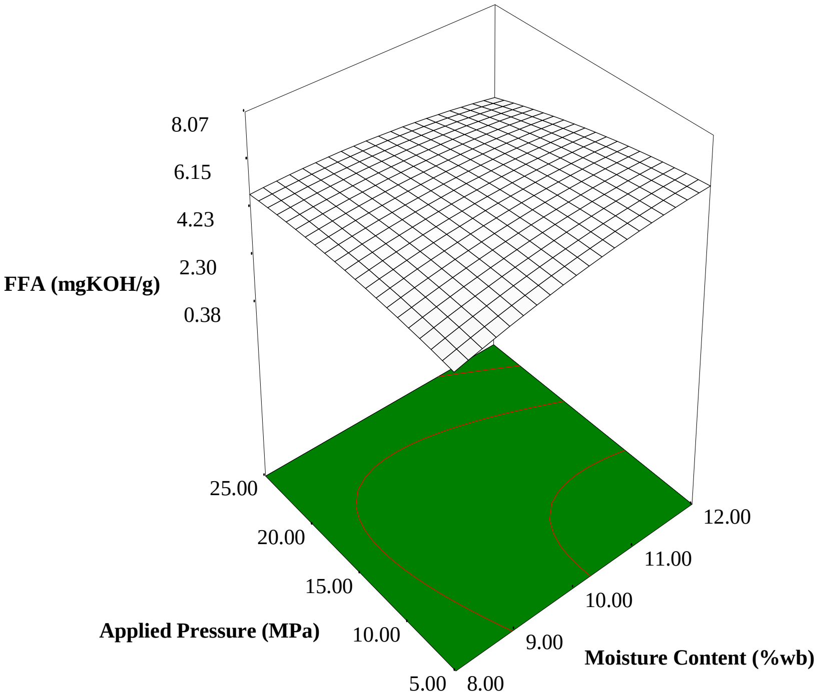

Figure 4.20. Effect of Moisture Content and Applied Pressure on Oil FFA

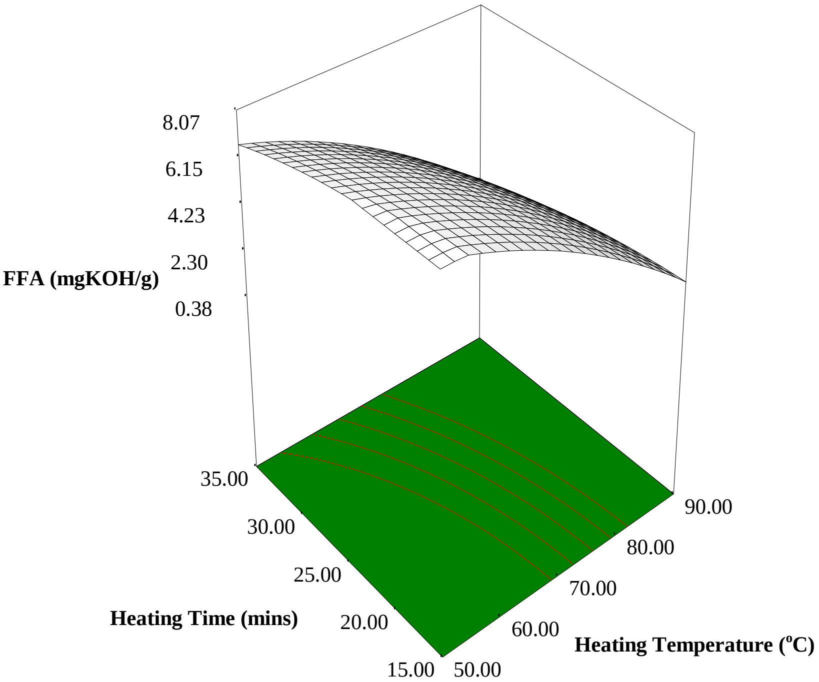

Figure 4.21. Effect of Heating Temperature and Heating Time on Oil FFA

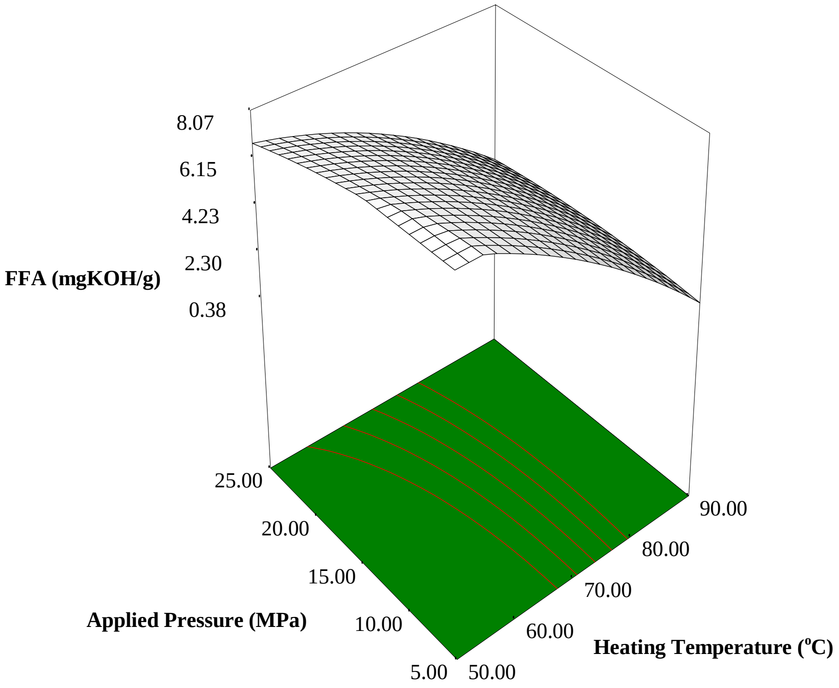

Figure 4.22. Effect of Heating Temperature and Applied Pressure on Oil FFA

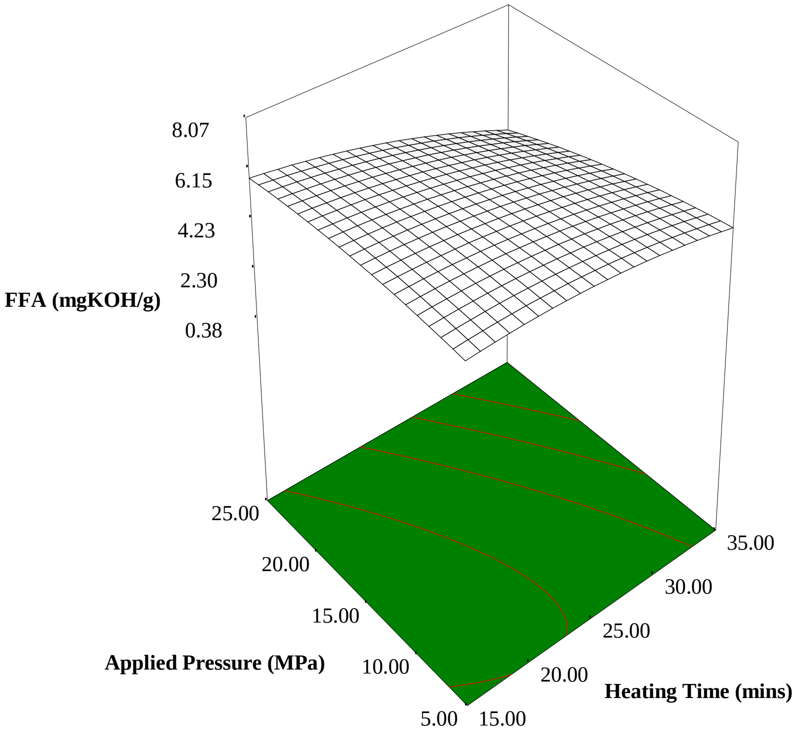

Figure 4.23. Effect of Heating Time and Applied Pressure on Oil FFA

other researchers on oil bearing seeds. Akinoso *et al.* (2006) also observed that colour intensity of sesame oil increased with increase moisture content. Adeeko and Ajibola (1990) and Olajide (2000) observed that increasing temperature and time of heating increased the colour intensity of oils. They observed respectively that at temperatures above 135°C and 105°C respectively, the colour of groundnut kernel oils were getting darker and unattractive. Olajide (2000) also observed the colour of sheanut kernel oil turning white at temperatures above 110°C and getting darkish at 130°C. Ajav and Olatunde (2011) observed an offensive burnt smell for groundnut expression at 120°C. Adeeko and Ajibola (1990) reported that increase in heating temperature or heating time causes moisture loss from the sample, thereby increasing the colour intensity of oils. These showed that increase heating temperature at prolonged heating times have adverse effects on the colour of expressed oil. Oil colour is due to the presence of carotenoid and chlorophyll pigments. It is noteworthy that co-oxidation of carotein and fatty acid causes significant colour formation during thermal process. High temperature accelerates oxidation with a consequent colour rise; but since the highest temperature was 90°C in this experiment, adverse colour change was not observed. The interactions between the process variables namely moisture content, heating temperature, heating time and applied pressure on the colour intensity of moringa oil during expression process are shown in Figures 4.24-4.29.

4.6.3 Oil Impurity

This has to do with the quality of the oil. The impurity ranges between 2.12-3.20% for all the processing conditions. It was observed that the impurity increases with increase in moisture content. Moisture constitutes about 87% of volatile impurities in vegetable oil, this account for the noticeable influence of moisture content on impurities. Conversely, impurity decreases with other processing conditions. Increase in heating temperature and time results in a decrease of moisture, therefore, impurities decrease with increase in heating temperature and time. This was in agreement with earlier reports by Akinoso (2006) who obtained a similar trend while investigating the effects of processing conditions on volatile impurities of palm kernel and sesame seed oils at 105°C. The interactions between the process variables namely moisture content, heating temperature, heating time and applied pressure on the moringa oil impurities during expression process are shown in Figures 4.30-4.35.

4.7 Predictive Models for The Physico-chemical Properties of Moringa Oil

Four different models namely linear, two factorial interaction (2FI), quadratic and cubic were used to analyze the physico-chemical properties of moringa seeds namely free fatty acid, colour intensity and oil impurity. The models were fitted to the experimental data using Design

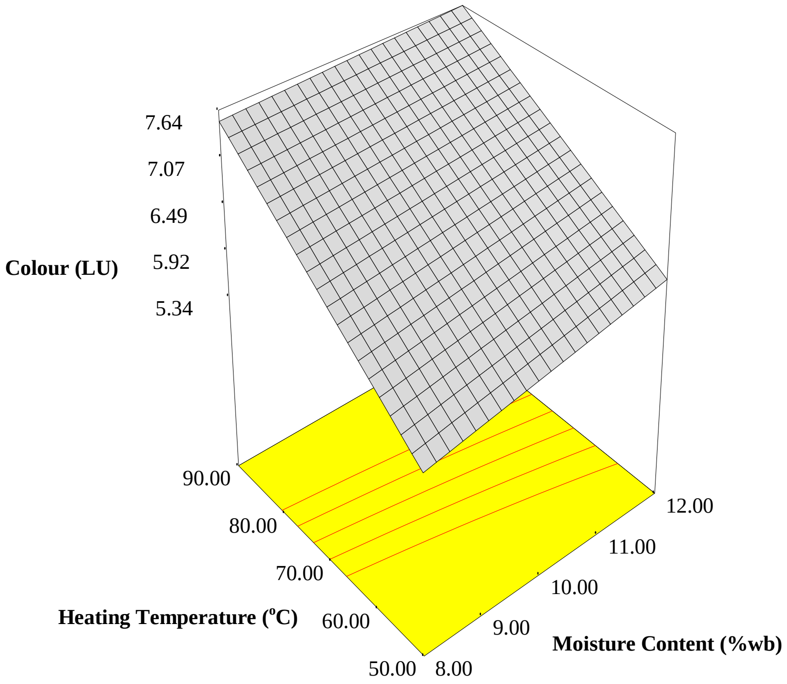

Figure 4.24. Effect of Moisture Content and Heating Temperature on Oil Colour Intensity

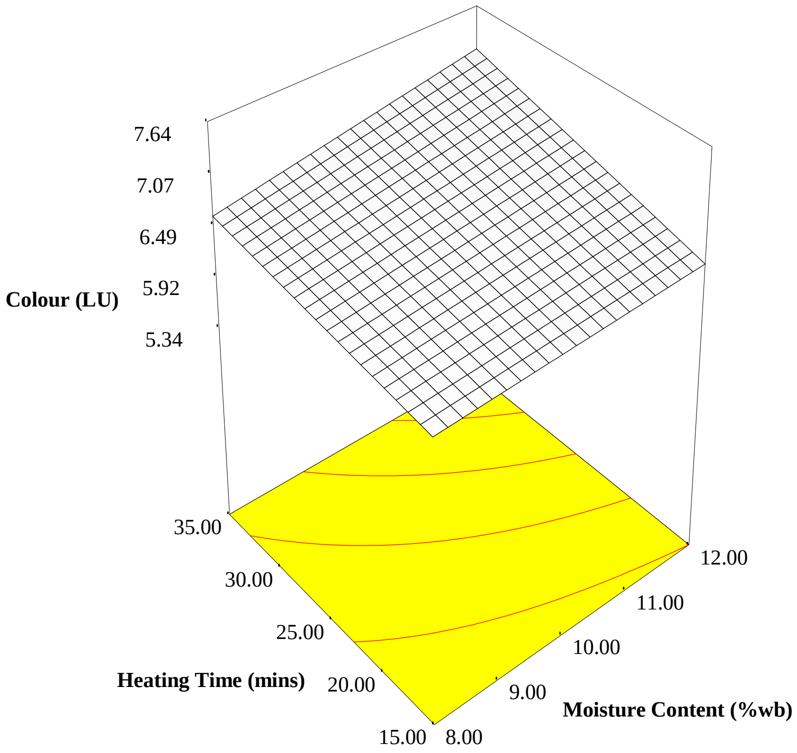

Figure 4.25. Effect of Moisture Content and Heating Time on Oil Colour Intensity

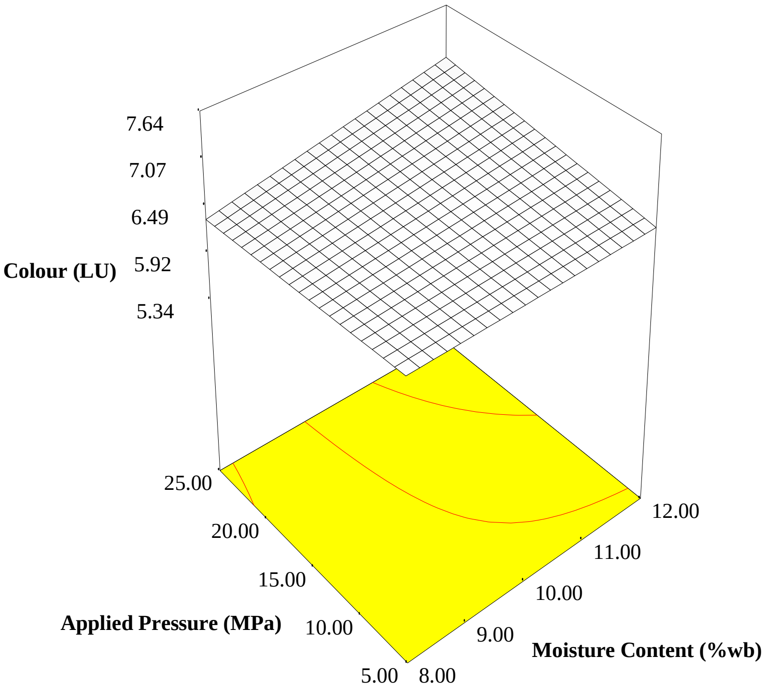

Figure 4.26. Effect of Moisture Content and Applied Pressure on Oil Colour Intensity

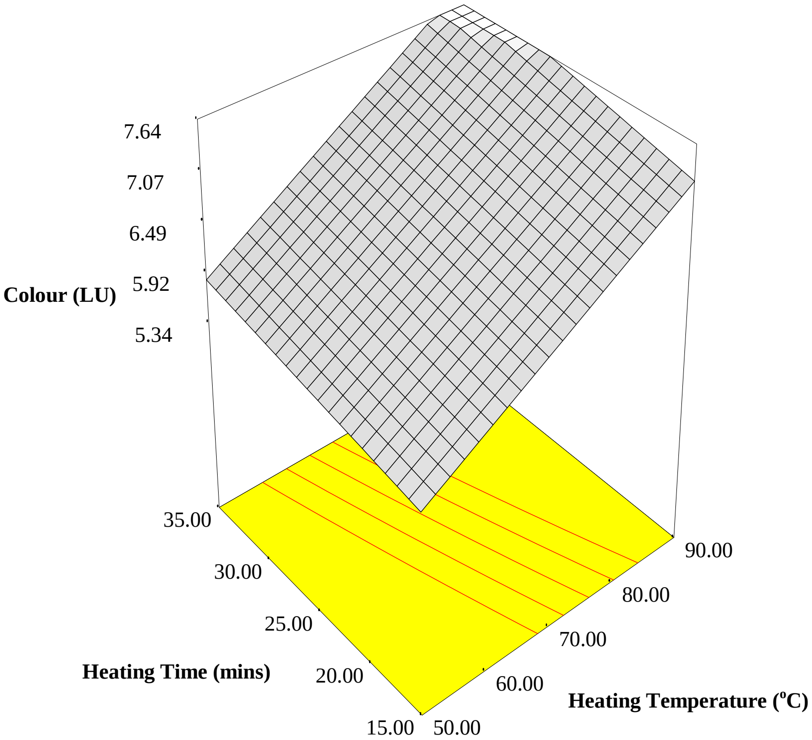

Figure 4.27. Effect of Heating Temperature and Heating Time on Oil Colour Intensity

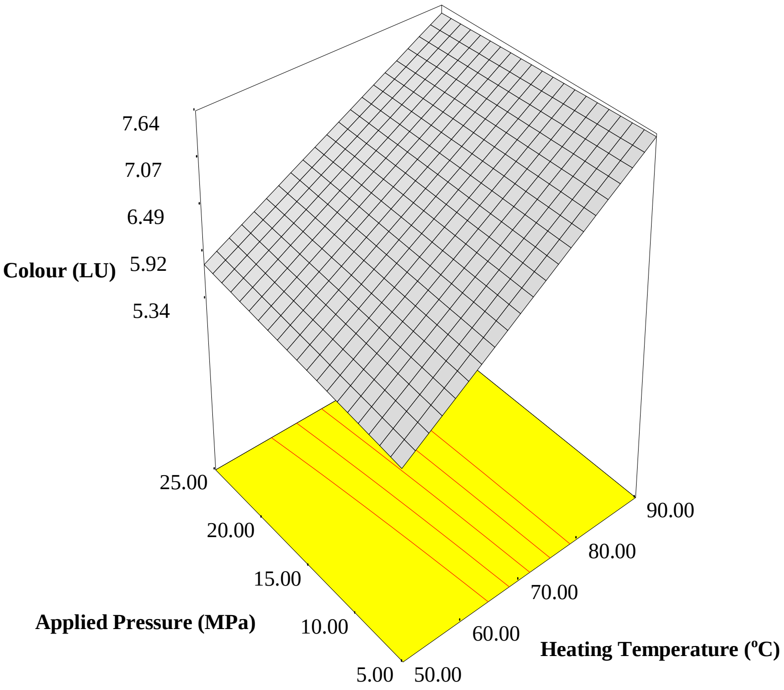

Figure 4.28. Effect of Heating Temperature and Applied Pressure on Oil Colour Intensity

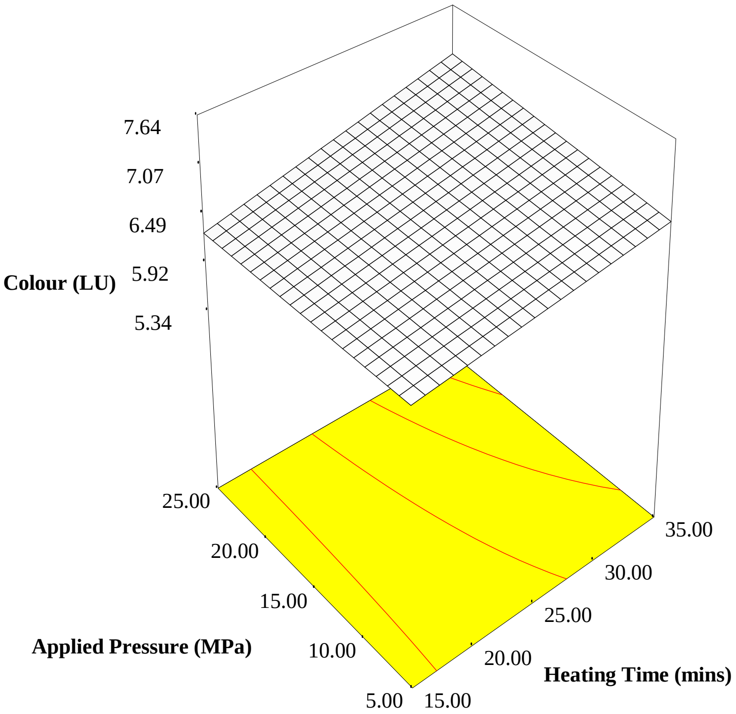

Figure 4.29. Effect of Heating Time and Applied Pressure on Oil Colour Intensity

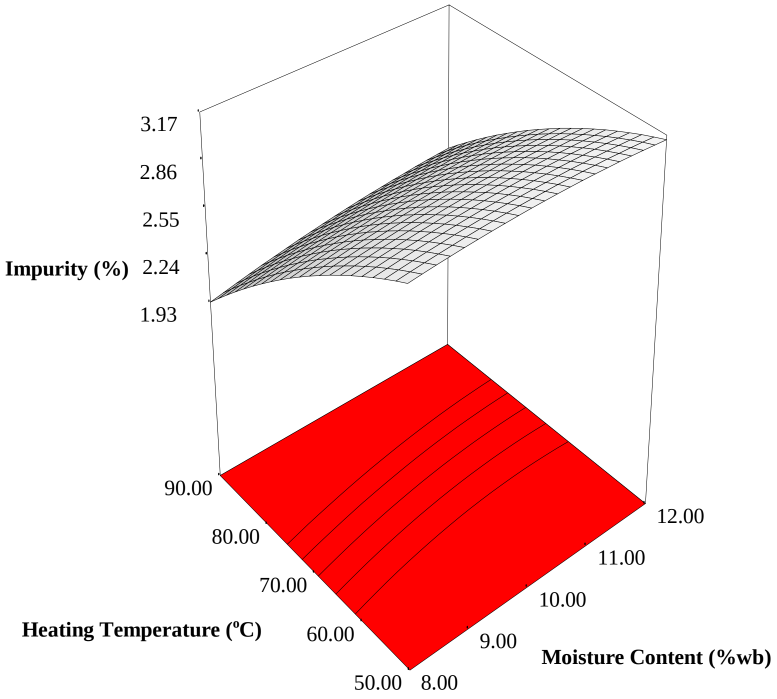

Figure 4.30. Effect of Moisture Content and Heating Temperature on Oil Impurity

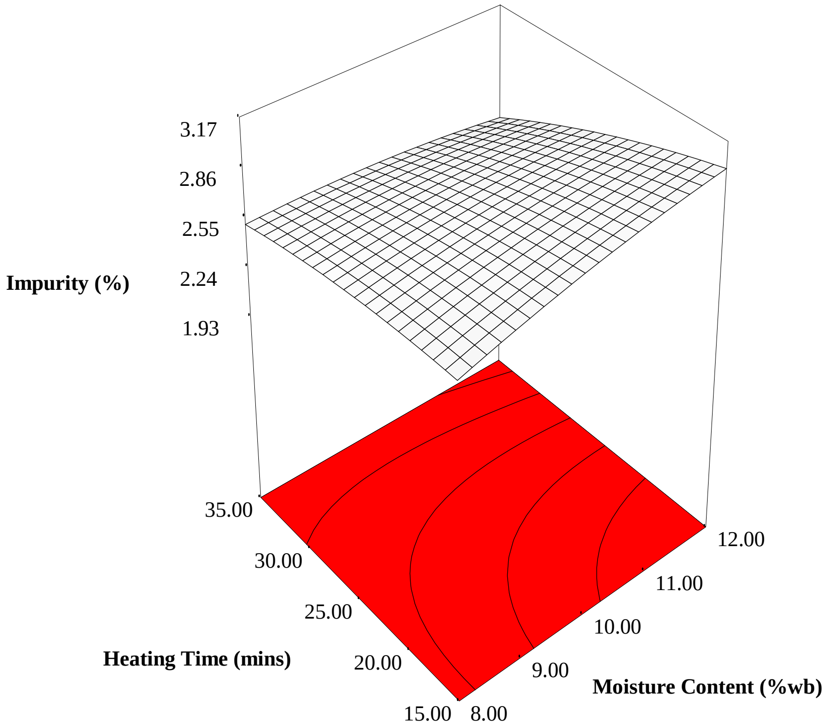

Figure 4.31. Effect of Moisture Content and Heating Time on Oil Impurity

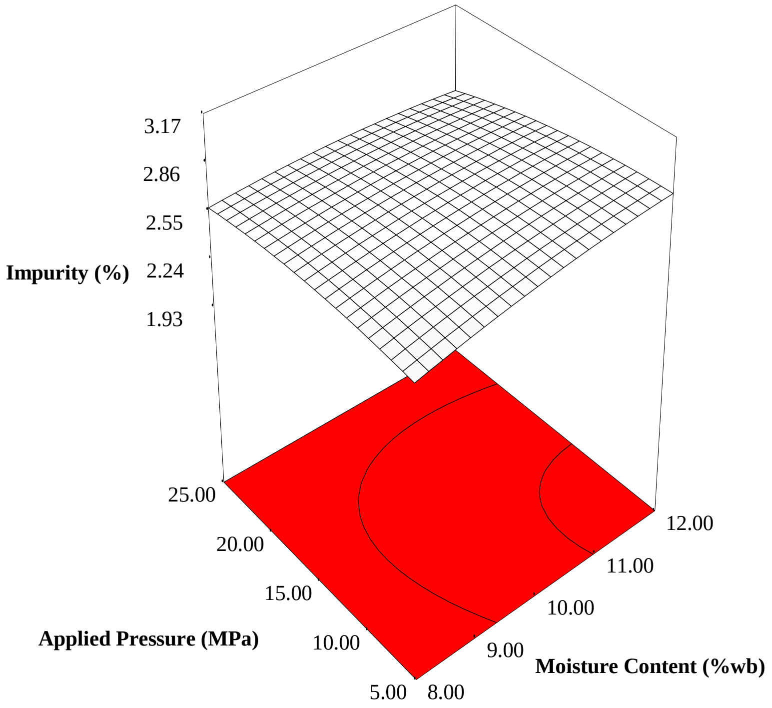

Figure 4.32. Effect of Moisture Content and Applied Pressure on Oil Impurity

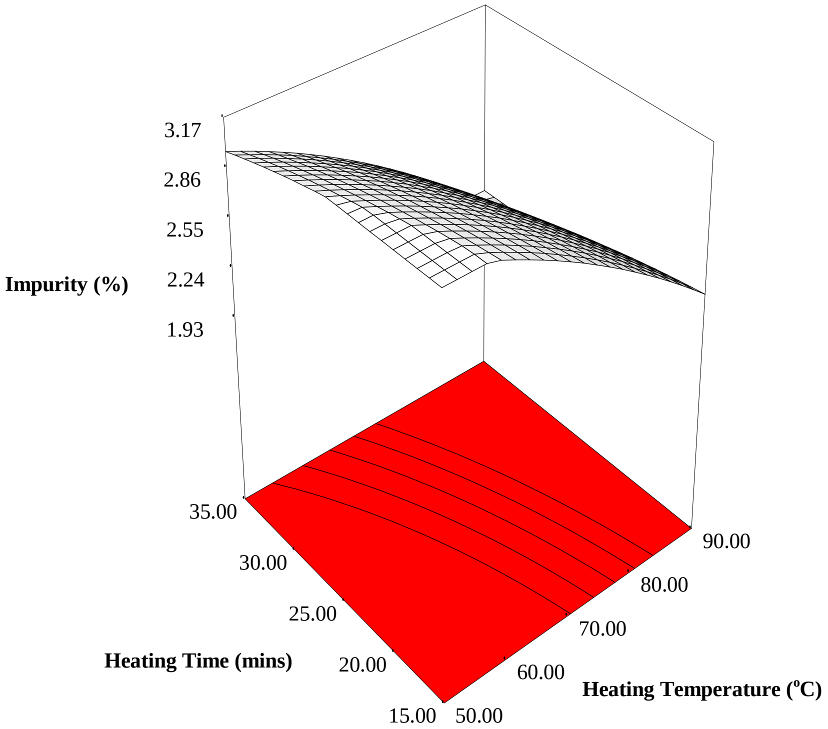

Figure 4.33. Effect of Heating Temperature and Heating Time on Oil Impurity

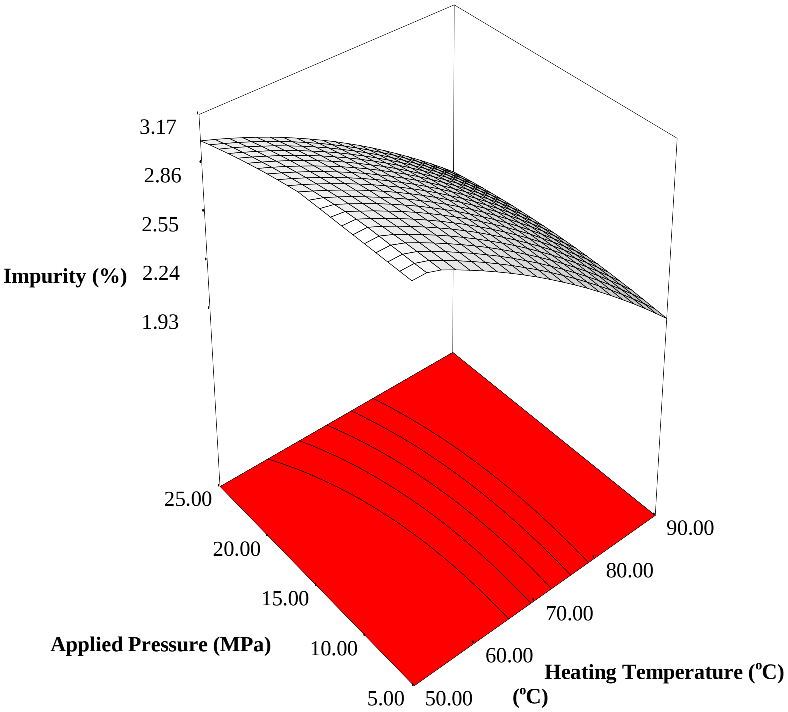

Figure 4.34. Effect of Heating Temperature and Applied Pressure on Oil Impurity

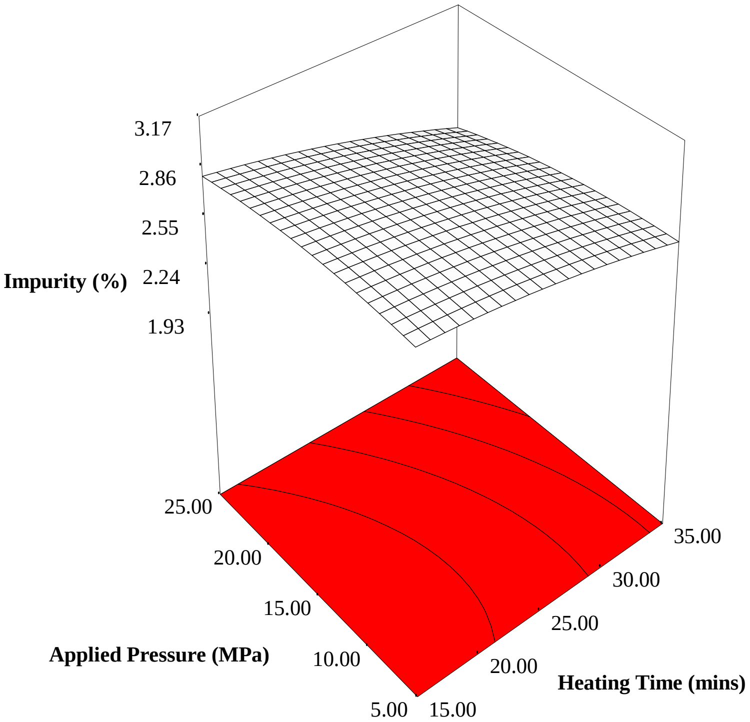

Figure 4.35. Effect of Heating Time and Applied Pressure on Oil Impurity

Expert software. The appropriate model was chosen based on the selection of the highest order polynomial where the additional terms are significant and the model is not aliased, insignificant lack-of-fit and the maximization of the “Adjusted R-Squared” and the “Predicted R-Squared”. Considering these, for the FFA, only the linear model was suggested and therefore chosen. For the colour intensity, the linear and 2FI models were suggested. In terms of higher coefficient of determination (R^2) and lower standard deviation values, the 2FI model was finally chosen. For the oil impurity, only the linear model was suggested and therefore chosen. The final equations for the FFA, colour and oil impurity are given below:

$$FFA = +18.18808 + 0.10375M_c - 0.16004H_T - 0.088917H_t - 0.043917A_p \qquad \ldots (90)$$

(Std. Dev. = 0.53, R-Squared = 0.9052, Mean = 5.14, Adj R-Squared = 0.8901 C.V. = 10.35, Pred R-Squared = 0.8574, PRESS = 10.65, Adeq Precision = 29.468).

$$CI = +2.42250 + 0.020833M_c + 0.075417H_T - 0.054167H_t - 0.058333A_p - 0.002500M_cH_T + 0.005000M_cH_t + 0.007500M_cA_p + 0.000250H_TH_t - 0.000500H_TA_p + 0.001000H_tA_p \qquad \ldots (91)$$

(Std. Dev. = 0.064, R-Squared = 0.9884, Mean = 6.59, Adj R-Squared = 0.9822
C.V. = 0.97, Pred R-Squared = 0.9614, PRESS = 0.26, Adeq Precision = 51.018).

$$OI = +4.76817 + 0.033333M_c - 0.026917H_T - 0.018000H_t - 0.005667A_p \qquad \ldots (92)$$

(Std. Dev. = 0.063, R-Squared = 0.9529, Mean = 2.68, Adj R-Squared = 0.9454 C.V. = 2.33, Pred R-Squared = 0.9300, PRESS = 0.15, Adeq Precision = 42.168).

Where,
M_c = Moisture content, %wb
H_T = Heating temperature, ^oC
H_t = Heating time, mins
A_p = Applied pressure, MPa
FFA = Free Fatty Acid, mg/KOH/g
CI = Colour Intensity, LU
OI = Oil Impurity, %

Deviations between experimental and predicted values were low and ranged from 0.01-0.68, 0.01-0.12 and 0.01-0.12 for the FFA, colour and oil impurity respectively. This implies that for the range of variables studied, the models chosen could predict the FFA, colour intensity and oil impurity adequately.

The statistical analysis of the FFA showed that only the moisture content, heating temperature, heating time, applied pressure and the interaction between the heating temperature and heating time are significant; while the other interactions are non-significant. This implies that all the processing variables have significant effects on the FFA of moringa oil during expression process, more especially, the heating temperature and heating time. This testifies to the fact that free fatty acid value measures the extent to which the glycerides in the oil have been decomposed by lipase action and the decomposition is accelerated by light and heat. It has a mean of 5.156, standard error of 0.030 and lower and upper bounds of 5.079 and 5.234 respectively.

The statistical analysis of the colour intensity showed that only the moisture content, heating temperature and heating time are significant, while the applied pressure and all the various interactions were non-significant. Even though the heating temperature and heating time have significant effects on the colour intensity of moringa oil, their interactions do not have because of the careful selection of medium heating temperature and heating time values used in this experiment. At higher heating temperatures and heating times, the effect of colour change becomes pronounced; therefore, having a significant effect. It has a mean of 6.583, standard error of 0.010 and lower and upper bounds of 6.557 and 6.609 respectively.

The statistical analysis of the oil impurity showed that only the moisture content, heating temperature, heating time, applied pressure and the interaction between moisture content and heating time as well as heating temperature and heating time are significant; while the other interactions are non-significant. This implies that all the processing variables have significant effects on oil impurity of moringa during expression process, more especially, the heating time. Moisture constitutes about 87% of volatile impurities in vegetable oil and increase in heating temperature and time results in a decrease of moisture. It has a mean of 2.682, standard error of 0.003 and lower and upper bounds of 2.674 and 2.690 respectively.

The results of the statistical analysis are presented in Appendix H.

4.8 Efficiency of the Moringa Oil Expeller

The efficiencies of the moringa oil expeller in terms of extraction and material balance were calculated from the oil yield, and the oil and cake output respectively as given in equations (84) and (85). The average summary of the material balance in terms of oil and cake output is presented in Table 4.7.

The total oil content was found to be 35% (Appendix C). This was in agreement with most researchers who observed that moringa seeds have 30-40% (w/w) of oil content (Mohammed *et al.*, 2003; Anwar *et al.*, 2006; Anwar and Rashid, 2007; Nzikou *et al.*, 2009; Uzama *et al*., 2011; Adejumo *et al.*, 2013; Ogunsina *et al.*, 2011, Goja, 2013 and Orhevba, 2013 amongst others). From equation (84), the maximum oil yield of 28.58% corresponds to an efficiency of 81.7%. This was taken as the extraction efficiency of the machine in terms of the oil yield. To determine the material balance efficiency of the machine in terms of the oil and cake output, average efficiency was calculated from the oil and cake output results as shown in Table 4.7. An efficiency of 93.8% was obtained. Overall, the performance of the moringa oil expeller was satisfactory as evident from the efficiencies in terms of the extraction and material balance.

4.9 Cost Analysis of the Moringa Oil Expeller

The cost of fabrication materials, bought-out components and others for the moringa oil expeller is shown in Table 4.8. At an exchange rate of N160 equivalent to $1, the most expensive component was the electric gear motor which costs N40,000 ($250), while the least expensive components were bolts and nuts N60 ($0.38). The labour cost was N20,000 ($125) for the fabrication and electrical connection of the machine. Overall, the total cost of the oil expeller was estimated to be N160,540 ($1003.38). Since solvent extraction method is capital intensive, this expeller serves as a suitable option for small to medium scale moringa farmers and oil processors for efficient extraction of oil from moringa seeds. The maintenance of the expeller is cheap, as it involves cleaning of the expression chamber daily after use to prevent the hardening of the cake stuck to the wormshaft. Apart from the electric motor, the various parts are relatively cheap and easily affordable in case of failure of any part of the machine.

Table 4.7. Material Balance in terms of Oil and Cake Output

S/No	MC	HT	Ht	AP	Oil Output	Cake Output (g)	Total Output (g)	Efficiency (%)
1	10.00	70.00	25.00	15.00	243.4	703.8	947.2	94.72
2	11.00	60.00	20.00	20.00	232.6	694.9	927.5	92.75
3	11.00	80.00	30.00	10.00	253.3	677.0	930.3	93.03
4	9.00	80.00	30.00	10.00	188.8	755.7	944.5	94.45
5	10.00	70.00	35.00	15.00	182.3	756.9	939.2	93.92
6	10.00	70.00	25.00	15.00	240.9	693.6	934.5	93.45
7	11.00	80.00	20.00	10.00	261.6	677.7	939.3	93.93
8	12.00	70.00	25.00	15.00	172.7	766.2	938.9	93.89
9	11.00	80.00	20.00	20.00	277.9	652.6	930.5	93.05
10	9.00	60.00	20.00	20.00	163.2	784.1	947.3	94.73
11	10.00	70.00	25.00	25.00	236.6	705.8	942.4	94.24
12	11.00	60.00	30.00	20.00	245.5	678.7	924.2	92.42
13	9.00	80.00	30.00	20.00	206.8	725.9	932.7	93.27
14	9.00	60.00	30.00	20.00	172.0	771.7	943.7	94.37
15	8.00	70.00	25.00	15.00	136.8	794.9	931.7	93.17
16	11.00	60.00	20.00	10.00	202.0	733.2	935.2	93.52
17	10.00	70.00	25.00	15.00	240.8	696.6	937.4	93.74
18	10.00	70.00	25.00	5.00	114.2	821.6	935.8	93.58
19	11.00	80.00	30.00	20.00	285.8	661.8	947.6	94.76
20	10.00	70.00	15.00	15.00	142.3	779.5	941.8	94.18
21	10.00	70.00	25.00	15.00	242.0	712.7	954.7	95.47
22	10.00	70.00	25.00	15.00	242.4	695.5	937.9	93.79
23	11.00	60.00	30.00	10.00	193.6	746.4	940.0	94.00
24	9.00	60.00	20.00	10.00	149.1	779.6	928.7	92.87
25	10.00	70.00	25.00	15.00	243.0	690.3	933.3	93.33
26	10.00	50.00	25.00	15.00	174.6	760.2	934.8	93.48
27	9.00	80.00	20.00	20.00	170.0	776.0	946.0	94.60
28	10.00	90.00	25.00	15.00	203.4	741.4	944.8	94.48
29	9.00	80.00	20.00	10.00	161.0	768.1	929.1	92.91
30	9.00	60.00	30.00	10.00	144.6	795.2	939.8	93.98

Table 4.8. Cost Analysis of the Moringa Oil Expeller

Materials	Quantity	Specifications	Rate	Amount
Angle Iron	6	1 length, 50mm x 50mm	N2000	N12000
Galvanized Metal Sheet	1	2400mm x 1200mm x 2mm	N7000	N7000
Mild Steel Bar	8	10mm x 10mm x 1000mm	N2000	N16000
Mild Steel Plate	2	1200mm x 600mm x 5mm	N7000	N14000
Hollow Pipe	1	500mm x 25mm, ϴ80mm	N1500	N1500
Mild Steel Solid Shaft	1	1000mm long, ϴ40mm	N6000	N6000
Driven Pulleys	2	90mm	N1500	N3000
Driving Pulleys	2	230mm	N3000	N6000
Pillow Bearings	3	ϴ40mm	N4000	N12000
Leather Belts	3	B42, V-Type	N1200	N3600
Electric Gear Motor	1	3-phase, 1.8hp, 180rpm	N40000	N40000
Temperature Regulator	1		N3000	N3000
Heater wires	2yards		N300	N600
Cutting Disc	4	ϴ 300mm	N500	N2000
Grinding Disc	2	ϴ 300mm	N500	N1000
Mild Steel Electrode	1packet	Gauge 10	N2000	N2000
Mild Steel Electrode	1packet	Gauge 12	N2000	N2000
Bolts and Nuts	24		N60	N1440
Hacksaw Blade	2	300mm long	N300	N600
Drill bits	4	3,5,7 and 10mm	N200	N800
Paint	2		N1500	N3000
Transportation	-		N3000	N3000
Labour	-		N20000	N20000
TOTAL				**N160, 540 ($1,003.38)**

Year 2014

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The engineering properties (physical and mechanical properties) of moringa seeds were established as design parameters for the development of an oil expeller for the crop. Subsequently, the moringa oil expeller was successfully designed and fabricated based on the determined physical and mechanical properties.

For the range of variables considered in the study, highest oil yield of 28.58% was obtained when moringa seeds were conditioned to a moisture content of 11% wet basis, heated at 80^{o}C for 30 mins at an applied pressure of 20 MPa. Predicted optimum oil yield of 28.2% at moisture content of 11.30% wet basis, temperature of 85.57^{o}C, duration of 27.17 mins and pressure of 19.63 MPa was obtained. Under these optimal conditions, the experimental value was 28.22% which was in agreement with those predicted by computation. Deviations between experimental and predicted values ranged from 0.01-6.20. It was established that moisture content, applied pressure, heating temperature and duration influenced the quantity of oil recovery from moringa seeds using expeller. A model equation was generated with a satisfactory coefficient of determination ($R^2 = 0.7691$). The coefficient of determination showed excellent correlations between the independent variables. For the range of variables studied, the model chosen adequately predicted the yield for moringa oil expression.

Extraction and material balance efficiencies of 81.7% and 93.8% were obtained. High oil expression efficiency obtained makes the expeller a potential for moringa oil expression since the use of solvent is only economic on large scale and it is not affordable by most farmers. Also, the cake obtained thereafter can be dried and used as animal feed, thereby making the expeller a more viable option for oil expression.

The FFA, oil impurity and colour ranged from 2.42-7.40 mg/KOH/g, 2.12-3.20% and 5.70-7.60 LU respectively and fell within acceptable limits. It was found out that moisture content, applied pressure, heating temperature and duration have significant effects on the quality of moringa oil expressed using expeller. Deviations between experimental and predicted values were low and ranged from 0.01-0.68, 0.01-0.12 and 0.01-0.12 for the FFA, colour and oil impurity respectively. The coefficients of determination (R^2) for the FFA, oil impurity and colour were 0.94, 0.98 and 0.99 respectively.

Overall, the data generated in this study will serve as a useful tool in process and equipment design for moringa oil processors in developing countries, most especially Nigeria.

This will help in improving the yield and quality attributes, thereby making more oil and fat available both for domestic and industrial purposes.

5.2 Recommendations

The following recommendations are made for further studies:

(i) The effects of particle size on oil yield of moringa seeds should be further investigated.
(ii) The effects of hulled and de-hulled moringa seeds on oil yield of moringa seeds and the physico-chemical properties of the expressed moringa oil should be investigated.
(iii) The capacity of the oil expeller should be increased so that larger oil quantity can be produced per unit time.

5.3 Contributions to Knowledge

From the study, the physical and mechanical properties of moringa seeds in relation to the design of oil expeller and other moringa processing machines have been investigated and established.

It was also ascertained that moisture content, heating temperature, heating time and applied pressure affect the yield and quality of moringa oil during expression. These processing conditions have to be controlled during oil expression from moringa seeds in order to obtain high yield and good quality oil. It was found out that at low temperatures, moringa seeds require more time to break down the oil cells and adjust the moisture content; while at higher temperatures, these are achieved at a faster rate at short durations leading to increased oil yield. However, it was established that extending the heating duration at higher temperatures cause substantial moisture loss which leads to reduction in oil yield. This research therefore developed mathematical model which provided optimal conditions for the moisture content, heating temperature, heating time and applied pressure through optimisation of the various process parameters. This model would serve as useful tool for moringa oil processors. The methodology adopted in the study could therefore be successfully employed to any process where an analysis of the effects and interactions of many experimental factors are required.

It was shown that expeller serves as a viable option for moringa oil expression for small to medium scale moringa oil processors due to the high extraction efficiency obtained. The maintenance of the expeller is cheap, the component parts are relatively cheap, available and affordable and the parts can be easily replaced in case of failure.

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APPENDIX A

PHYSICAL PROPERTIES OF MORINGA SEEDS

Table A1. Moisture Content of Moringa Seeds

	Sample A	**Sample B**	**Sample C**
Weight of Container (g)	24.4	23.6	24.1
Weight of Container + Sample before drying (g)	74.6	73.7	74.2
Weight of Container + Sample after drying (g)	70.6	70.0	70.4
Loss in Weight (g)	3.5	3.7	3.8
Moisture Content (% wet basis)	6.97	7.39	7.58

Average Moisture Content of Moringa Seeds = $\frac{6.97+7.39+7.58}{3}$

Average Moisture Content of Moringa Seeds = 7.31% wet basis

Table A2. Linear Dimensions of Moringa Seeds

S/NO	**L (mm)**	**W (mm)**	**T (mm)**	**D_a (mm)**	**D_g (mm)**	**S (mm^2)**	**Φ**	**R_a**
1	9.31	8.23	6.95	8.163	8.105	206.37	0.871	0.884
2	10.02	9.10	5.72	8.280	8.049	203.53	0.803	0.908
3	9.29	8.59	7.82	8.567	8.646	229.44	0.931	0.925
4	9.78	8.84	7.14	8.587	8.515	227.78	0.871	0.904
5	9.28	8.32	7.06	8.220	8.169	209.65	0.880	0.897
6	10.30	9.16	7.06	8.840	8.733	239.59	0.848	0.889
7	9.14	8.90	7.51	8.517	8.485	226.18	0.928	0.974
8	10.68	7.85	6.99	8.507	8.368	219.99	0.784	0.735
9	8.84	7.68	6.61	7.710	7.656	184.14	0.866	0.869
10	9.08	7.95	6.84	7.957	7.904	196.27	0.870	0.876
11	7.95	7.55	6.63	7.377	7.355	169.95	0.925	0.950
12	8.59	8.27	6.68	7.847	7.800	191.13	0.908	0.963
13	9.19	7.79	7.49	8.157	8.124	207.34	0.884	0.848
14	7.86	7.15	6.80	7.270	7.257	165.45	0.923	0.910
15	8.22	7.72	7.11	7.683	7.670	184.82	0.933	0.939
16	7.85	7.33	6.96	7.380	7.371	170.69	0.939	0.934
17	8.30	8.16	7.69	8.050	8.046	203.38	0.969	0.983
18	8.85	8.38	7.55	8.260	8.242	213.41	0.931	0.947
19	8.55	8.43	7.75	8.243	8.236	213.10	0.963	0.986
20	8.52	8.28	7.25	8.017	7.997	200.91	0.939	0.972
21	9.36	7.23	6.88	7.823	7.751	188.74	0.828	0.772
22	10.42	9.91	6.56	8.963	8.782	242.29	0.843	0.951
23	9.21	8.19	7.95	8.450	8.433	223.42	0.916	0.889
24	8.25	8.03	6.61	7.630	7.594	181.17	0.920	0.973
25	8.46	8.07	7.42	7.983	7.972	199.66	0.942	0.954

Table A2 (Cont'd)

S/NO	L (mm)	W (mm)	T (mm)	D_a (mm^2)	D_g (mm^2)	S (mm^2)	R_a	Φ
26	9.31	8.60	6.31	8.073	7.965	199.31	0.856	0.924
27	8.47	7.62	7.36	7.817	7.803	191.28	0.921	0.900
28	8.97	8.68	7.64	8.430	8.410	222.20	0.938	0.968
29	8.39	8.02	7.22	7.877	7.861	194.14	0.937	0.956
30	9.50	8.04	7.58	8.373	8.335	218.25	0.877	0.846
31	9.51	8.67	6.91	8.363	8.290	215.90	0.872	0.912
32	8.74	8.52	6.74	8.000	7.947	198.41	0.909	0.975
33	9.65	9.23	6.65	8.510	8.398	221.57	0.870	0.956
34	9.09	8.58	7.02	8.230	8.181	210.26	0.900	0.944
35	8.45	8.25	7.66	8.120	8.113	206.78	0.960	0.976
36	9.28	8.50	7.82	8.533	8.513	227.67	0.917	0.916
37	9.26	8.96	6.84	8.353	8.279	215.33	0.894	0.968
38	8.82	8.57	7.24	8.210	8.180	210.21	0.927	0.972
39	8.49	8.08	7.30	7.957	7.941	198.11	0.935	0.952
40	8.95	8.66	7.58	8.397	8.375	220.35	0.936	0.968
41	8.68	8.27	7.37	8.107	8.088	205.51	0.932	0.953
42	8.86	8.66	6.59	8.037	7.967	199.41	0.899	0.977
43	8.83	7.89	6.54	7.753	7.695	186.02	0.871	0.894
44	9.82	8.81	6.34	8.323	8.186	210.52	0.834	0.897
45	8.55	8.34	7.41	8.100	8.084	205.31	0.945	0.975
46	9.67	8.81	6.39	8.290	8.165	209.44	0.844	0.911
47	8.63	8.40	7.72	8.250	8.241	213.36	0.955	0.973
48	8.12	7.58	6.95	7.550	7.535	178.37	0.928	0.933
49	8.28	7.80	6.44	7.507	7.465	175.07	0.902	0.942
50	8.96	8.63	7.19	8.260	8.223	212.43	0.918	0.963

Table A2 (Cont'd)

S/NO	L (mm)	W (mm)	T (mm)	D_a (mm^2)	D_g (mm^2)	S (mm^2)	R_a	Φ
51	8.88	8.27	7.97	8.373	8.365	219.83	0.942	0.931
52	9.72	8.73	6.59	8.347	8.239	213.25	0.848	0.898
53	8.60	7.81	7.35	7.920	7.903	196.22	0.919	0.908
54	9.24	7.28	6.99	7.837	7.776	189.96	0.842	0.788
55	9.12	8.25	7.73	8.367	8.347	218.88	0.915	0.905
56	8.51	8.23	7.13	7.957	7.934	197.76	0.932	0.967
57	8.66	8.22	7.21	8.030	8.006	201.36	0.924	0.949
58	9.03	8.84	7.30	8.390	8.353	219.20	0.925	0.979
59	9.60	8.68	7.59	8.623	8.584	231.49	0.894	0.904
60	10.17	9.33	6.55	8.683	8.534	228.80	0.839	0.917
61	8.63	8.23	4.91	7.257	7.039	155.66	0.816	0.954
62	7.39	6.91	5.60	6.633	6.588	136.35	0.891	0.935
63	7.61	7.44	4.12	6.390	6.156	119.05	0.809	0.978
64	7.00	6.71	6.07	6.593	6.582	136.10	0.940	0.957
65	8.86	8.58	6.73	8.057	7.998	200.96	0.903	0.968
66	8.88	8.60	4.84	7.440	7.177	161.82	0.808	0.968
67	7.68	6.83	5.46	6.657	6.592	136.52	0.858	0.889
68	7.10	6.77	5.77	6.547	6.521	133.59	0.918	0.954
69	10.15	9.69	4.48	8.107	7.609	181.89	0.750	0.955
70	8.63	8.40	4.17	7.067	6.711	141.49	0.778	0.973
71	6.58	6.06	5.82	6.153	6.145	118.63	0.934	0.921
72	7.15	6.71	4.77	6.210	6.117	117.55	0.856	0.938
73	7.64	7.07	4.98	6.563	6.455	130.90	0.845	0.925
74	7.99	7.69	5.46	7.047	6.948	151.66	0.870	0.962
75	7.46	7.04	6.95	7.150	7.147	160.47	0.958	0.944

Table A2 (Cont'd)

S/NO	L (mm)	W (mm)	T (mm)	D_a (mm^2)	D_g (mm^2)	S (mm^2)	R_a	Φ
76	8.19	7.08	4.37	6.547	6.328	125.80	0.773	0.864
77	6.90	6.56	4.94	6.133	6.070	115.75	0.880	0.951
78	7.45	7.16	4.63	6.413	6.274	123.66	0.842	0.961
79	7.29	6.62	5.40	6.437	6.388	128.20	0.876	0.908
80	7.75	7.07	4.61	6.477	6.321	125.52	0.816	0.912
81	7.47	7.00	5.31	6.593	6.524	133.71	0.873	0.937
82	8.26	7.60	4.51	6.790	6.566	135.44	0.795	0.920
83	7.10	6.08	5.36	6.180	6.139	118.40	0.865	0.856
84	7.07	6.24	5.89	6.400	6.381	127.92	0.903	0.883
85	7.24	6.97	6.40	6.870	6.861	147.89	0.948	0.963
86	8.11	7.43	6.50	7.347	7.317	168.20	0.902	0.916
87	6.44	6.05	5.73	6.073	6.066	115.60	0.942	0.939
88	6.58	6.36	4.50	5.813	5.732	103.22	0.871	0.967
89	7.07	6.62	4.11	5.933	5.773	104.70	0.817	0.936
90	7.09	6.58	5.54	6.403	6.370	127.48	0.898	0.928
91	7.01	6.35	4.09	5.817	5.668	100.93	0.809	0.906
92	6.75	6.27	5.97	6.330	6.322	125.56	0.937	0.929
93	7.87	6.92	4.46	6.417	6.239	122.29	0.793	0.879
94	7.64	5.67	4.92	6.077	5.973	112.08	0.782	0.742
95	7.70	7.54	7.12	7.453	7.449	174.32	0.967	0.979
96	7.07	6.88	6.27	6.740	6.731	142.33	0.952	0.973
97	8.07	7.93	7.32	7.773	7.766	189.47	0.962	0.983
98	6.98	6.53	4.52	6.010	5.906	109.58	0.846	0.936
99	7.27	5.98	5.23	6.160	6.104	117.05	0.840	0.823
100	9.49	8.78	7.10	8.457	8.395	221.41	0.885	0.925

Table A3. True Density of Moringa Seeds

S/No	Mass (g)	Volume (cm^3)	True Density (gcm^{-3})
1	10.20	14.00	0.729
2	10.00	12.00	0.833
3	20.10	20.00	1.005
4	20.20	20.00	1.010
5	30.20	30.00	1.007
6	30.00	28.00	1.071
7	40.20	40.00	1.005
8	40.10	40.00	1.003
9	50.00	50.00	1.000
10	50.10	48.00	1.044

Table A4. Bulk Density of Moringa Seeds

S/No	Mass (g)	Volume (cm^3)	Bulk Density (gcm^{-3})
1	163.70	260.00	0.630
2	145.10	230.00	0.631
3	173.60	275.00	0.631
4	141.80	205.00	0.692
5	142.60	207.00	0.689
6	162.00	250.00	0.648
7	157.10	228.00	0.689
8	175.80	266.00	0.661
9	138.70	203.00	0.683
10	148.80	225.00	0.661

Table A5. One Thousand Seed Weight of Moringa Seeds

S/No	Measured Value (g)	W_{1000}
1	23.8	238.00
2	24.0	240.00
3	24.6	246.00
4	23.4	234.00
5	24.1	241.00
6	23.7	237.00
7	24.0	240.00
8	23.8	238.00
9	23.9	239.00
10	23.9	239.00

Table A6. Dynamic Angle of Repose of Moringa Seeds

S/No	h (mm)	D (mm)	θ
1	3.5	17.5	21.8
2	3.6	18.5	21.3
3	4.0	20.7	21.1
4	4.0	20.3	21.5
5	3.4	18.0	20.7
6	3.8	18.2	22.7
7	3.6	19.0	20.8
8	3.8	19.2	21.6
9	3.6	19.3	20.4
10	3.8	18.3	22.6

Table A7. Static Coefficient of Friction of Moringa Seeds on different Surfaces

S/No	Glass		Stainless Steel		Mild Steel		Galvanized Steel		Rubber		Wood	
	°	μ	°	μ	°	μ	°	μ	°	μ	°	μ
1	50	1.192	48	1.111	52	1.280	45	1.000	67	2.356	58	1.600
2	43	0.932	49	1.150	51	1.235	52	1.280	67	2.356	54	1.376
3	45	1.000	49	1.150	58	1.600	45	1.000	62	1.881	53	1.327
4	45	1.000	48	1.111	56	1.483	55	1.428	62	1.881	60	1.732
5	47	1.072	46	1.036	53	1.327	46	1.036	63	1.963	55	1.428
6	45	1.000	48	1.111	53	1.327	51	1.235	69	2.605	63	1.963
7	44	0.966	47	1.072	54	1.376	51	1.235	67	2.356	62	1.881
8	47	1.072	48	1.111	52	1.280	55	1.428	65	2.145	63	1.963
9	45	1.000	49	1.150	55	1.428	55	1.428	68	2.475	55	1.428
10	46	1.036	48	1.111	55	1.428	53	1.327	63	1.963	54	1.376

APPENDIX B

MECHANICAL PROPERTIES OF MORINGA SEEDS

Table B1. Mechanical Properties of Moringa Seeds at Peak

S/No	Force at Peak (N)	Deformation at Peak (mm)	Stress at Peak (N/mm^2)	Energy to Peak (N.m)
1	53.800	5.0660	44.800	0.1268
2	60.400	5.2500	50.300	0.1371
3	57.900	5.1770	48.300	0.1043
4	59.700	5.0790	49.800	0.1564
5	66.900	5.1110	55.800	0.1662
6	65.600	5.1270	54.700	0.1419
7	53.700	5.0810	44.700	0.1317
8	51.000	5.0730	42.500	0.1121
9	58.600	4.8500	48.800	0.1347
10	63.500	5.1340	52.900	0.1395
11	54.300	5.0980	45.300	0.1185
12	59.300	5.0620	49.400	0.1708
13	56. 300	5.3540	46.900	0.1348
14	48. 900	5.0760	40.800	0.1056
15	59. 700	5.0350	49.800	0.1309
16	50.400	5.0950	42.000	0.1188
17	67.000	5.0650	55.800	0.1393
18	62.700	5.1330	52.300	0.1523
19	63.100	5.0610	52.600	0.1264
20	57.900	5.0610	48.300	0.1384

Table B2. Mechanical Properties of Moringa Seeds at Break

S/No	Force at Break (N)	Deformation at Break (mm)	Stress at Break (N/mm^2)	Energy to Break (N.m)
1	53.700	5.1910	44.800	0.1335
2	60.400	5.2500	50.300	0.1371
3	57.500	5.2270	47.900	0.1072
4	59.300	5.0920	49.400	0.1572
5	66.900	5.1110	55.800	0.1662
6	65.600	5.1270	54.700	0.1419
7	53.700	5.0810	44.800	0.1317
8	51.000	5.0730	42.500	0.1121
9	57.700	5.0650	48.100	0.1471
10	63.500	5.1340	52.900	0.1395
11	54.300	5.0980	45.300	0.1185
12	59.300	5.0620	49.400	0.1708
13	56.300	5.3540	46.900	0.1348
14	48.900	5.0760	40.800	0.1056
15	59.300	5.0530	49.400	0.1319
16	50.400	5.0950	42.000	0.1188
17	67.000	5.0650	55.800	0.1393
18	62.600	5.1510	52.200	0.1534
19	63.100	5.0610	52.600	0.1264
20	57.900	5.1150	48.300	0.1415

Table B3. Mechanical Properties of Moringa Seeds at Yield

S/No	Force at Yield (N)	Stress at Yield (N/mm^2)	Energy to Yield (N.m)	Young Modulus (N/mm^2)
1	37.800	31.500	0.0425	116.94
2	40.000	33.300	0.0685	81.52
3	33.600	28.000	0.0415	106.12
4	46.600	38.800	0.0595	127.46
5	32.800	27.300	0.0297	147.95
6	39.000	32.500	0.0530	97.37
7	46.700	38.900	0.0873	83.02
8	41.000	34.100	0.0717	87.32
9	43.700	36.400	0.0645	88.75
10	43.000	35.800	0.0662	108.78
11	42.500	35.400	0.0752	90.59
12	54.300	45.200	0.1215	98.66
13	25.600	21.300	0.0316	77.13
14	19.800	16.500	0.0205	66.65
15	42.400	35.300	0.0677	116.25
16	39.600	33.000	0.0630	78.34
17	34.400	28.600	0.0439	88.62
18	37.000	30.800	0.0465	92.58
19	40.200	33.500	0.0594	97.34
20	39.700	33.100	0.0536	101.82

APPENDIX C

TOTAL OIL CONTENT OF MORINGA SEEDS BY SOXHLET METHOD

Table C1. Total Oil Content of Moringa Seeds

	Sample A	**Sample B**	**Sample C**
Weight of filter paper (g)	0.54	0.52	0.52
Weight of sample	10.00	10.00	10.00
Weight of filter paper + sample before extraction (g)	10.54	10.52	10.52
Weight of filter paper + sample after extraction (g)	6.81	6.89	6.82
Loss in Weight (g)	3.73	3.63	3.70
Oil Content (%)	35.4	34.5	35.2

Average Oil Content of Moringa Seeds = $\frac{35.4+34.5+35.2}{3}$

Average Oil Content of Moringa Seeds = 35.03%

APPENDIX D

AMOUNT OF WATER ADDED TO MORINGA SAMPLES

Amount of water to be added to moringa samples to raise the moisture content from 7.31% to 8%

$(\frac{100-7.31}{100-8.00} - 1) \times 1000 = 7.5$ ml

Amount of water to be added to moringa samples to raise the moisture content from 7.31% to 9%

$(\frac{100-7.31}{100-9.00} - 1) \times 1000 = 18.6$ ml

Amount of water to be added to moringa samples to raise the moisture content from 7.31% to 10%

$(\frac{100-7.31}{100-10.00} - 1) \times 1000 = 29.9$ ml

Amount of water to be added to moringa samples to raise the moisture content from 7.31% to 11%

$(\frac{100-7.31}{100-11.00} - 1) \times 1000 = 41.5$ ml

Amount of water to be added to moringa samples to raise the moisture content from 7.31% to 12%

$(\frac{100-7.31}{100-12.00} - 1) \times 1000 = 53.3$ ml

APPENDIX E

OIL YIELD OF MORINGA AT DIFFERENT PROCESSING CONDITIONS

Table E1. Yield of Moringa Oil at different Processing Conditions (Experiment 1)

S/No	MC	HT	Ht	AP	Oil Yield
1	12.00	70.00	25.00	15.00	24.78
2	14.00	60.00	20.00	20.00	22.51
3	14.00	80.00	30.00	10.00	26.81
4	10.00	80.00	30.00	10.00	18.87
5	12.00	70.00	35.00	15.00	19.04
6	12.00	70.00	25.00	15.00	22.98
7	14.00	80.00	20.00	10.00	25.41
8	16.00	70.00	25.00	15.00	18.51
9	14.00	80.00	20.00	20.00	27.73
10	10.00	60.00	20.00	20.00	16.97
11	12.00	70.00	25.00	25.00	23.82
12	14.00	60.00	30.00	20.00	23.23
13	10.00	80.00	30.00	20.00	21.63
14	10.00	60.00	30.00	20.00	17.01
15	8.00	70.00	25.00	15.00	13.82
16	14.00	60.00	20.00	10.00	20.55
17	12.00	70.00	25.00	15.00	24.84
18	12.00	70.00	25.00	5.00	10.84
19	14.00	80.00	30.00	20.00	29.10
20	12.00	70.00	15.00	15.00	13.33
21	12.00	70.00	25.00	15.00	25.18
22	12.00	70.00	25.00	15.00	24.73
23	14.00	60.00	30.00	10.00	21.25
24	10.00	60.00	20.00	10.00	15.88
25	12.00	70.00	25.00	15.00	23.24
26	12.00	50.00	25.00	15.00	18.85
27	10.00	80.00	20.00	20.00	16.77
28	12.00	90.00	25.00	15.00	20.65
29	10.00	80.00	20.00	10.00	16.76
30	10.00	60.00	30.00	10.00	15.41

Table E2. Yield of Moringa Oil at different Processing Conditions (Experiment 2)

S/No	MC	HT	Ht	AP	Oil Yield
1	12.00	70.00	25.00	15.00	23.73
2	14.00	60.00	20.00	20.00	23.82
3	14.00	80.00	30.00	10.00	25.11
4	10.00	80.00	30.00	10.00	18.41
5	12.00	70.00	35.00	15.00	17.73
6	12.00	70.00	25.00	15.00	25.45
7	14.00	80.00	20.00	10.00	25.86
8	16.00	70.00	25.00	15.00	16.33
9	14.00	80.00	20.00	20.00	28.21
10	10.00	60.00	20.00	20.00	15.96
11	12.00	70.00	25.00	25.00	24.77
12	14.00	60.00	30.00	20.00	25.05
13	10.00	80.00	30.00	20.00	20.45
14	10.00	60.00	30.00	20.00	16.76
15	8.00	70.00	25.00	15.00	13.45
16	14.00	60.00	20.00	10.00	18.20
17	12.00	70.00	25.00	15.00	23.63
18	12.00	70.00	25.00	5.00	12.63
19	14.00	80.00	30.00	20.00	27.86
20	12.00	70.00	15.00	15.00	14.97
21	12.00	70.00	25.00	15.00	22.85
22	12.00	70.00	25.00	15.00	24.89
23	14.00	60.00	30.00	10.00	19.44
24	10.00	60.00	20.00	10.00	14.73
25	12.00	70.00	25.00	15.00	25.10
26	12.00	50.00	25.00	15.00	16.97
27	10.00	80.00	20.00	20.00	16.82
28	12.00	90.00	25.00	15.00	20.97
29	10.00	80.00	20.00	10.00	15.89
30	10.00	60.00	30.00	10.00	13.77

Table E3. Yield of Moringa Oil at different Processing Conditions (Experiment 3)

S/No	MC	HT	Ht	AP	Oil Yield
1	12.00	70.00	25.00	15.00	24.51
2	14.00	60.00	20.00	20.00	23.44
3	14.00	80.00	30.00	10.00	24.73
4	10.00	80.00	30.00	10.00	19.37
5	12.00	70.00	35.00	15.00	17.93
6	12.00	70.00	25.00	15.00	23.83
7	14.00	80.00	20.00	10.00	26.57
8	16.00	70.00	25.00	15.00	16.98
9	14.00	80.00	20.00	20.00	27.44
10	10.00	60.00	20.00	20.00	16.03
11	12.00	70.00	25.00	25.00	22.40
12	14.00	60.00	30.00	20.00	25.37
13	10.00	80.00	30.00	20.00	19.96
14	10.00	60.00	30.00	20.00	17.84
15	8.00	70.00	25.00	15.00	13.76
16	14.00	60.00	20.00	10.00	19.92
17	12.00	70.00	25.00	15.00	23.78
18	12.00	70.00	25.00	5.00	10.78
19	14.00	80.00	30.00	20.00	28.77
20	12.00	70.00	15.00	15.00	14.38
21	12.00	70.00	25.00	15.00	24.57
22	12.00	70.00	25.00	15.00	23.11
23	14.00	60.00	30.00	10.00	19.33
24	10.00	60.00	20.00	10.00	14.11
25	12.00	70.00	25.00	15.00	24.56
26	12.00	50.00	25.00	15.00	16.55
27	10.00	80.00	20.00	20.00	17.41
28	12.00	90.00	25.00	15.00	19.41
29	10.00	80.00	20.00	10.00	15.65
30	10.00	60.00	30.00	10.00	14.20

APPENDIX F

MATERIAL BALANCE IN TERMS OF OIL AND CAKE OUTPUT

Table F1. Material Balance in terms of Oil and Cake Output (Experiment 1)

S/No	MC	HT	Ht	AP	Oil Output	Cake Output (g)	Total Output (g)	Efficiency (%)
1	10.00	70.00	25.00	15.00	247.8	706.8	954.6	95.46
2	11.00	60.00	20.00	20.00	225.1	691.4	916.5	91.65
3	11.00	80.00	30.00	10.00	254.1	686.2	940.3	94.03
4	9.00	80.00	30.00	10.00	188.7	751.4	940.1	94.01
5	10.00	70.00	35.00	15.00	190.4	747.7	938.1	93.81
6	10.00	70.00	25.00	15.00	229.8	697.8	927.6	92.76
7	11.00	80.00	20.00	10.00	268.1	677.6	945.7	94.57
8	12.00	70.00	25.00	15.00	185.1	753.6	938.7	93.87
9	11.00	80.00	20.00	20.00	277.3	646.4	923.7	92.37
10	9.00	60.00	20.00	20.00	169.7	794.0	963.7	96.37
11	10.00	70.00	25.00	25.00	238.2	687.6	925.8	92.58
12	11.00	60.00	30.00	20.00	232.3	701.1	933.4	93.34
13	9.00	80.00	30.00	20.00	216.3	706.0	922.3	92.23
14	9.00	60.00	30.00	20.00	170.1	776.5	946.6	94.66
15	8.00	70.00	25.00	15.00	138.2	801.2	939.4	93.94
16	11.00	60.00	20.00	10.00	212.5	740.7	953.2	95.32
17	10.00	70.00	25.00	15.00	248.4	696.0	944.4	94.44
18	10.00	70.00	25.00	5.00	108.4	843.2	951.6	95.16
19	11.00	80.00	30.00	20.00	291.0	675.3	966.3	96.63
20	10.00	70.00	15.00	15.00	133.3	778.7	912.0	91.20
21	10.00	70.00	25.00	15.00	251.8	698.8	950.6	95.06
22	10.00	70.00	25.00	15.00	247.3	695.9	943.2	94.32
23	11.00	60.00	30.00	10.00	205.5	716.6	922.1	92.21
24	9.00	60.00	20.00	10.00	158.8	756.9	915.7	91.57
25	10.00	70.00	25.00	15.00	232.4	696.5	928.9	92.89
26	10.00	50.00	25.00	15.00	188.5	743.2	931.7	93.17
27	9.00	80.00	20.00	20.00	167.7	799.6	967.3	96.73
28	10.00	90.00	25.00	15.00	206.5	750.9	957.4	95.74
29	9.00	80.00	20.00	10.00	167.6	765.8	933.4	93.34
30	9.00	60.00	30.00	10.00	154.1	801.6	955.7	95.57

Table F2. Material Balance in terms of Oil and Cake Output (Experiment 2)

S/No	MC	HT	Ht	AP	Oil Output	Cake Output (g)	Total Output (g)	Efficiency (%)
1	10.00	70.00	25.00	15.00	237.3	700.9	938.2	93.82
2	11.00	60.00	20.00	20.00	238.2	704.8	943.0	94.30
3	11.00	80.00	30.00	10.00	258.6	669.6	928.2	92.82
4	9.00	80.00	30.00	10.00	184.1	760.9	945.0	94.50
5	10.00	70.00	35.00	15.00	177.3	764.9	942.2	94.22
6	10.00	70.00	25.00	15.00	254.5	664.0	918.5	91.85
7	11.00	80.00	20.00	10.00	251.1	687.7	938.8	93.88
8	12.00	70.00	25.00	15.00	163.3	771.3	934.6	93.46
9	11.00	80.00	20.00	20.00	282.1	662.3	944.4	94.44
10	9.00	60.00	20.00	20.00	159.6	763.5	923.1	92.31
11	10.00	70.00	25.00	25.00	247.7	712.6	960.3	96.03
12	11.00	60.00	30.00	20.00	250.5	668.6	919.1	91.91
13	9.00	80.00	30.00	20.00	204.5	746.7	951.2	95.12
14	9.00	60.00	30.00	20.00	167.6	778.4	946.0	94.60
15	8.00	70.00	25.00	15.00	134.5	786.2	920.7	92.07
16	11.00	60.00	20.00	10.00	194.4	725.3	919.7	91.97
17	10.00	70.00	25.00	15.00	236.3	692.2	928.5	92.85
18	10.00	70.00	25.00	5.00	126.3	806.7	933.0	93.30
19	11.00	80.00	30.00	20.00	278.6	662.0	940.6	94.06
20	10.00	70.00	15.00	15.00	149.7	813.6	963.3	96.33
21	10.00	70.00	25.00	15.00	228.5	737.6	966.1	96.61
22	10.00	70.00	25.00	15.00	248.9	702.9	951.8	95.18
23	11.00	60.00	30.00	10.00	182.0	786.1	968.1	96.81
24	9.00	60.00	20.00	10.00	147.3	785.9	933.2	93.32
25	10.00	70.00	25.00	15.00	251.0	674.3	925.3	92.53
26	10.00	50.00	25.00	15.00	169.7	786.8	956.5	95.65
27	9.00	80.00	20.00	20.00	168.2	759.1	927.3	92.73
28	10.00	90.00	25.00	15.00	209.7	726.8	936.5	93.65
29	9.00	80.00	20.00	10.00	158.9	763.3	922.2	92.22
30	9.00	60.00	30.00	10.00	137.7	801.7	939.4	93.94

Table F3. Material Balance in terms of Oil and Cake Output (Experiment 3)

S/No	MC	HT	Ht	AP	Oil Output	Cake Output (g)	Total Output (g)	Efficiency (%)
1	10.00	70.00	25.00	15.00	245.1	703.7	948.8	94.88
2	11.00	60.00	20.00	20.00	234.4	688.4	922.8	92.28
3	11.00	80.00	30.00	10.00	247.3	675.3	922.6	92.26
4	9.00	80.00	30.00	10.00	193.7	754.7	948.4	94.84
5	10.00	70.00	35.00	15.00	179.3	758.2	937.5	93.57
6	10.00	70.00	25.00	15.00	238.3	719.0	957.3	95.73
7	11.00	80.00	20.00	10.00	265.7	667.7	933.4	93.34
8	12.00	70.00	25.00	15.00	169.8	773.6	943.4	94.34
9	11.00	80.00	20.00	20.00	274.4	649.2	923.6	92.36
10	9.00	60.00	20.00	20.00	160.3	794.8	955.1	95.51
11	10.00	70.00	25.00	25.00	224.0	717.3	941.3	94.13
12	11.00	60.00	30.00	20.00	253.7	666.4	920.1	92.01
13	9.00	80.00	30.00	20.00	199.6	725.0	924.6	92.46
14	9.00	60.00	30.00	20.00	178.4	760.3	938.7	93.87
15	8.00	70.00	25.00	15.00	137.6	797.4	935.0	93.50
16	11.00	60.00	20.00	10.00	199.2	733.5	932.7	93.27
17	10.00	70.00	25.00	15.00	237.8	701.7	939.5	93.95
18	10.00	70.00	25.00	5.00	107.8	815.0	922.8	92.28
19	11.00	80.00	30.00	20.00	287.7	648.1	935.8	93.58
20	10.00	70.00	15.00	15.00	143.8	806.3	950.1	95.01
21	10.00	70.00	25.00	15.00	245.7	701.6	947.3	94.73
22	10.00	70.00	25.00	15.00	231.1	687.7	918.8	91.88
23	11.00	60.00	30.00	10.00	193.3	736.4	929.7	92.97
24	9.00	60.00	20.00	10.00	141.1	796.0	937.1	93.71
25	10.00	70.00	25.00	15.00	245.6	700.0	945.6	94.56
26	10.00	50.00	25.00	15.00	165.5	750.5	916.0	91.60
27	9.00	80.00	20.00	20.00	174.1	769.4	943.5	94.35
28	10.00	90.00	25.00	15.00	194.1	746.5	940.6	94.06
29	9.00	80.00	20.00	10.00	156.5	775.2	931.7	93.17
30	9.00	60.00	30.00	10.00	142.0	782.4	924.4	92.44

APPENDIX G

MODELLING OF OIL YIELD
Design Summary

Study Type	Response Surface	**Experiments**	30
Initial Design	Central Composite	**Blocks**	No Blocks
Design Model	Quadratic		

Response	Name	Units	Obs	Minimum	Maximum	Trans	Model
Y_1	Yield	%	30	11.42	28.58	None	Quadratic

Factor	Name	Units	Type	Low Actual	High Actual	Low Coded	High Coded
A	Moisture Content	% wb	Numeric	9.00	11.00	-1.000	1.000
B	Heating Temp.	^{o}C	Numeric	60.00	80.00	-1.000	1.000
C	Heating Time	mins	Numeric	20.00	30.00	-1.000	1.000
D	Applied Pressure	MPa	Numeric	10.00	20.00	-1.000	1.000

Design Matrix Evaluation for Response Surface Quadratic Model

4 Factors: A, B, C, D

Degrees of Freedom for Evaluation

Model	14
Residuals	15
Lack 0f Fit	*10*
Pure Error	*5*
Corr Total	29

				Power at 5 % alpha level for effect of		
Term	**StdErr****	**VIF**	**Ri-Squared**	**1/2 Std. Dev.**	**1 Std. Dev.**	**2 Std. Dev.**
A	0.20	1.00	0.0000	20.9 %	63.0 %	99.5 %
B	0.20	1.00	0.0000	20.9 %	63.0 %	99.5 %
C	0.20	1.00	0.0000	20.9 %	63.0 %	99.5 %
D	0.20	1.00	0.0000	20.9 %	63.0 %	99.5 %
A^2	0.19	1.05	0.0476	68.7 %	99.8 %	99.9 %
B^2	0.19	1.05	0.0476	68.7 %	99.8 %	99.9 %
C^2	0.19	1.05	0.0476	68.7 %	99.8 %	99.9 %
D^2	0.19	1.05	0.0476	68.7 %	99.8 %	99.9 %
AB	0.25	1.00	0.0000	15.5 %	46.5 %	96.2 %
AC	0.25	1.00	0.0000	15.5 %	46.5 %	96.2 %
AD	0.25	1.00	0.0000	15.5 %	46.5 %	96.2 %
BC	0.25	1.00	0.0000	15.5 %	46.5 %	96.2 %
BD	0.25	1.00	0.0000	15.5 %	46.5 %	96.2 %
CD	0.25	1.00	0.0000	15.5 %	46.5 %	96.2 %

**Basis Std. Dev. = 1.0

Measures Derived From the $(X'X)^{-1}$ Matrix

Std	Leverage	Point Type
1	0.5833	Fact
2	0.5833	Fact
3	0.5833	Fact
4	0.5833	Fact
5	0.5833	Fact
6	0.5833	Fact
7	0.5833	Fact
8	0.5833	Fact
9	0.5833	Fact
10	0.5833	Fact
11	0.5833	Fact
12	0.5833	Fact
13	0.5833	Fact
14	0.5833	Fact
15	0.5833	Fact
16	0.5833	Fact
17	0.5833	Axial
18	0.5833	Axial
19	0.5833	Axial
20	0.5833	Axial
21	0.5833	Axial
22	0.5833	Axial
23	0.5833	Axial
24	0.5833	Axial
25	0.1667	Center
26	0.1667	Center
27	0.1667	Center
28	0.1667	Center
29	0.1667	Center
30	0.1667	Center
Average =	0.5000	

Maximum Prediction Variance (at a design point) = 0.583

Average Prediction Variance = 0.500

Condition Number of Coefficient Matrix = 1.667

G Efficiency (calculated from the design points) = 85.7 %

Scaled D-optimality Criterion = 1.388

Correlation Matrix of Regression Coefficients

	Intercept	A	B	C	D	A^2	B^2
Intercept	1.000						
A	-0.000	1.000					
B	-0.000	-0.000	1.000				
C	-0.000	-0.000	-0.000	1.000			
D	-0.000	-0.000	-0.000	-0.000	1.000		
A^2	-0.535	-0.000	-0.000	-0.000	-0.000	1.000	
B^2	-0.535	-0.000	-0.000	-0.000	-0.000	0.143	1.000
C^2	-0.535	-0.000	-0.000	-0.000	-0.000	0.143	0.143
D^2	-0.535	-0.000	-0.000	-0.000	-0.000	0.143	0.143
AB	-0.000	-0.000	-0.000	-0.000	-0.000	-0.000	-0.000
AC	-0.000	-0.000	-0.000	-0.000	-0.000	-0.000	-0.000
AD	-0.000	-0.000	-0.000	-0.000	-0.000	-0.000	-0.000
BC	-0.000	-0.000	-0.000	-0.000	-0.000	-0.000	-0.000
BD	-0.000	-0.000	-0.000	-0.000	-0.000	-0.000	-0.000
CD	-0.000	-0.000	-0.000	-0.000	-0.000	-0.000	-0.000

	C^2	D^2	AB	AC	AD	BC	BD	CD
C^2	1.000							
D^2	0.143	1.000						
AB	-0.000	-0.000	1.000					
AC	-0.000	-0.000	-0.000	1.000				
AD	-0.000	-0.000	-0.000	-0.000	1.000			
BC	-0.000	-0.000	-0.000	-0.000	-0.000	1.000		
BD	-0.000	-0.000	-0.000	-0.000	-0.000	-0.000	1.000	
CD	-0.000	-0.000	-0.000	-0.000	-0.000	-0.000	-0.000	1.000

Correlation Matrix of Factors [Pearson's r]

	A	B	C	D	A^2	B^2	C^2
A	1.000						
B	0.000	1.000					
C	0.000	0.000	1.000				
D	0.000	0.000	0.000	1.000			
A^2	0.000	0.000	0.000	0.000	1.000		
B^2	0.000	0.000	0.000	0.000	-0.111	1.000	
C^2	0.000	0.000	0.000	0.000	-0.111	-0.111	1.000
D^2	0.000	0.000	0.000	0.000	-0.111	-0.111	-0.111
AB	0.000	0.000	0.000	0.000	0.000	0.000	0.000
AC	0.000	0.000	0.000	0.000	0.000	0.000	0.000
AD	0.000	0.000	0.000	0.000	0.000	0.000	0.000
BC	0.000	0.000	0.000	0.000	0.000	0.000	0.000
BD	0.000	0.000	0.000	0.000	0.000	0.000	0.000
CD	0.000	0.000	0.000	0.000	0.000	0.000	0.000

	D^2	AB	AC	AD	BC	BD	CD
D^2	1.000						
AB	0.000	1.000					
AC	0.000	0.000	1.000				
AD	0.000	0.000	0.000	1.000			
BC	0.000	0.000	0.000	0.000	1.000		
BD	0.000	0.000	0.000	0.000	0.000	1.000	
CD	0.000	0.000	0.000	0.000	0.000	0.000	1.000

Sequential Model Sum of Squares

Source	Sum of Squares	DF	Mean Square	F Value	Prob > F	
Mean	12497.86	1	12497.86			
Linear	337.16	4	84.29	7.58	0.0004	Suggested
2FI	14.06	6	2.34	0.17	0.9821	
Quadratic	121.80	4	30.45	3.22	0.0429	Suggested
Cubic	71.36	8	8.92	0.88	0.5712	Aliased
Residual	70.63	7	10.09			
Total	13112.86	30	437.10			

Lack of Fit Test

Source	Sum of Squares	DF	Mean Square	F Value	Prob > F	
Linear	277.78	20	13.89	1212.33	< 0.0001	Suggested
2FI	263.73	14	18.84	1644.27	< 0.0001	
Quadratic	141.93	10	14.19	1238.86	< 0.0001	Suggested
Cubic	70.57	2	35.28	3079.77	< 0.0001	Aliased
Pure Error	0.057	5	0.011			

Model Summary Statistics

Source	Std. Dev.	R-Squared	Adjusted R-Squared	Predicted R-Squared	PRESS	
Linear	3.33	0.5482	0.4759	0.3634	391.50	Suggested
2FI	3.73	0.5711	0.3453	0.2246	476.85	
Quadratic	3.08	0.7691	0.5536	-0.3294	817.61	Suggested
Cubic	3.18	0.8852	0.5242	-15.5233	10161.83	Aliased

ANOVA for Response Surface Quadratic Model

Analysis of variance table [Partial sum of squares]

Source	Sum of Squares	DF	Mean Square	F Value	Prob > F	
Model	473.01	14	33.79	3.57	0.0099	significant
A	186.26	1	186.26	19.68	0.0005	
B	54.06	1	54.06	5.71	0.0304	
C	14.48	1	14.48	1.53	0.2352	
D	82.36	1	82.36	8.70	0.0099	
A^2	68.22	1	68.22	7.21	0.0170	
B^2	14.25	1	14.25	1.51	0.2387	
C^2	52.87	1	52.87	5.59	0.0320	
D^2	30.87	1	30.87	3.26	0.0911	
AB	7.18	1	7.18	0.76	0.3974	
AC	0.62	1	0.62	0.065	0.8021	
AD	2.46	1	2.46	0.26	0.6173	
BC	1.90	1	1.90	0.20	0.6602	
BD	1.45	1	1.45	0.15	0.7008	
CD	0.44	1	0.44	0.046	0.8330	
Residual	141.99	15	9.47			
Lack of Fit	141.93	10	14.19	1238.86	< 0.0001	significant
Pure Error	0.057	5	0.011			
Cor Total	615.00	29				

Std. Dev.	3.08	R-Squared	0.7691
Mean	20.41	Adj R-Squared	0.5536
C.V.	15.07	Pred R-Squared	-0.3294
PRESS	817.61	Adeq Precision	6.952

Coefficient	Standard			95% CI	95% CI	
Factor	Estimate	DF	Error	Low	High	VIF
Intercept	24.21	1	1.26	21.53	26.89	
A-A	2.79	1	0.63	1.45	4.12	1.00
B-B	1.50	1	0.63	0.16	2.84	1.00
C-C	0.78	1	0.63	-0.56	2.12	1.00
D-D	1.85	1	0.63	0.51	3.19	1.00
A^2	-1.58	1	0.59	-2.83	-0.32	1.05
B^2	-0.72	1	0.59	-1.97	0.53	1.05
C^2	-1.39	1	0.59	-2.64	-0.14	1.05
D^2	-1.06	1	0.59	-2.31	0.19	1.05
AB	0.67	1	0.77	-0.97	2.31	1.00
AC	-0.20	1	0.77	-1.84	1.44	1.00
AD	0.39	1	0.77	-1.25	2.03	1.00
BC	0.35	1	0.77	-1.29	1.98	1.00
BD	-0.30	1	0.77	-1.94	1.34	1.00
CD	0.37	1	0.77	-1.47	1.80	1.00

Linear Model for Oil Yield

Final Equation in Terms of Coded Factors:

$Y = +20.41 + 2.79M_c + 1.50H_T + 0.78H_t + 1.85A_p$

Final Equation in Terms of Actual Factors:

$Y = -27.39433 + 2.78583M_c + 0.15008H_T + 0.15533H_t + 0.37050A_p$

[Std. Dev. = 3.33, R-Squared = 0.5482, Mean = 20.41, Adj R-Squared = 0.4759 C.V. = 16.33, Pred R-Squared = 0.3634, PRESS = 391.50, Adeq Precision = 10.163].

2FI Model for Oil Yield

Final Equation in Terms of Coded Factors:

$Y = +20.41 + 2.79M_c + 1.50H_T + 0.78H_t + 1.85A_p + 0.67M_cH_T - 0.20M_cH_t + 0.39M_cA_p + 0.35H_TH_t - 0.30H_TA_p + 0.17H_tA_p$

Final Equation in Terms of Actual Factors:

$Y = +29.69192 - 2.10042M_c - 0.60204H_T - 0.034167H_t - 0.15775A_p + 0.067000M_cH_T - 0.039250M_cH_t + 0.078500M_cA_p + 0.006900H_TH_t – 0.006025H_TA_p + 0.006600H_tA_p$

[Std. Dev. = 3.73, R-Squared = 0.5711, Mean = 20.41, Adj R-Squared = 0.3453
C.V. = 18.26, Pred R-Squared = 0.2246, PRESS = 476.85, Adeq Precision = 6.130].

Quadratic Model for Oil Yield

Final Equation in Terms of Coded Factors

$Y = +24.21 + 2.79M_c + 1.50H_T + 0.78H_t + 1.85A_p - 1.58M_c^2 - 0.72H_T^2 - 1.39H_t^2 - 1.06A_p^2 + 0.67M_cH_T - 0.20M_cH_t + 0.39M_cA_p + 0.35H_TH_t - 0.30H_TA_p + 0.17H_tA_p$

Final Equation in Terms of Actual Factors

$Y = -203.79542 + 29.44125M_c + 0.40712H_T + 2.74250H_t + 1.11525A_p – 1.57708\ M_c^2 – 0.007208H_T^2 – 0.055533H_t^2 – 0.042433A_p^2 + 0.067000M_cH_T – 0.039250M_cH_t + 0.078500M_cA_p + 0.006900H_TH_t – 0.006025H_TA_p + 0.006600H_tA_p$

[Std. Dev. = 3.08, R-Squared = 0.7691, Mean = 20.41, Adj R-Squared = 0.5536, C.V. = 15.07, Pred R-Squared = -0.3294, PRESS = 817.61, Adeq Precision = 6.952].

Cubic Model for Oil Yield

Final Equation in Terms of Coded Factors:

$Y = +24.21 + 4.67M_c + 2.28H_T + 0.55H_t + 0.64A_p - 1.58M_c^2 - 0.72H_T^2 - 1.39H_t^2 - 1.06A_p^2 + 0.67M_cH_T - 0.20M_cH_t + 0.39M_cA_p + 0.35H_TH_t - 0.30H_TA_p + 0.17H_tA_p - 0.94M_c^3 - 0.39H_T^3 + 0.11H_t^3 + 0.60A_p^3 - 0.41M_cH_TH_t - 0.12\ M_cH_TA_p - 0.11M_cH_tA_p - 0.058H_TH_tA_p$

Final Equation in Terms of Actual Factors:

Not available for aliased models.

[Std. Dev. = 3.18, R-Squared = 0.8852, Mean = 20.41, Adj R-Squared = 0.5242,
C.V. = 15.56, Pred R-Squared = -15.5233, PRESS = 10161.83, Adeq Precision = 5.080].

Where,

Y = Oil yield (%)

M_c = Moisture content (%wb)

H_T = Heating temperature (^oC)

H_t = Heating time (mins)

A_p = Applied pressure (MPa)

Diagnostics Case Statistics

Standard Order	Actual Value	Predicted Value	Residual	Leverage	Student Residual	Cook's Distance	Outlier t	Run Order
1	14.91	13.62	1.29	0.583	0.649	0.039	0.636	24
2	19.36	17.46	1.90	0.583	0.957	0.085	0.954	16
3	16.10	15.19	0.91	0.583	0.456	0.019	0.444	29
4	25.33	21.71	3.62	0.583	1.821	0.309	1.993	7
5	14.46	14.55	-0.086	0.583	-0.043	0.000	-0.042	30
6	20.20	17.60	2.60	0.583	1.309	0.160	1.344	23
7	18.88	17.50	1.38	0.583	0.695	0.045	0.682	4
8	26.16	23.23	2.93	0.583	1.473	0.203	1.539	3
9	16.32	16.81	-0.49	0.583	-0.248	0.006	-0.240	10
10	23.26	22.22	1.04	0.583	0.523	0.025	0.510	2
11	17.00	17.18	-0.18	0.583	-0.092	0.001	-0.089	27
12	27.79	25.27	2.52	0.583	1.268	0.150	1.297	9
13	17.20	18.40	-1.20	0.583	-0.604	0.034	-0.590	14
14	24.55	23.02	1.53	0.583	0.769	0.055	0.758	12
15	20.68	20.15	0.53	0.583	0.268	0.007	0.259	13
16	28.58	27.45	1.13	0.583	0.568	0.030	0.555	19
17	13.68	12.33	1.35	0.583	0.681	0.043	0.668	15
18	17.27	23.47	-6.20	0.583	-3.123	0.910	-5.100 *	8
19	17.46	18.32	-0.86	0.583	-0.435	0.018	-0.423	26
20	20.34	24.33	-3.99	0.583	-2.007	0.376	-2.268	28
21	14.23	17.10	-2.87	0.583	-1.446	0.195	-1.506	20
22	18.23	20.21	-1.98	0.583	-0.996	0.093	-0.996	5
23	11.42	16.26	-4.84	0.583	-2.437	0.554	-3.029	18
24	23.66	23.67	-0.010	0.583	-0.005	0.000	-0.005	11
25	24.30	24.21	0.092	0.167	0.033	0.000	0.032	25
26	24.09	24.21	-0.12	0.167	-0.042	0.000	-0.041	6
27	24.34	24.21	0.13	0.167	0.047	0.000	0.045	1
28	24.08	24.21	-0.13	0.167	-0.046	0.000	-0.044	17
29	24.24	24.21	0.032	0.167	0.011	0.000	0.011	22
30	24.20	24.21	-8.333E-003	0.167	-0.003	0.000	-0.003	21

* Case(s) with |Outlier T| > 3.50

APPENDIX H

STATISTICAL ANALYSIS RESULTS

Tests of Between-Subjects Effects

Dependent Variable: Yield

Source	Type III Sum of Squares	Df	Mean Square	F	Sig.
Corrected Model	614.945[a]	24	25.623	2236.489	.000
Intercept	4360.995	1	4360.995	380651.270	.000
MC	311.447	3	103.816	9061.608	.000
HT	101.561	4	25.390	2216.197	.000
TH	110.887	3	36.962	3226.275	.000
AP	163.243	3	54.414	4749.580	.000
MC * HT	3.566	1	3.566	311.243	.000
MC * TH	.990	1	.990	86.415	.000
MC * AP	1.346	1	1.346	117.451	.000
HT * TH	.717	1	.717	62.570	.001
HT * AP	1.243	1	1.243	108.515	.000
TH * AP	.197	1	.197	17.155	.009
MC * HT * TH	1.361	1	1.361	118.817	.000
MC * HT * AP	.123	1	.123	10.694	.022
MC * TH * AP	.110	1	.110	9.641	.027
HT * TH * AP	.030	1	.030	2.620	.166
MC * HT * TH * AP	.000	0	.	.	.
Error	.057	5	.011		
Total	13112.862	30			
Corrected Total	615.002	29			

a. R Squared = 1.000 (Adjusted R Squared = .999)

Estimated Marginal Means

Grand Mean

Dependent Variable: Yield

Mean	Std. Error	95% Confidence Interval	
		Lower Bound	Upper Bound
19.651[a]	.021	19.597	19.705

Univariate Analysis of Variance

Between-Subjects Factors

		Value Label	N
Moisture Cont	8.00	Lowest	1
	9.00	Lower	8
	10.00	Medium	12
	11.00	Higher	8
	12.00	Highest	1
Heating Temp	50.00	Lowest	1
	60.00	Lower	7
	70.00	Medium	13
	80.00	Higher	8
	90.00	Highest	1
Heating Time	15.00	Lowest	1
	20.00	Lower	8
	25.00	Medium	12
	30.00	Higher	8
	35.00	Highest	1
App. Pressure	5.00	Lowest	1
	10.00	Lower	8
	15.00	Medium	12
	20.00	Higher	8
	25.00	Highest	1

Tests of Between-Subjects Effects

Dependent Variable: FFA

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	77.550[a]	24	3.231	137.911	.000
Intercept	378.570	1	378.570	16157.475	.000
MC	1.194	3	.398	16.986	.005
HT	69.816	4	17.454	744.943	.000
TH	3.438	3	1.146	48.912	.000
AP	.710	3	.237	10.094	.015
MC * HT	.002	1	.002	.086	.781
MC * TH	.008	1	.008	.333	.589
MC * AP	.002	1	.002	.086	.781
HT * TH	.250	1	.250	10.670	.022
HT * AP	.004	1	.004	.180	.689
TH * AP	4.444E-005	1	4.444E-005	.002	.967
MC * HT * TH	.005	1	.005	.193	.679
MC * HT * AP	.000	1	.000	.005	.947
MC * TH * AP	.002	1	.002	.090	.776
HT * TH * AP	.005	1	.005	.193	.679
MC * HT * TH * AP	.000	0	.	.	.
Error	.117	5	.023		
Total	892.303	30			
Corrected Total	77.667	29			

a. R Squared = .998 (Adjusted R Squared = .991)

Estimated Marginal Means

Grand Mean

Dependent Variable: FFA

Mean	Std. Error	95% Confidence Interval	
		Lower Bound	Upper Bound
5.156[a]	.030	5.079	5.234

Univariate Analysis of Variance

Between-Subjects Factors

		Value Label	N
Moisture Cont	8.00	Lowest	1
	9.00	Lower	8
	10.00	Medium	12
	11.00	Higher	8
	12.00	Highest	1
Heating Temp	50.00	Lowest	1
	60.00	Lower	7
	70.00	Medium	13
	80.00	Higher	8
	90.00	Highest	1
Heating Time	15.00	Lowest	1
	20.00	Lower	8
	25.00	Medium	12
	30.00	Higher	8
	35.00	Highest	1
App. Pressure	5.00	Lowest	1
	10.00	Lower	8
	15.00	Medium	12
	20.00	Higher	8
	25.00	Highest	1

Tests of Between-Subjects Effects

Dependent Variable: Colour

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	6.755[a]	24	.281	105.542	.000
Intercept	597.183	1	597.183	223943.497	.000
MC	.102	3	.034	12.779	.009
HT	6.145	4	1.536	576.080	.000
TH	.337	3	.112	42.090	.001
AP	.009	3	.003	1.121	.424
MC * HT	.000	1	.000	.104	.760
MC * TH	.000	1	.000	.104	.760
MC * AP	.000	1	.000	.104	.760
HT * TH	.014	1	.014	5.104	.073
HT * AP	.000	1	.000	.104	.760
TH * AP	.000	1	.000	.104	.760
MC * HT * TH	.005	1	.005	1.875	.229
MC * HT * AP	.001	1	.001	.469	.524
MC * TH * AP	.001	1	.001	.469	.524
HT * TH * AP	.005	1	.005	1.875	.229
MC * HT * TH * AP	.000	0	.	.	.
Error	.013	5	.003		
Total	1305.660	30			
Corrected Total	6.768	29			

a. R Squared = .998 (Adjusted R Squared = .989)

Estimated Marginal Means

Grand Mean

Dependent Variable: Colour

Mean	Std. Error	95% Confidence Interval	
		Lower Bound	Upper Bound
6.583[a]	.010	6.557	6.609

Univariate Analysis of Variance

Between-Subjects Factors

		Value Label	N
Moisture Cont	8.00	Lowest	1
	9.00	Lower	8
	10.00	Medium	12
	11.00	Higher	8
	12.00	Highest	1
Heating Temp	50.00	Lowest	1
	60.00	Lower	7
	70.00	Medium	13
	80.00	Higher	8
	90.00	Highest	1
Heating Time	15.00	Lowest	1
	20.00	Lower	8
	25.00	Medium	12
	30.00	Higher	8
	35.00	Highest	1
App. Pressure	5.00	Lowest	1
	10.00	Lower	8
	15.00	Medium	12
	20.00	Higher	8
	25.00	Highest	1

Tests of Between-Subjects Effects

Dependent Variable: Impurity

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	2.117[a]	24	.088	367.465	.000
Intercept	100.960	1	100.960	420665.954	.000
MC	.038	3	.013	52.369	.000
HT	1.837	4	.459	1913.795	.000
TH	.137	3	.046	190.055	.000
AP	.008	3	.003	11.163	.012
MC * HT	2.500E-005	1	2.500E-005	.104	.760
MC * TH	.002	1	.002	8.438	.034
MC * AP	6.944E-005	1	6.944E-005	.289	.614
HT * TH	.005	1	.005	20.417	.006
HT * AP	.000	1	.000	1.157	.331
TH * AP	2.778E-006	1	2.778E-006	.012	.919
MC * HT * TH	.001	1	.001	5.208	.071
MC * HT * AP	.000	1	.000	.833	.403
MC * TH * AP	.000	1	.000	1.875	.229
HT * TH * AP	1.250E-005	1	1.250E-005	.052	.829
MC * HT * TH * AP	.000	0	.	.	.
Error	.001	5	.000		
Total	219.201	30			
Corrected Total	2.118	29			

a. R Squared = .999 (Adjusted R Squared = .997)

Estimated Marginal Means

Grand Mean

Dependent Variable: Impurity

Mean	Std. Error	95% Confidence Interval	
		Lower Bound	Upper Bound
2.682[a]	.003	2.674	2.690

a. Based on modified population marginal mean.

Between-Subjects Factors

		Value Label	N
Moisture Cont	8.00	Lowest	1
	9.00	Lower	8
	10.00	Medium	12
	11.00	Higher	8
	12.00	Highest	1
Heating Temp	50.00	Lowest	1
	60.00	Lower	7
	70.00	Medium	13
	80.00	Higher	8
	90.00	Highest	1
Heating Time	15.00	Lowest	1
	20.00	Lower	8
	25.00	Medium	12
	30.00	Higher	8
	35.00	Highest	1
App. Pressure	5.00	Lowest	1
	10.00	Lower	8
	15.00	Medium	12
	20.00	Higher	8
	25.00	Highest	1

Multivariate Tests[a]

Effect		Value	F	Hypothesis df	Error df	Sig.
Intercept	Pillai's Trace	1.000	634411.992[b]	3.000	3.000	.000
	Wilks' Lambda	.000	634411.992[b]	3.000	3.000	.000
	Hotelling's Trace	634411.992	634411.992[b]	3.000	3.000	.000
	Roy's Largest Root	634411.992	634411.992[b]	3.000	3.000	.000
MC	Pillai's Trace	1.783	2.440	9.000	15.000	.061
	Wilks' Lambda	.001	11.504	9.000	7.452	.002
	Hotelling's Trace	154.565	28.623	9.000	5.000	.001
	Roy's Largest Root	150.856	251.427[c]	3.000	5.000	.000
HT	Pillai's Trace	2.269	3.878	12.000	15.000	.008
	Wilks' Lambda	.000	54.150	12.000	8.229	.000
	Hotelling's Trace	3225.408	447.973	12.000	5.000	.000
	Roy's Largest Root	3202.698	4003.373[c]	4.000	5.000	.000
TH	Pillai's Trace	2.166	4.330	9.000	15.000	.006
	Wilks' Lambda	.000	30.751	9.000	7.452	.000
	Hotelling's Trace	212.549	39.361	9.000	5.000	.000
	Roy's Largest Root	182.729	304.548[c]	3.000	5.000	.000
AP	Pillai's Trace	1.692	2.157	9.000	15.000	.090
	Wilks' Lambda	.018	3.526	9.000	7.452	.050
	Hotelling's Trace	19.450	3.602	9.000	5.000	.086
	Roy's Largest Root	17.627	29.378[c]	3.000	5.000	.001
MC * HT	Pillai's Trace	.269	.369[b]	3.000	3.000	.783
	Wilks' Lambda	.731	.369[b]	3.000	3.000	.783
	Hotelling's Trace	.369	.369[b]	3.000	3.000	.783
	Roy's Largest Root	.369	.369[b]	3.000	3.000	.783
MC * TH	Pillai's Trace	.830	4.867[b]	3.000	3.000	.113
	Wilks' Lambda	.170	4.867[b]	3.000	3.000	.113
	Hotelling's Trace	4.867	4.867[b]	3.000	3.000	.113
	Roy's Largest Root	4.867	4.867[b]	3.000	3.000	.113
MC * AP	Pillai's Trace	.103	.115[b]	3.000	3.000	.946
	Wilks' Lambda	.897	.115[b]	3.000	3.000	.946
	Hotelling's Trace	.115	.115[b]	3.000	3.000	.946
	Roy's Largest Root	.115	.115[b]	3.000	3.000	.946
HT * TH	Pillai's Trace	.904	9.424[b]	3.000	3.000	.049
	Wilks' Lambda	.096	9.424[b]	3.000	3.000	.049
	Hotelling's Trace	9.424	9.424[b]	3.000	3.000	.049
	Roy's Largest Root	9.424	9.424[b]	3.000	3.000	.049
HT * AP	Pillai's Trace	.461	.854[b]	3.000	3.000	.550
	Wilks' Lambda	.539	.854[b]	3.000	3.000	.550
	Hotelling's Trace	.854	.854[b]	3.000	3.000	.550
	Roy's Largest Root	.854	.854[b]	3.000	3.000	.550

TH * AP	Pillai's Trace	.045	.047[b]	3.000	3.000	.984
	Wilks' Lambda	.955	.047[b]	3.000	3.000	.984
	Hotelling's Trace	.047	.047[b]	3.000	3.000	.984
	Roy's Largest Root	.047	.047[b]	3.000	3.000	.984
MC * HT * TH	Pillai's Trace	.890	8.070[b]	3.000	3.000	.060
	Wilks' Lambda	.110	8.070[b]	3.000	3.000	.060
	Hotelling's Trace	8.070	8.070[b]	3.000	3.000	.060
	Roy's Largest Root	8.070	8.070[b]	3.000	3.000	.060
MC * HT * AP	Pillai's Trace	.577	1.365[b]	3.000	3.000	.402
	Wilks' Lambda	.423	1.365[b]	3.000	3.000	.402
	Hotelling's Trace	1.365	1.365[b]	3.000	3.000	.402
	Roy's Largest Root	1.365	1.365[b]	3.000	3.000	.402
MC * TH * AP	Pillai's Trace	.669	2.025[b]	3.000	3.000	.289
	Wilks' Lambda	.331	2.025[b]	3.000	3.000	.289
	Hotelling's Trace	2.025	2.025[b]	3.000	3.000	.289
	Roy's Largest Root	2.025	2.025[b]	3.000	3.000	.289
HT * TH * AP	Pillai's Trace	.589	1.432[b]	3.000	3.000	.388
	Wilks' Lambda	.411	1.432[b]	3.000	3.000	.388
	Hotelling's Trace	1.432	1.432[b]	3.000	3.000	.388
	Roy's Largest Root	1.432	1.432[b]	3.000	3.000	.388
MC * HT * TH * AP	Pillai's Trace	.000	.[b]	.000	.000	.
	Wilks' Lambda	1.000	.[b]	.000	4.000	.
	Hotelling's Trace	.000	.[b]	.000	2.000	.
	Roy's Largest Root	.000	.000[b]	3.000	2.000	1.000

a. Design: Intercept + MC + HT + TH + AP + MC * HT + MC * TH + MC * AP + HT * TH + HT * AP + TH * AP + MC * HT * TH + MC * HT * AP + MC * TH * AP + HT * TH * AP + MC * HT * TH * AP

b. Exact statistic

c. The statistic is an upper bound on F that yields a lower bound on the significance level.

Tests of Between-Subjects Effects

Source	Dependent Variable	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	FFA	77.550[a]	24	3.231	137.911	.000
	Colour	6.755[b]	24	.281	105.542	.000
	Impurity	2.117[c]	24	.088	367.465	.000
Intercept	FFA	378.570	1	378.570	16157.475	.000
	Colour	597.183	1	597.183	223943.497	.000
	Impurity	100.960	1	100.960	420665.954	.000
MC	FFA	1.194	3	.398	16.986	.005
	Colour	.102	3	.034	12.779	.009
	Impurity	.038	3	.013	52.369	.000
HT	FFA	69.816	4	17.454	744.943	.000
	Colour	6.145	4	1.536	576.080	.000
	Impurity	1.837	4	.459	1913.795	.000
TH	FFA	3.438	3	1.146	48.912	.000
	Colour	.337	3	.112	42.090	.001
	Impurity	.137	3	.046	190.055	.000
AP	FFA	.710	3	.237	10.094	.015
	Colour	.009	3	.003	1.121	.424
	Impurity	.008	3	.003	11.163	.012
MC * HT	FFA	.002	1	.002	.086	.781
	Colour	.000	1	.000	.104	.760
	Impurity	2.500E-005	1	2.500E-005	.104	.760
MC * TH	FFA	.008	1	.008	.333	.589
	Colour	.000	1	.000	.104	.760
	Impurity	.002	1	.002	8.438	.034
MC * AP	FFA	.002	1	.002	.086	.781
	Colour	.000	1	.000	.104	.760
	Impurity	6.944E-005	1	6.944E-005	.289	.614
HT * TH	FFA	.250	1	.250	10.670	.022
	Colour	.014	1	.014	5.104	.073
	Impurity	.005	1	.005	20.417	.006
HT * AP	FFA	.004	1	.004	.180	.689
	Colour	.000	1	.000	.104	.760
	Impurity	.000	1	.000	1.157	.331
TH * AP	FFA	4.444E-005	1	4.444E-005	.002	.967
	Colour	.000	1	.000	.104	.760
	Impurity	2.778E-006	1	2.778E-006	.012	.919
MC * HT * TH	FFA	.005	1	.005	.193	.679
	Colour	.005	1	.005	1.875	.229
	Impurity	.001	1	.001	5.208	.071
MC * HT *	FFA	.000	1	.000	.005	.947

AP	Colour	.001	1	.001	.469	.524
	Impurity	.000	1	.000	.833	.403
MC * TH * AP	FFA	.002	1	.002	.090	.776
	Colour	.001	1	.001	.469	.524
	Impurity	.000	1	.000	1.875	.229
HT * TH * AP	FFA	.005	1	.005	.193	.679
	Colour	.005	1	.005	1.875	.229
	Impurity	1.250E-005	1	1.250E-005	.052	.829
MC * HT * TH * AP	FFA	.000	0	.	.	.
	Colour	.000	0	.	.	.
	Impurity	.000	0	.	.	.
Error	FFA	.117	5	.023		
	Colour	.013	5	.003		
	Impurity	.001	5	.000		
Total	FFA	892.303	30			
	Colour	1305.660	30			
	Impurity	219.201	30			
Corrected Total	FFA	77.667	29			
	Colour	6.768	29			
	Impurity	2.118	29			

a. R Squared = .998 (Adjusted R Squared = .991)

b. R Squared = .998 (Adjusted R Squared = .989)

c. R Squared = .999 (Adjusted R Squared = .997)

APPENDIX I

MODELLING OF FREE FATTY ACID

Design Summary

Study Type	Response Surface	**Experiments**	30
Initial Design	Central Composite	**Blocks**	No Blocks
Design Model	Linear		

Response	Name	Units	Obs	Minimum	Maximum	Trans	Model
Y1	FFA	mg/KOH/g	30	2.42	7.40	None	Linear

Factor	Name	Units	Type	Low Actual	High Actual	Low Coded	High Coded
A	Moisture Content	% wb	Numeric	9.00	11.00	-1.000	1.000
B	Heating Temp.	^{o}C	Numeric	60.00	80.00	-1.000	1.000
C	Heating Time	mins	Numeric	20.00	30.00	-1.000	1.000
D	Applied Pressure	MPa	Numeric	10.00	20.00	-1.000	1.000

Design Matrix Evaluation for Response Surface Linear Model

4 Factors: A, B, C, D

Degrees of Freedom for Evaluation

Model	4
Residuals	25
Lack 0f Fit	*20*
Pure Error	*5*
Corr Total	29

				Power at 5 % alpha level for effect of		
Term	**StdErr****	**VIF**	**Ri-Squared**	**1/2 Std. Dev.**	**1 Std. Dev.**	**2 Std. Dev.**
A	0.20	1.00	0.0000	21.8 %	65.3 %	99.7 %
B	0.20	1.00	0.0000	21.8 %	65.3 %	99.7 %
C	0.20	1.00	0.0000	21.8 %	65.3 %	99.7 %
D	0.20	1.00	0.0000	21.8 %	65.3 %	99.7 %

**Basis Std. Dev. = 1.0

Measures Derived From the $(X'X)^{-1}$ Matrix

Std	Leverage	Point Type
1	0.2000	Fact
2	0.2000	Fact
3	0.2000	Fact
4	0.2000	Fact
5	0.2000	Fact
6	0.2000	Fact
7	0.2000	Fact
8	0.2000	Fact
9	0.2000	Fact
10	0.2000	Fact
11	0.2000	Fact
12	0.2000	Fact
13	0.2000	Fact
14	0.2000	Fact
15	0.2000	Fact
16	0.2000	Fact
17	0.2000	Axial
18	0.2000	Axial
19	0.2000	Axial
20	0.2000	Axial
21	0.2000	Axial
22	0.2000	Axial
23	0.2000	Axial
24	0.2000	Axial
25	0.0333	Center
26	0.0333	Center
27	0.0333	Center
28	0.0333	Center
29	0.0333	Center
30	0.0333	Center
Average =	0.1667	

Maximum Prediction Variance (at a design point) = 0.200

Average Prediction Variance = 0.167

Condition Number of Coefficient Matrix = 1.000

G Efficiency (calculated from the design points) = 83.3 %

Scaled D-optimality Criterion = 1.195

Correlation Matrix of Regression Coefficients

	Intercept	A	B	C	D
Intercept	1.000				
A	-0.000	1.000			
B	-0.000	-0.000	1.000		
C	-0.000	-0.000	-0.000	1.000	
D	-0.000	-0.000	-0.000	-0.000	1.000

Correlation Matrix of Factors [Pearson's r]

	A	B	C	D
A	1.000			
B	0.000	1.000		
C	0.000	0.000	1.000	
D	0.000	0.000	0.000	1.000

Sequential Model Sum of Squares

Source	Sum of Squares	DF	Mean Square	F Value	Prob > F	
Mean	792.90	1	792.90			
Linear	67.63	4	16.91	59.71	< 0.0001	Suggested
2FI	1.56	6	0.26	0.89	0.5202	
Quadratic	1.20	4	0.30	1.04	0.4213	
Cubic	3.48	8	0.44	3.61	0.539	Aliased
Residual	0.84	7	0.12			
Total	867.61	30	28.92			

Lack of Fit Tests

Source	Sum of Squares	DF	Mean Square	F Value	Prob > F	
Linear	6.96	20	0.35	14.86	0.0036	Suggested
2FI	5.41	14	0.39	16.48	0.0030	
Quadratic	4.21	10	0.42	17.97	0.0026	
Cubic	0.73	2	0.36	15.52	0.0072	Aliased
Pure Error	0.12	5	0.023			

Model Summary Statistics

Source	Std. Dev.	R-Squared	Adjusted R-Squared	Predicted R-Squared	PRESS	
Linear	0.53	0.9052	0.8901	0.8574	10.65	Suggested
2FI	0.54	0.9261	0.8872	0.7488	18.77	
Quadratic	0.54	0.9421	0.8880	0.6731	24.42	
Cubic	0.35	0.9887	0.9532	-0.4037	104.87	Aliased

ANOVA for Response Surface Linear Model

Analysis of variance table [Partial sum of squares]

Source	Sum of Squares	DF	Mean Square	F Value	Prob > F	
Model	67.63	4	16.91	3.57	< 0.0001	significant
A	0.26	1	0.26	19.68	0.3486	
B	61.47	1	61.47	5.71	< 0.0001	
C	4.74	1	4.74	1.53	0.0004	
D	1.16	1	1.16	4.09	0.0540	
Residual	7.08	25	0.28			
Lack of Fit	6.96	20	0.35	14.86	0.0036	significant
Pure Error	0.12	5	0.023			
Cor Total	74.71	29				

Std. Dev.	0.53	R-Squared	0.9052
Mean	5.41	Adj R-Squared	0.8901
C.V.	10.35	Pred R-Squared	0.8574
PRESS	10.65	Adeq Precision	29.468

Coefficient Factor	Standard Estimate	DF	Error	95% CI Low	95% CI High	VIF
Intercept	5.14	1	0.097	4.94	5.34	
A-A	0.10	1	0.11	-0.12	0.33	1.00
B-B	1.60	1	0.11	-1.82	-1.38	1.00
C-C	0.44	1	0.11	-0.67	-0.22	1.00
D-D	0.22	1	0.11	-0.44	4.124E-003	1.00

Linear Model for Free Fatty Acid

Final Equation in Terms of Coded Factors:

$FFA = +5.14 + 0.10M_c - 1.60H_T - 0.44H_t - 0.22A_p$

Final Equation in Terms of Actual Factors:

$FFA = +18.18808 + 0.10375M_c - 0.16004H_T - 0.088917H_t - 0.043917A_p$

[Std. Dev. = 0.53, R-Squared = 0.9052, Mean = 5.14, Adj R-Squared = 0.8901 C.V. = 10.35, Pred R-Squared = 0.8574, PRESS = 10.65, Adeq Precision = 29.468].

2FI Model for Free Fatty Acid

Final Equation in Terms of Coded Factors:

$FFA = +5.14 + 0.10M_c - 1.60H_T - 0.44H_t – 0.22A_p + 0.16M_cH_T - 0.15M_cH_t - 0.14M_cA_p - 0.01H_TH_t + 0.11H_TA_p - 0.13H_tA_p$

Final Equation in Terms of Actual Factors:

$FFA = +17.57746 + 0.16813M_c - 0.34592H_T + 0.30208H_t + 0.21033A_p + 0.\ 015687M_cH_T - 0.029625M_cH_t - 0.028125M_cA_p - 0.000213H_TH_t + 0.002288H_TA_p - 0.005325H_tA_p$

[Std. Dev. = 0.54, R-Squared = 0.9261, Mean = 5.14, Adj R-Squared = 0.8872

C.V. = 10.49, Pred R-Squared = 0.7488, PRESS = 18.77, Adeq Precision = 19.608].

Quadratic Model for Free Fatty Acid

Final Equation in Terms of Coded Factors

$FFA = +5.49 + 0.10M_c - 1.60H_T - 0.44H_t - 0.22A_p - 0.077M_c^2 - 0.19H_T^2 - 0.097H_t^2 – 0.067A_p^2 + 0.16M_cH_T - 0.15M_cH_t - 0.14M_cA_p - 0.011H_TH_t + 0.11H_TA_p - 0.13H_tA_p$

Final Equation in Terms of Actual Factors

$FFA = -2.07323 + 1.69937M_c - 0.079479H_T + 0.49521H_t + 0.29021A_p - 0.076562M_c^2 - 0.001903H_T^2 - 0.003863H_t^2 - 0.002663A_p^2 + 0.015687M_cH_T - 0.029625M_cH_t - 0.028125M_cA_p - 0.000213H_TH_t + 0.002288H_TA_p - 0.005325H_tA_p$

[Std. Dev. = 0.54, R-Squared = 0.9421, Mean = 5.14, Adj R-Squared = 0.8880,

C.V. = 10.45, Pred R-Squared = 0.6731, PRESS = 24.42, Adeq Precision = 16.854].

Cubic Model for Free Fatty Acid

Final Equation in Terms of Coded Factors:

$FFA = +5.49 – 0.15M_c - 1.96H_T - 0.33H_t - 0.15A_p – 0.077M_c^2 - 0.19H_T^2 - 0.097H_t^2 – 0.067A_p^2 + 0.16M_cH_T - 0.15M_cH_t - 0.14M_cA_p - 0.011H_TH_t + 0.11H_TA_p - 0.13H_tA_p + 0.12M_c^3 + 0.18H_T^3 - 0.059H_t^3 - 0.034A_p^3 + 0.099M_cH_TH_t + 0.13\ M_cH_TA_p - 0.12M_cH_tA_p + 0.15H_TH_tA_p$

Final Equation in Terms of Actual Factors:

Not available for aliased models.

[Std. Dev. = 0.35, R-Squared = 0.9887, Mean = 5.14, Adj R-Squared = 0.9532,

C.V. = 6.76, Pred R-Squared = -0.4037, PRESS = 104.87, Adeq Precision = 17.130].

Where,

M_c = Moisture content, %wb

H_T = Heating temperature, ^oC

H_t = Heating time, mins

A_p = Applied pressure, MPa

FFA = Free Fatty Acid, mg/KOH/g

Diagnostics Case Statistics

Standard Order	Actual Value	Predicted Value	Residual	Leverage	Student Residual	Cook's Distance	Outlier t	Run Order
1	7.06	7.30	-0.24	0.200	-0.508	0.013	-0.500	14
2	7.21	7.51	-0.30	0.200	-0.629	0.020	-0.621	18
3	3.45	4.10	-0.65	0.200	-1.368	0.094	-1.393	10
4	3.88	4.31	-0.43	0.200	-0.900	0.041	-0.897	12
5	6.84	6.41	0.43	0.200	0.898	0.040	0.894	15
6	7.05	6.62	0.43	0.200	0.903	0.041	0.900	23
7	2.76	3.21	-0.45	0.200	-0.949	0.045	-0.947	16
8	2.93	3.42	-0.49	0.200	-1.028	0.053	-1.029	19
9	7.03	6.86	0.17	0.200	0.352	0.006	0.345	26
10	7.16	7.07	0.090	0.200	0.189	0.002	0.185	20
11	3.34	3.66	-0.32	0.200	-0.676	0.023	-0.669	28
12	3.65	3.87	-0.22	0.200	-0.461	0.011	-0.453	24
13	6.74	5.97	0.77	0.200	1.610	0.130	1.667	21
14	4.83	6.18	-1.35	0.200	-2.839	0.403	-3.378	30
15	2.64	2.77	-0.13	0.200	-0.279	0.004	-0.274	4
16	2.82	2.98	-0.16	0.200	-0.337	0.006	-0.330	5
17	4.66	4.93	-0.27	0.200	-0.575	0.017	-0.567	8
18	6.07	5.35	0.72	0.200	1.516	0.115	1.559	22
19	7.40	8.34	-0.94	0.200	-1.979	0.196	-2.111	7
20	2.42	1.94	0.48	0.200	1.008	0.051	1.009	1
21	6.41	6.03	0.38	0.200	0.798	0.032	0.792	11
22	4.16	4.25	-0.092	0.200	-0.193	0.002	-0.189	17
23	5.98	5.58	0.40	0.200	0.840	0.035	0.835	2
24	4.83	4.70	0.13	0.200	0.269	0.004	0.264	9
25	5.36	5.14	0.22	0.033	0.419	0.001	0.412	29
26	5.67	5.14	0.53	0.033	1.011	0.007	1.012	13
27	5.55	5.14	0.41	0.033	0.782	0.004	0.775	27
28	5.27	5.14	0.13	0.033	0.247	0.000	0.242	6
29	5.61	5.14	0.47	0.033	0.896	0.006	0.893	3
30	5.45	5.14	0.31	0.033	0.591	0.002	0.583	25

APPENDIX J

MODELLING OF COLOUR INTENSITY

Design Summary

Study Type	Response Surface	**Experiments**	30
Initial Design	Central Composite	**Blocks**	No Blocks
Design Model	2FI		

Response	Name	Units	Obs	Minimum	Maximum	Trans	Model
Y2	Colour	LU	30	5.70	7.60	None	2FI

Factor	Name	Units	Type	Low Actual	High Actual	Low Coded	High Coded
A	Moisture Content	% wb	Numeric	9.00	11.00	-1.000	1.000
B	Heating Temp.	°C	Numeric	60.00	80.00	-1.000	1.000
C	Heating Time	mins	Numeric	20.00	30.00	-1.000	1.000
D	Applied Pressure	MPa	Numeric	10.00	20.00	-1.000	1.000

Design Matrix Evaluation for Response Surface 2FI Model

4 Factors: A, B, C, D

Degrees of Freedom for Evaluation

Model	10
Residuals	19
Lack 0f Fit	*14*
Pure Error	*5*
Corr Total	29

Power at 5 % alpha level for effect of

Term	StdErr**	VIF	Ri-Squared	1/2 Std. Dev.	1 Std. Dev.	2 Std. Dev.
A	0.20	1.00	0.0000	21.4 %	64.2 %	99.6 %
B	0.20	1.00	0.0000	21.4 %	64.2 %	99.6 %
C	0.20	1.00	0.0000	21.4 %	64.2 %	99.6 %
D	0.20	1.00	0.0000	21.4 %	64.2 %	99.6 %
AB	0.25	1.00	0.0000	15.8 %	46.5 %	96.6 %
AC	0.25	1.00	0.0000	15.8 %	47.6 %	96.6 %
AD	0.25	1.00	0.0000	15.8 %	47.6 %	96.6 %
BC	0.25	1.00	0.0000	15.8 %	47.6 %	96.6 %
BD	0.25	1.00	0.0000	15.8 %	47.6 %	96.6 %
CD	0.25	1.00	0.0000	15.8 %	47.6 %	96.6 %

**Basis Std. Dev. = 1.0

Measures Derived From the $(X'X)^{-1}$ Matrix

Std	Leverage	Point Type
1	0.5750	Fact
2	0.5750	Fact
3	0.5750	Fact
4	0.5750	Fact
5	0.5750	Fact
6	0.5750	Fact
7	0.5750	Fact
8	0.5750	Fact
9	0.5750	Fact
10	0.5750	Fact
11	0.5750	Fact
12	0.5750	Fact
13	0.5750	Fact
14	0.5750	Fact
15	0.5750	Fact
16	0.5750	Fact
17	0.2000	Axial
18	0. 2000	Axial
19	0. 2000	Axial
20	0. 2000	Axial
21	0. 2000	Axial
22	0. 2000	Axial
23	0. 2000	Axial
24	0. 2000	Axial
25	0.0333	Center
26	0.0333	Center
27	0.0333	Center
28	0.0333	Center
29	0.0333	Center
30	0.0333	Center
Average =	0.3667	

Maximum Prediction Variance (at a design point) = 0.575

Average Prediction Variance = 0.367

Condition Number of Coefficient Matrix = 1.000

G Efficiency (calculated from the design points) = 63.8 %

Scaled D-optimality Criterion = 1.528

Correlation Matrix of Regression Coefficients

	Intercept	A	B	C	D	AB	AC
Intercept	1.000						
A	-0.000	1.000					
B	-0.000	-0.000	1.000				
C	-0.000	-0.000	-0.000	1.000			
D	-0.000	-0.000	-0.000	-0.000	1.000		
AB	-0.000	-0.000	-0.000	-0.000	-0.000	1.000	
AC	-0.000	-0.000	-0.000	-0.000	-0.000	-0.000	1.000
AD	-0.000	-0.000	-0.000	-0.000	-0.000	-0.000	-0.000
BC	-0.000	-0.000	-0.000	-0.000	-0.000	-0.000	-0.000
BD	-0.000	-0.000	-0.000	-0.000	-0.000	-0.000	-0.000
CD	-0.000	-0.000	-0.000	-0.000	-0.000	-0.000	-0.000

	AD	BC	BD	CD
AD	1.000			
BC	-0.000	1.000		
BD	-0.000	-0.000	1.000	
CD	-0.000	-0.000	-0.000	1.000

Correlation Matrix of Factors [Pearson's r]

	A	B	C	D	AB	AC	AD
A	1.000						
B	0.000	1.000					
C	0.000	0.000	1.000				
D	0.000	0.000	0.000	1.000			
AB	0.000	0.000	0.000	0.000	1.000		
AC	0.000	0.000	0.000	0.000	0.000	1.000	
AD	0.000	0.000	0.000	0.000	0.000	0.000	1.000
BC	0.000	0.000	0.000	0.000	0.000	0.000	0.000
BD	0.000	0.000	0.000	0.000	0.000	0.000	0.000
CD	0.000	0.000	0.000	0.000	0.000	0.000	0.000

	BC	BD	CD
BC	1.000		
BD	0.000	1.000	
CD	0.000	0.000	1.000

Sequential Model Sum of Squares

Source	Sum of Squares	DF	Mean Square	F Value	Prob > F	
Mean	1304.16	1	1304.16			
Linear	6.48	4	1.62	285.06	< 0.0001	Suggested
2FI	0.065	6	0.011	2.67	0.0472	Suggested
Quadratic	0.020	4	5.083E-003	1.35	0.2989	
Cubic	0.033	8	4.167E-003	1.25	0.3908	Aliased
Residual	0.023	7	3.333E-003			
Total	1310.78	30	43.69			

Lack of Fit Tests

Source	Sum of Squares	DF	Mean Square	F Value	Prob > F	
Linear	0.13	20	6.433E-003	2.41	0.1669	Suggested
2FI	0.064	14	4.548E-003	1.71	0.2895	Suggested
Quadratic	0.043	10	4.333E-003	1.63	0.3086	
Cubic	0.010	2	5.000E-003	1.88	0.2468	Aliased
Pure Error	0.013	5	2.667E-003			

Model Summary Statistics

Source	Std. Dev.	R-Squared	Adjusted R-Squared	Predicted R-Squared	PRESS	
Linear	0.075	0.9785	0.9751	0.9678	0.21	Suggested
2FI	0.064	0.9884	0.9822	0.9614	0.26	Suggested
Quadratic	0.061	0.9914	0.9834	0.9594	0.27	
Cubic	0.058	0.9965	0.9854	0.7795	1.46	Aliased

ANOVA for Response Surface 2FI Model

Analysis of variance table [Partial sum of squares]

Source	**Sum of Squares**	**DF**	**Mean Square**	**F Value**	**Prob > F**	
Model	6.54	10	0.65	161.42	< 0.0001	significant
A	0.17	1	0.17	41.13	< 0.0001	
B	5.80	1	5.80	1431.58	< 0.0001	
C	0.48	1	0.48	118.85	< 0.0001	
D	0.027	1	0.027	6.58	0.0189	
AB	1.000E-002	1	1.000E-002	2.47	0.1327	
AC	1.000E-002	1	1.000E-002	2.47	0.1327	
AD	0.022	1	0.022	5.55	0.0293	
BC	2.500E-003	1	2.500E-003	0.62	0.4419	
BD	1.000E-002	1	1.000E-002	2.47	0.1327	
CD	1.000E-002	1	1.000E-002	2.47	0.1327	
Residual	0.077	19	4.053E-003			
Lack of Fit	0.064	14	4.548E-003	1.71	0.2895	not significant
Pure Error	0.013	5	2.667E-003			
Cor Total	6.62	29				

Std. Dev.	0.064	R-Squared	0.9884
Mean	6.59	Adj R-Squared	0.9822
C.V.	0.97	Pred R-Squared	0.9614
PRESS	0.26	Adeq Precision	51.018

Coefficient Factor	Standard Estimate	DF	Error	95% CI Low	95% CI High	VIF
Intercept	6.59	1	0.012	6.57	6.62	
A-A	0.083	1	0.013	0.056	0.11	1.00
B-B	0.49	1	0.013	0.46	0.52	1.00
C-C	0.14	1	0.013	0.11	0.17	1.00
D-D	0.033	1	0.013	6.135E-003	0.061	1.00
AB	-0.025	1	0.016	-0.058	8.311E-003	1.00
AC	0.025	1	0.016	-8.311E-003	0.058	1.00
AD	0.037	1	0.016	4.189E-003	0.071	1.00
BC	0.012	1	0.016	-0.021	0.046	1.00
BD	-0.025	1	0.016	-0.058	8.311E-003	1.00
CD	0.025	1	0.016	-8.311E-003	0.058	1.00

Linear Model for Colour Intensity

Final Equation in Terms of Coded Factors:

$CI = +6.59 + 0.083M_c + 0.49H_T + 0.14H_t + 0.033A_p$

Final Equation in Terms of Actual Factors:

$CI = +1.51000 + 0.083333M_c + 0.0491674H_T + 0.028333H_t + 0.006667A_p$

[Std. Dev. = 0.075, R-Squared = 0.9785, Mean = 6.59, Adj R-Squared = 0.9751 C.V. = 1.14, Pred R-Squared = 0.9678, PRESS = 0.21, Adeq Precision = 63.919].

2FI Model for Colour Intensity

Final Equation in Terms of Coded Factors:

$CI = +6.59 + 0.083M_c + 0.49H_T + 0.14H_t + 0.033A_p - 0.025M_cH_T + 0.025M_cH_t + 0.037M_cA_p + 0.012H_TH_t - 0.025H_TA_p + 0.025H_tA_p$

Final Equation in Terms of Actual Factors:

$CI = +2.42250 + 0.020833M_c + 0.075417H_T - 0.054167H_t - 0.058333A_p - 0.002500M_cH_T + 0.005000M_cH_t + 0.007500M_cA_p + 0.000250H_TH_t - 0.000500H_TA_p + 0.001000H_tA_p$

[Std. Dev. = 0.064, R-Squared = 0.9884, Mean = 6.59, Adj R-Squared = 0.9822

C.V. = 0.97, Pred R-Squared = 0.9614, PRESS = 0.26, Adeq Precision = 51.018].

Quadratic Model for Colour Intensity

Final Equation in Terms of Coded Factors

$CI = +6.57 + 0.083M_c + 0.49H_T + 0.14H_t + 0.033A_p + 0.002M_c^2 + 0.027H_T^2 + 0.002H_t^2 + 0.002A_p^2 - 0.025M_cH_T + 0.025M_cH_t + 0.037M_cA_p + 0.012H_TH_t - 0.025H_TA_p + 0.025H_tA_p$

Final Equation in Terms of Actual Factors

$CI = +4.00208 - 0.020833M_c + 0.037500H_T - 0.058333H_t - 0.060833A_p + 0.002083M_c^2 + 0.000271H_T^2 + 0.000083H_t^2 + 0.000083A_p^2 - 0.002500M_cH_T + 0.005000M_cH_t + 0.007500M_cA_p + 0.000250H_TH_t - 0.000500H_TA_p + 0.001000H_tA_p$

[Std. Dev. = 0.061, R-Squared = 0.9914, Mean = 6.59, Adj R-Squared = 0.9834, C.V. = 0.93, Pred R-Squared = 0.9594, PRESS = 0.27, Adeq Precision = 45.251].

Cubic Model for Colour Intensity

Final Equation in Terms of Coded Factors:

$CI = +6.57 + 0.092M_c + 0.51H_T + 0.16H_t + 0.042A_p + 0.002M_c^2 + 0.027H_T^2 + 0.002H_t^2 + 0.002A_p^2 - 0.025M_cH_T + 0.025M_cH_t + 0.037M_cA_p + 0.012H_TH_t - 0.025H_TA_p + 0.025H_tA_p + 0.004M_c^3 - 0.008H_T^3 - 0.008H_t^3 - 0.004A_p^3 - 0.012M_cH_TH_t - 0.025\ M_cH_TA_p + 0.025M_cH_tA_p - 0.012H_TH_tA_p$

Final Equation in Terms of Actual Factors:

Not available for aliased models.

[Std. Dev. = 0.058, R-Squared = 0.9965, Mean = 6.59, Adj R-Squared = 0.9854,
C.V. = 0.88, Pred R-Squared = 0.7795, PRESS = 1.46, Adeq Precision = 37.585].

Where,

M_c = Moisture content, %wb
H_T = Heating temperature, ^oC
H_t = Heating time, mins
A_p = Applied pressure, MPa
CI = Colour Intensity, LU

Diagnostics Case Statistics

Standard Order	Actual Value	Predicted Value	Residual	Leverage	Student Residual	Cook's Distance	Outlier t	Run Order
1	5.90	5.89	6.667E-003	0.575	0.161	0.003	0.156	14
2	6.00	5.98	0.015	0.575	0.361	0.016	0.353	18
3	6.90	6.95	-0.052	0.575	-1.245	0.191	-1.264	10
4	7.00	6.94	0.057	0.575	1.365	0.229	1.399	12
5	6.10	6.05	0.048	0.575	1.165	0.167	1.176	15
6	6.20	6.24	-0.043	0.575	-1.044	0.134	-1.047	23
7	7.20	7.16	0.040	0.575	0.964	0.114	0.962	16
8	7.30	7.25	0.048	0.575	1.165	0.167	1.176	19
9	5.90	5.89	0.015	0.575	0.361	0.016	0.353	26
10	6.10	6.13	-0.027	0.575	-0.643	0.051	-0.632	20
11	6.90	6.84	0.057	0.575	1.365	0.229	1.399	28
12	7.00	6.98	0.015	0.575	0.361	0.016	0.353	24
13	6.10	6.14	-0.043	0.575	-1.044	0.134	-1.047	21
14	6.60	6.48	0.12	0.575	2.771	0.944	3.494	30
15	7.20	7.15	0.048	0.575	1.165	0.167	1.176	4
16	7.40	7.39	6.667E-003	0.575	0.161	0.003	0.156	5
17	6.40	6.43	-0.027	0.200	-0.468	0.005	-0.458	8
18	6.70	6.76	-0.060	0.200	-1.054	0.025	-1.057	22
19	5.70	5.61	0.090	0.200	1.581	0.057	1.651	7
20	7.60	7.58	0.023	0.200	0.410	0.004	0.401	1
21	6.30	6.31	-1.000E-002	0.200	-0.176	0.001	-0.171	11
22	6.80	6.88	-0.077	0.200	-1.346	0.041	-1.378	17
23	6.50	6.53	-0.027	0.200	-0.468	0.005	-0.458	2
24	6.60	6.66	-0.060	0.200	-1.054	0.025	-1.057	9
25	6.60	6.59	6.667E-003	0.033	0.107	0.000	0.104	29
26	6.60	6.59	6.667E-003	0.033	0.107	0.000	0.104	13
27	6.60	6.59	6.667E-003	0.033	0.107	0.000	0.104	27
28	6.50	6.59	-0.093	0.033	-1.491	0.007	-1.545	6
29	6.60	6.59	6.667E-003	0.033	0.107	0.000	0.104	3
30	6.50	6.59	-0.093	0.033	-1.491	0.007	-1.545	25

APPENDIX K

MODELLING OF OIL IMPURITY

Design Summary

Study Type	Response Surface	**Experiments**	30
Initial Design	Central Composite	**Blocks**	No Blocks
Design Model	Linear		

Response	Name	Units	Obs	Minimum	Maximum	Trans	Model
Y3	Impurity	%	30	2.12	3.20	None	Linear

Factor	Name	Units	Type	Low Actual	High Actual	Low Coded	High Coded
A	Moisture Content	% wb	Numeric	9.00	11.00	-1.000	1.000
B	Heating Temp.	^oC	Numeric	60.00	80.00	-1.000	1.000
C	Heating Time	mins	Numeric	20.00	30.00	-1.000	1.000
D	Applied Pressure	MPa	Numeric	10.00	20.00	-1.000	1.000

Design Matrix Evaluation for Response Surface Linear Model

4 Factors: A, B, C, D

Degrees of Freedom for Evaluation

Model	4
Residuals	25
Lack 0f Fit	*20*
Pure Error	*5*
Corr Total	29

Power at 5 % alpha level for effect of

Term	StdErr**	VIF	Ri-Squared	1/2 Std. Dev.	1 Std. Dev.	2 Std. Dev.
A	0.20	1.00	0.0000	21.8 %	65.3 %	99.7 %
B	0.20	1.00	0.0000	21.8 %	65.3 %	99.7 %
C	0.20	1.00	0.0000	21.8 %	65.3 %	99.7 %
D	0.20	1.00	0.0000	21.8 %	65.3 %	99.7 %

**Basis Std. Dev. = 1.0

Measures Derived From the $(X'X)^{-1}$ Matrix

Std	Leverage	Point Type
1	0.2000	Fact
2	0.2000	Fact
3	0.2000	Fact
4	0.2000	Fact
5	0.2000	Fact
6	0.2000	Fact
7	0.2000	Fact
8	0.2000	Fact
9	0.2000	Fact
10	0.2000	Fact
11	0.2000	Fact
12	0.2000	Fact
13	0.2000	Fact
14	0.2000	Fact
15	0.2000	Fact
16	0.2000	Fact
17	0.2000	Axial
18	0.2000	Axial
19	0.2000	Axial
20	0.2000	Axial
21	0.2000	Axial
22	0.2000	Axial
23	0.2000	Axial
24	0.2000	Axial
25	0.0333	Center
26	0.0333	Center
27	0.0333	Center
28	0.0333	Center
29	0.0333	Center
30	0.0333	Center

Average = 0.1667

Maximum Prediction Variance (at a design point) = 0.200

Average Prediction Variance = 0.167

Condition Number of Coefficient Matrix = 1.000

G Efficiency (calculated from the design points) = 83.3 %

Scaled D-optimality Criterion = 1.195

Correlation Matrix of Regression Coefficients

	Intercept	A	B	C	D
Intercept	1.000				
A	-0.000	1.000			
B	-0.000	-0.000	1.000		
C	-0.000	-0.000	-0.000	1.000	
D	-0.000	-0.000	-0.000	-0.000	1.000

Correlation Matrix of Factors [Pearson's r]

	A	B	C	D
A	1.000			
B	0.000	1.000		
C	0.000	0.000	1.000	
D	0.000	0.000	0.000	1.000

Sequential Model Sum of Squares

Source	Sum of Squares	DF	Mean Square	F Value	Prob > F	
Mean	215.85	1	215.85			
Linear	1.98	4	0.49	126.50	< 0.0001	Suggested
2FI	0.024	6	3.942E-003	1.01	0.4478	
Quadratic	0.022	4	5.595E-003	1.62	0.2205	
Cubic	0.032	8	3.950E-003	1.37	0.3450	Aliased
Residual	0.020	7	2.880E-003			
Total	217.92	30	7.26			

Lack of Fit Tests

Source	Sum of Squares	DF	Mean Square	F Value	Prob > F	
Linear	0.097	20	4.829E-003	20.12	0.0017	Suggested
2FI	0.073	14	5.210E-003	21.71	0.0016	
Quadratic	0.051	10	5.056E-003	21.07	0.0018	
Cubic	0.019	2	9.479E-003	39.50	0.0009	Aliased
Pure Error	1.200E-003	5	2.400E-003			

Model Summary Statistics

Source	Std. Dev.	R-Squared	Adjusted R-Squared	Predicted R-Squared	PRESS	
Linear	0.063	0.9529	0.9454	0.9300	0.15	Suggested
2FI	0.062	0.9643	0.9455	0.8717	0.27	
Quadratic	0.059	0.9751	0.9518	0.8590	0.29	
Cubic	0.054	0.9903	0.9598	-0.3153	2.73	Aliased

ANOVA for Response Surface Linear Model

Analysis of variance table [Partial sum of squares]

Source	Sum of Squares	DF	Mean Square	F Value	Prob > F	
Model	1.98	4	0.49	126.50	< 0.0001	significant
A	0.027	1	0.027	6.82	0.0150	
B	1.74	1	1.74	444.54	< 0.0001	
C	0.19	1	0.19	49.70	< 0.0001	
D	0.019	1	0.019	4.93	0.0358	
Residual	0.098	25	3.911E-003			
Lack of Fit	0.097	20	4.829E-003	20.12	0.0017	significant
Pure Error	1.200E-003	5	2.400E-004			
Cor Total	2.08	29				

Std. Dev.	0.063	R-Squared	0.9529
Mean	2.68	Adj R-Squared	0.9454
C.V.	2.33	Pred R-Squared	0.9300
PRESS	0.15	Adeq Precision	42.168

Coefficient Factor	Standard Estimate	DF	Error	95% CI Low	95% CI High	VIF
Intercept	2.68	1	0.011	2.66	2.71	
A-A	0.033	1	0.013	7.041E-003	0.060	1.00
B-B	-0.27	1	0.013	-0.30	-0.24	1.00
C-C	-0.090	1	0.013	-0.12	-0.064	1.00
D-D	-0.028	1	0.013	-0.055	-2.041E-003	1.00

Linear Model for Oil Impurity

Final Equation in Terms of Coded Factors:

$CL = +2.68 + 0.033M_c - 0.27H_T - 0.090H_t - 0.028A_p$

Final Equation in Terms of Actual Factors:

$CL = +4.76817 + 0.033333M_c - 0.026917H_T - 0.018000H_t - 0.005667A_p$

[Std. Dev. = 0.063, R-Squared = 0.9529, Mean = 2.68, Adj R-Squared = 0.9454 C.V. = 2.33, Pred R-Squared = 0.9300, PRESS = 0.15, Adeq Precision = 42.168].

2FI Model for Oil Impurity

Final Equation in Terms of Coded Factors:

$OI = +2.68 + 0.033M_c + 0.27H_T - 0.090H_t - 0.028A_p + 0.014M_cH_T - 0.028M_cH_t - 0.015M_cA_p - 0.005H_TH_t + 0.012H_TA_p - 0.011H_tA_p$

Final Equation in Terms of Actual Factors:

$OI = +3.82442 + 0.11958M_c - 0.041917H_T + 0.050750H_t + 0.018083A_p + 0.001375M_cH_T - 0.005500M_cH_t - 0.003000M_cA_p - 0.000100H_TH_t + 0.000250H_TA_p - 0.000450H_tA_p$

[Std. Dev. = 0.062, R-Squared = 0.9643, Mean = 2.68, Adj R-Squared = 0.9455
C.V. = 2.33, Pred R-Squared = 0.8717, PRESS = 0.27, Adeq Precision = 28.465].

Quadratic Model for Oil Impurity

Final Equation in Terms of Coded Factors

$OI = +2.73 + 0.033M_c - 0.27H_T - 0.090H_t - 0.028A_p - 0.010M_c^2 - 0.026H_T^2 - 0.011H_t^2 - 0.013A_p^2 + 0.014M_cH_T - 0.028M_cH_t - 0.015M_cA_p - 0.005H_TH_t + 0.012H_TA_p - 0.011H_tA_p$

Final Equation in Terms of Actual Factors

$OI = +1.25708 + 0.311250M_c - 0.005750H_T + 0.072417H_t + 0.034083A_p - 0.009583M_c^2 - 0.000258H_T^2 - 0.000433H_t^2 - 0.000533A_p^2 + 0.001375M_cH_T - 0.005500M_cH_t – 0.003000M_cA_p - 0.000100H_TH_t + 0.000250H_TA_p - 0.000450H_tA_p$

[Std. Dev. = 0.059, R-Squared = 0.9751, Mean = 2.68, Adj R-Squared = 0.9518, C.V. = 2.19, Pred R-Squared = 0.8590, PRESS = 0.29, Adeq Precision = 25.921].

Cubic Model for Oil Impurity

Final Equation in Terms of Coded Factors:

$OI = +2.73 + 0.024M_c - 0.27H_T - 0.12H_t - 0.032A_p - 0.010M_c^2 - 0.026H_T^2 - 0.011H_t^2 - 0.013A_p^2 + 0.014M_cH_T - 0.028M_cH_t - 0.015M_cA_p - 0.005H_TH_t + 0.012H_TA_p - 0.011H_tA_p + 0.005M_c^3 - 0.001H_T^3 + 0.017H_t^3 + 0.002A_p^3 + 0.023M_cH_TH_t + 0.015 M_cH_TA_p - 0.011M_cH_tA_p + 0.011H_TH_tA_p$

Final Equation in Terms of Actual Factors:

Not available for aliased models.

[Std. Dev. = 0.054, R-Squared = 0.9903, Mean = 2.68, Adj R-Squared = 0.9598,
C.V. = 2.00, Pred R-Squared = -0.3153, PRESS = 2.73, Adeq Precision = 22.985].

Where,

M_c = Moisture content, %wb

H_T = Heating temperature, ^oC

H_t = Heating time, mins

A_p = Applied pressure, MPa

OI = Oil Impurity, %

Diagnostics Case Statistics

Standard Order	Actual Value	Predicted Value	Residual	Leverage	Student Residual	Cook's Distance	Outlier t	Run Order
1	2.98	3.04	-0.056	0.200	-1.010	0.051	-1.010	14
2	3.11	3.10	6.833E-003	0.200	0.122	0.001	0.120	18
3	2.46	2.50	-0.038	0.200	-0.682	0.023	-0.675	10
4	2.57	2.56	5.167E-003	0.200	0.092	0.000	0.091	12
5	2.86	2.86	3.500E-003	0.200	0.063	0.000	0.061	15
6	2.91	2.92	-0.013	0.200	-0.235	0.003	-0.231	23
7	2.26	2.32	-0.058	0.200	-1.040	0.054	-1.042	16
8	2.32	2.38	-0.065	0.200	-1.159	0.067	-1.167	19
9	2.94	2.98	-0.040	0.200	-0.712	0.025	-0.705	26
10	3.07	3.05	0.024	0.200	0.420	0.009	0.413	20
11	2.44	2.44	-1.500E-003	0.200	-0.027	0.000	-0.026	28
12	2.52	2.51	0.012	0.200	0.212	0.002	0.207	24
13	2.85	2.80	0.050	0.200	0.897	0.040	0.893	21
14	2.66	2.87	-0.21	0.200	-3.692	0.681	-5.363 *	30
15	2.21	2.26	-0.051	0.200	-0.921	0.042	-0.918	4
16	2.30	2.33	-0.028	0.200	-0.504	0.013	-0.496	5
17	2.64	2.62	0.024	0.200	0.435	0.009	0.428	8
18	2.81	2.75	0.061	0.200	1.090	0.059	1.095	22
19	3.20	3.22	-0.021	0.200	-0.369	0.007	-0.363	7
20	2.12	2.14	-0.024	0.200	-0.429	0.009	-0.422	1
21	2.83	2.86	-0.032	0.200	-0.578	0.017	-0.570	11
22	2.61	2.50	0.11	0.200	1.925	0.185	2.043	17
23	2.76	2.74	0.021	0.200	0.375	0.007	0.369	2
24	2.66	2.63	0.034	0.200	0.614	0.019	0.606	9
25	2.72	2.68	0.038	0.033	0.613	0.003	0.605	29
26	2.72	2.68	0.038	0.033	0.613	0.003	0.605	13
27	2.71	2.68	0.028	0.033	0.450	0.001	0.443	27
28	2.74	2.68	0.058	0.033	0.938	0.006	0.935	6
29	2.74	2.68	0.058	0.033	0.938	0.006	0.935	3
30	2.75	2.68	0.068	0.033	1.100	0.008	1.105	25

APPENDIX L

AUTOCAD DRAWINGS OF THE MORINGA EXPELLER AND THE COMPONENT PARTS

Figure L1. The Hopper

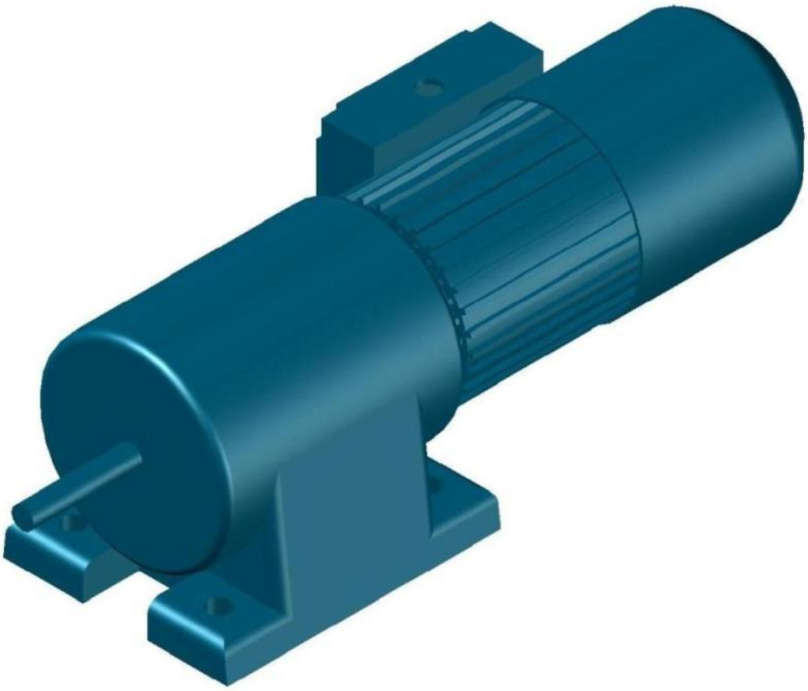


Figure L2. The Electric Motor

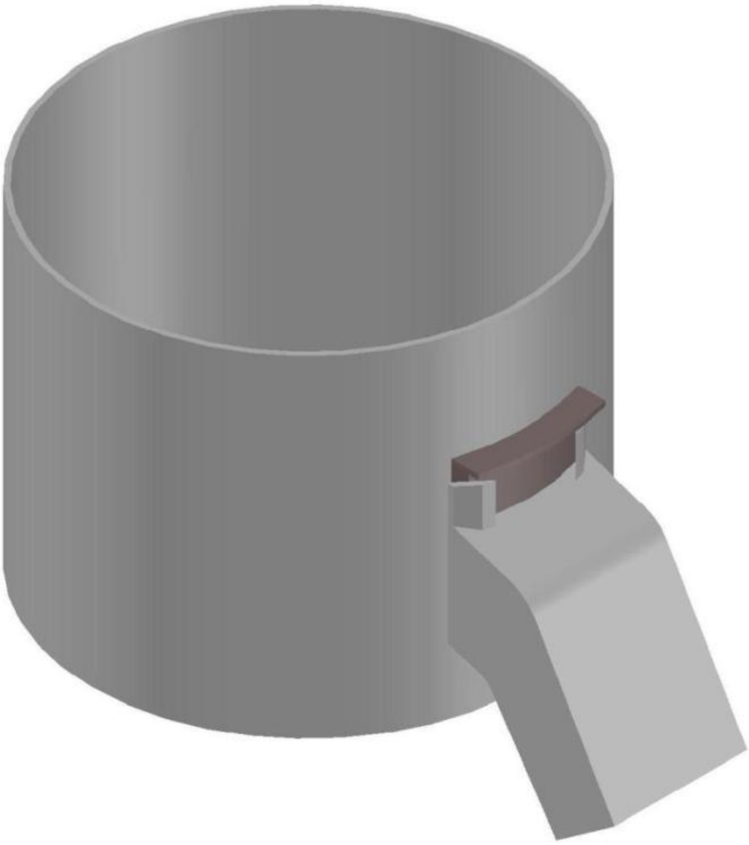


Figure L3. The Roasting Chamber

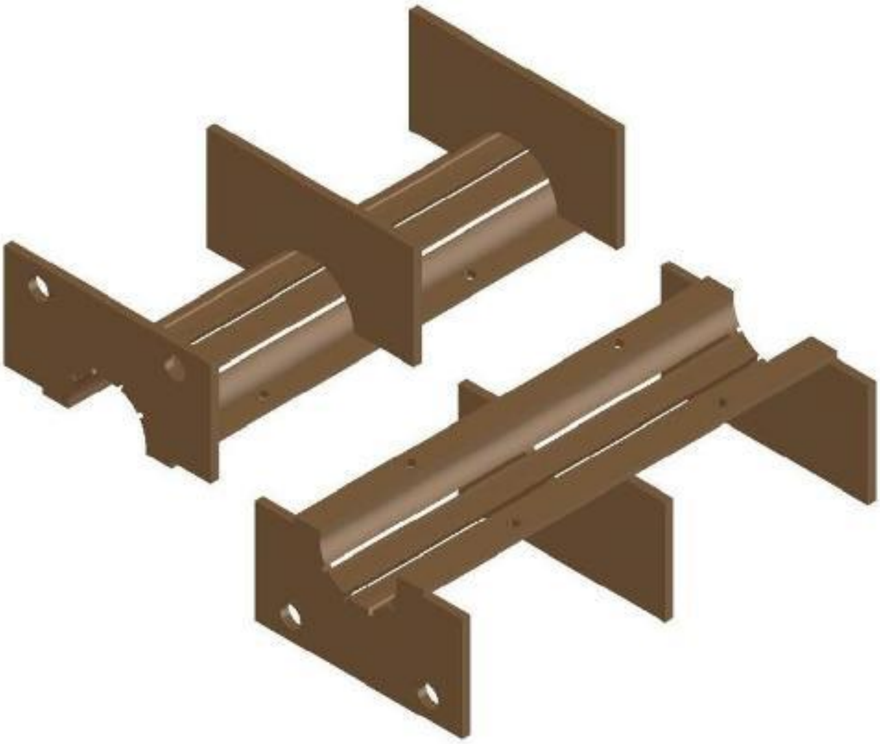


Figure L4. The Oil Barrel

Figure L5. The Wormshaft

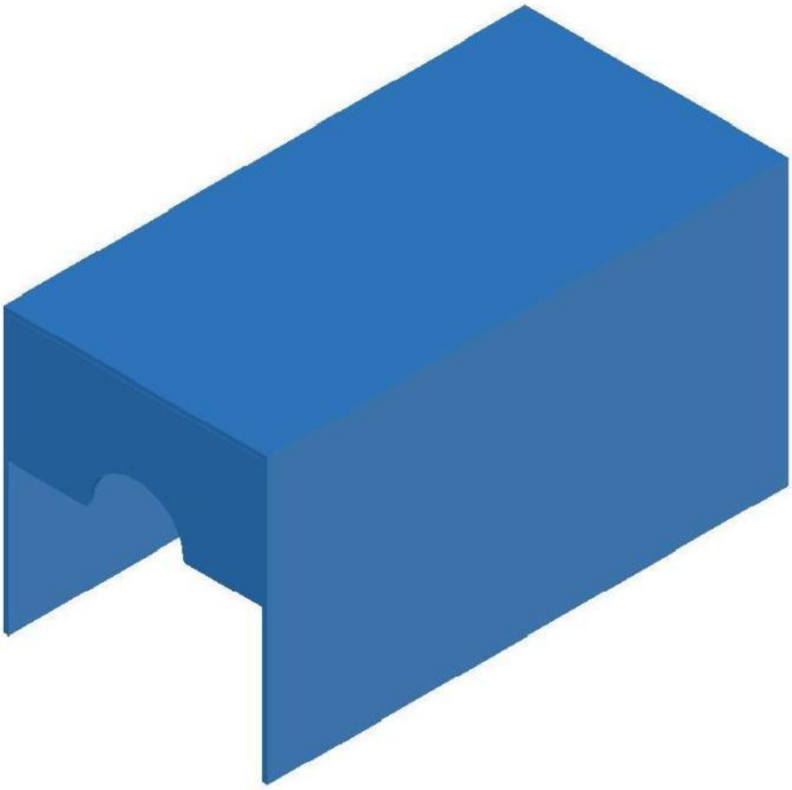


Figure L6. The Barrel Oil Cover

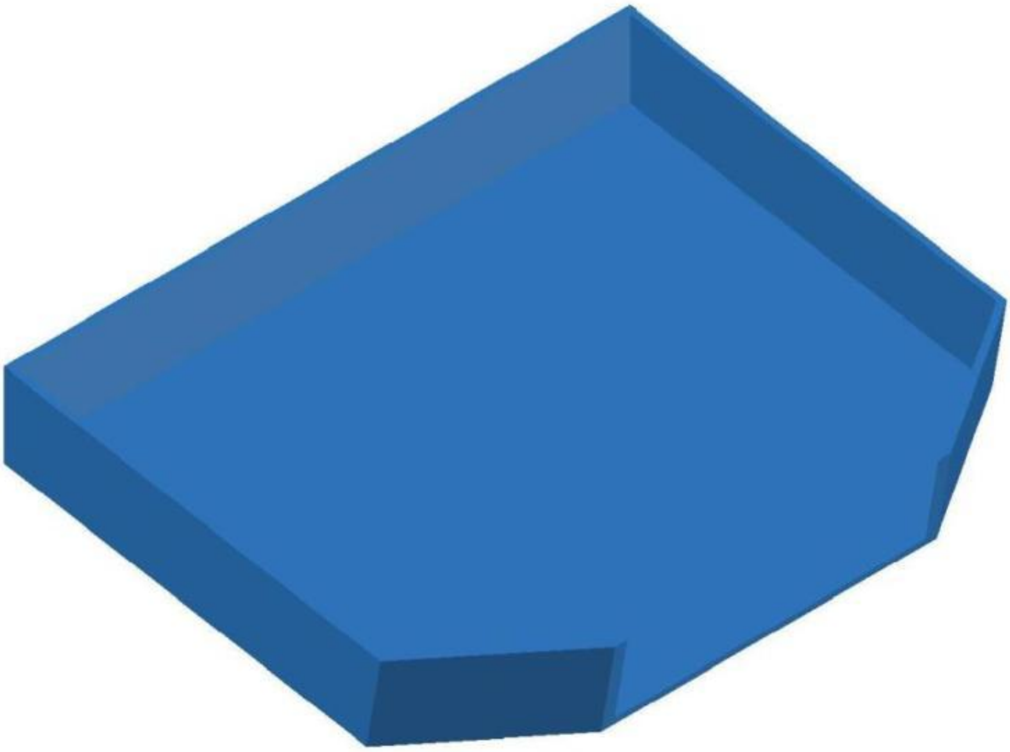


Figure L7. The Oil Trough

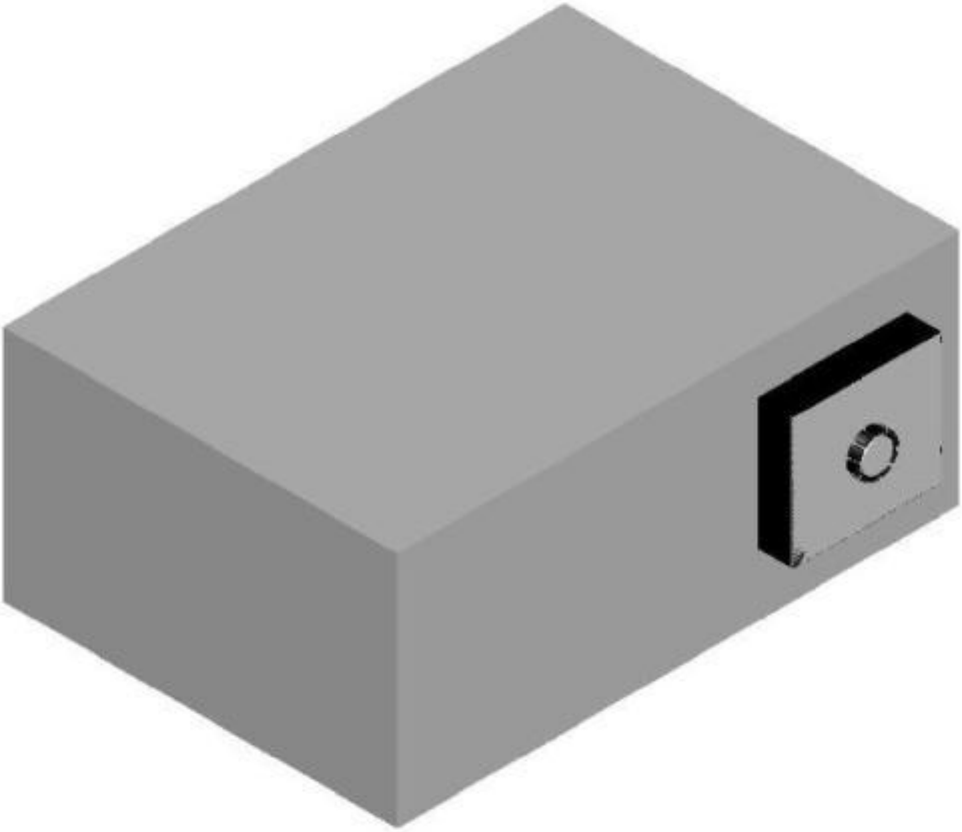


Figure L8. The Temperature Regulator

Figure L9. Belt and Pulley Arrangement

Figure L10. The Bevel Gears

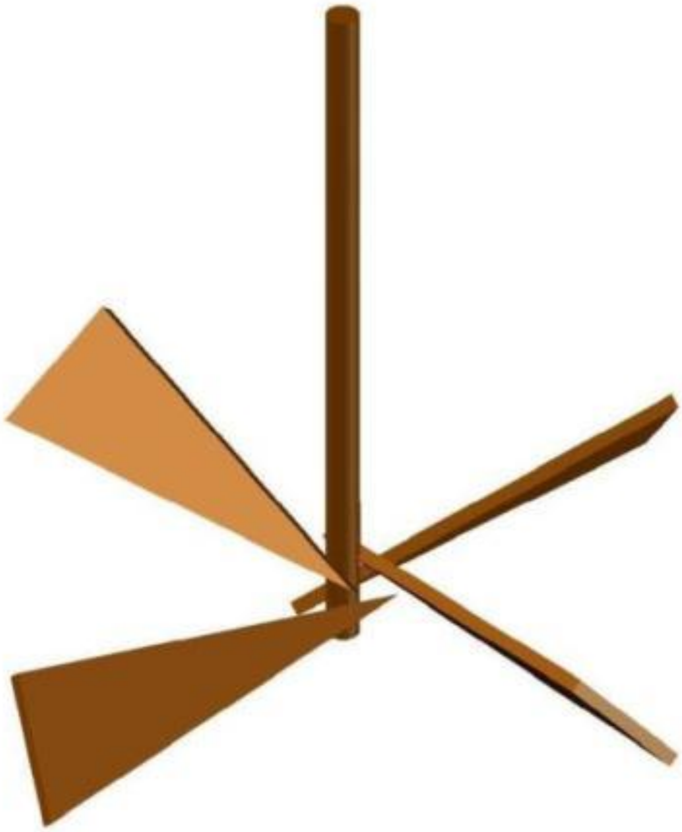


Figure L11. The Stirrer

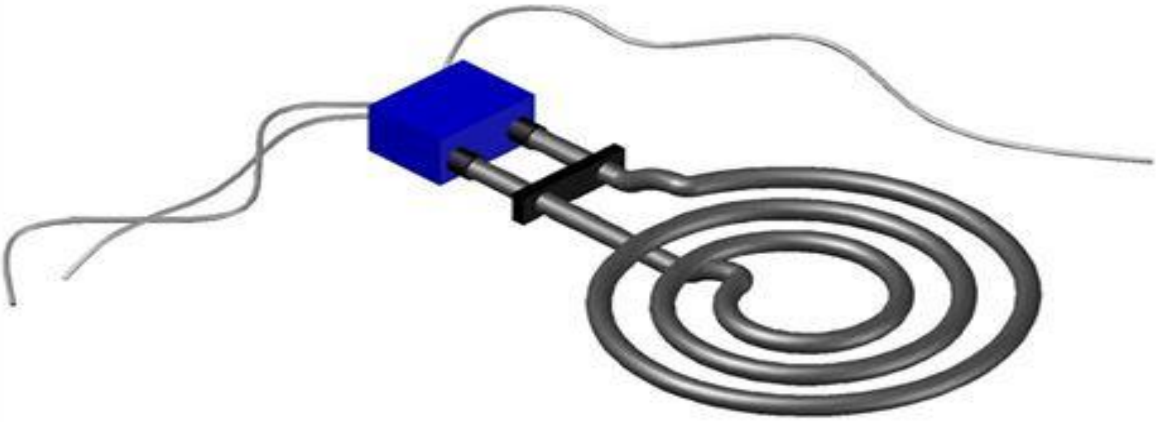


Figure L12. The Electric Heater

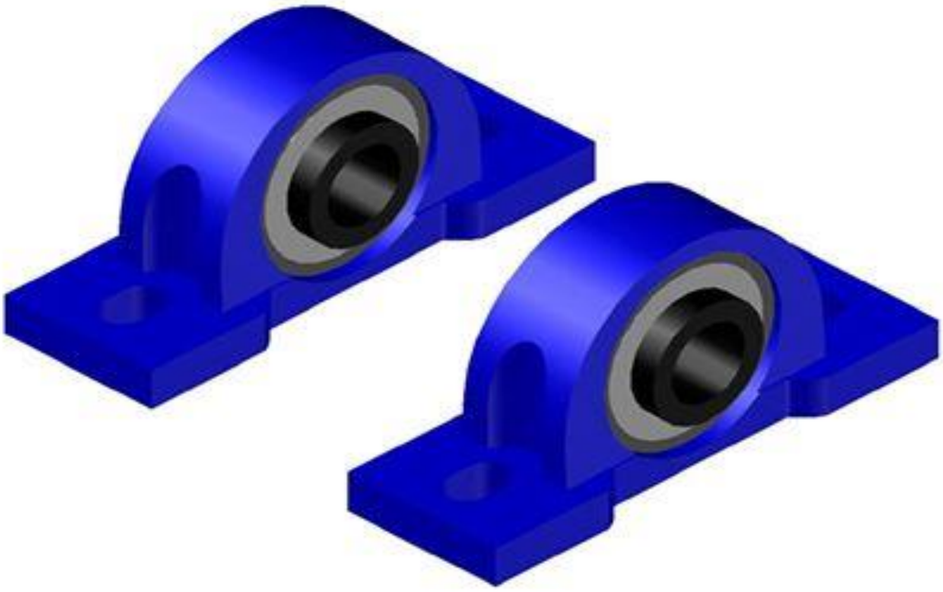


Figure L13. The Pillow Bearings

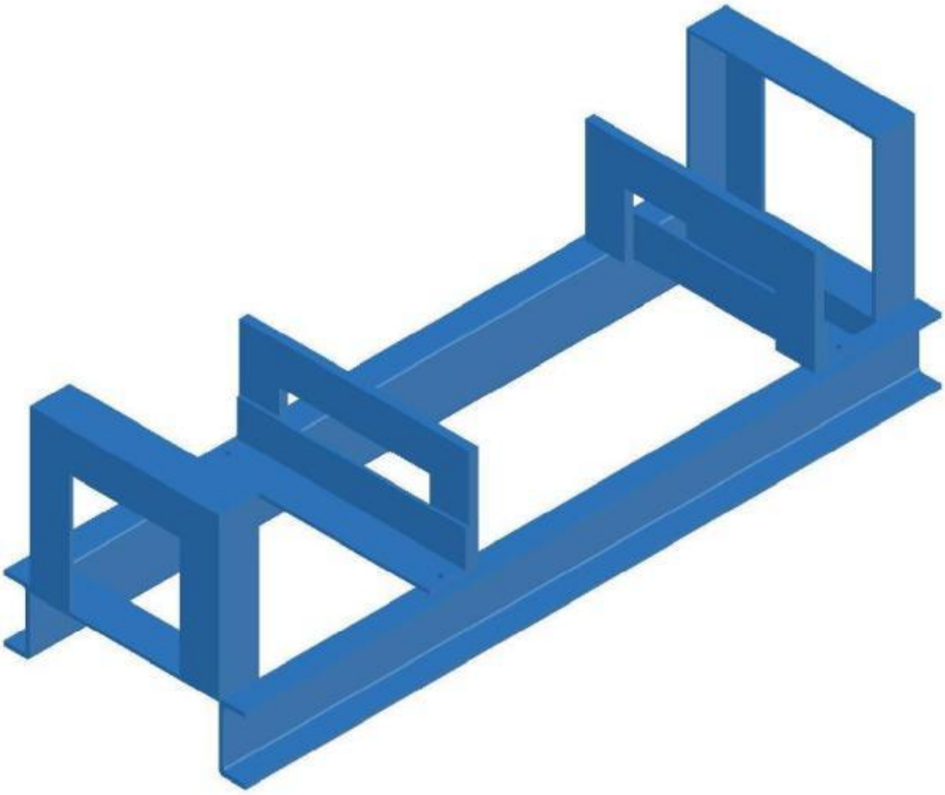
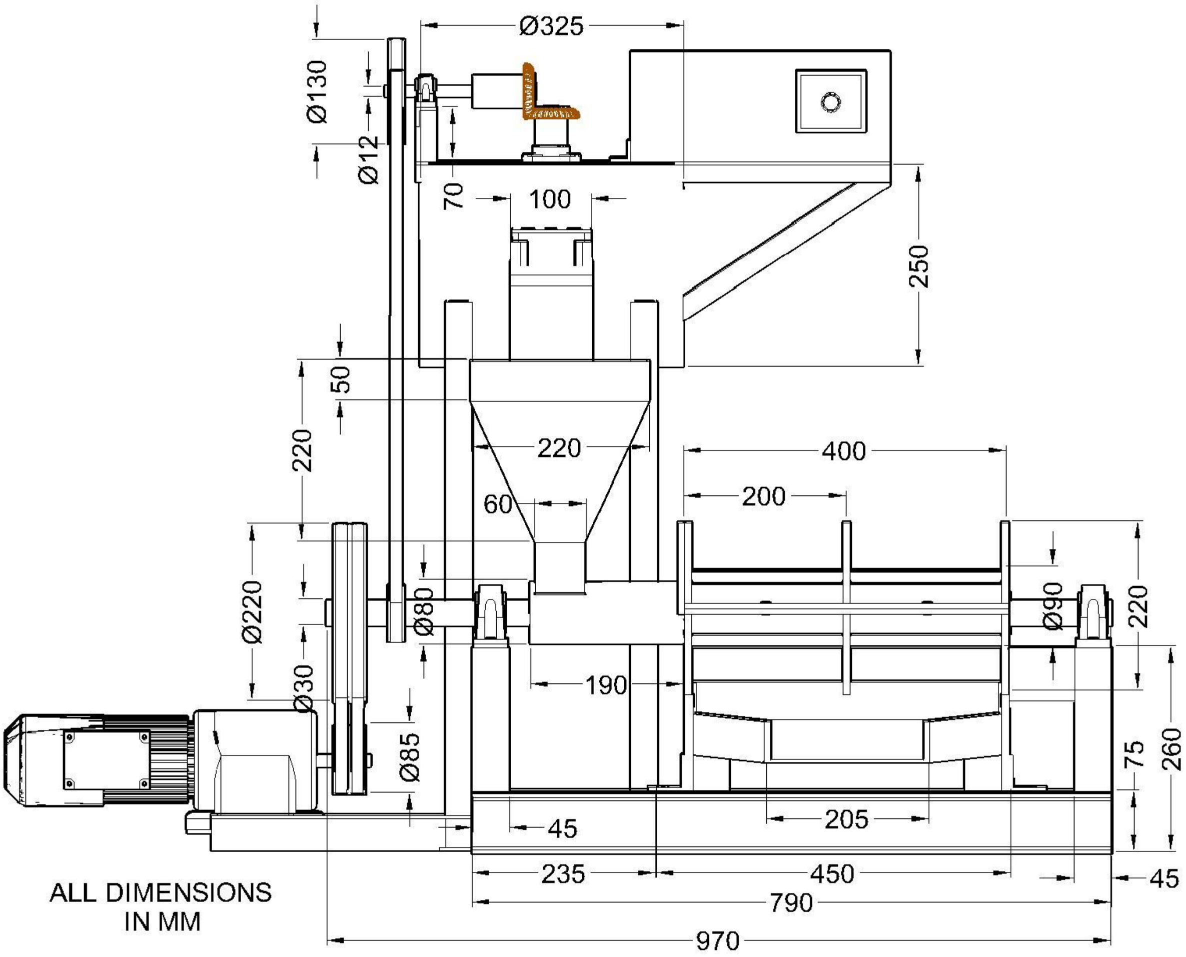


Figure L14. The Machine Base



ALL DIMENSIONS
IN MM

Figure L15. The Front View

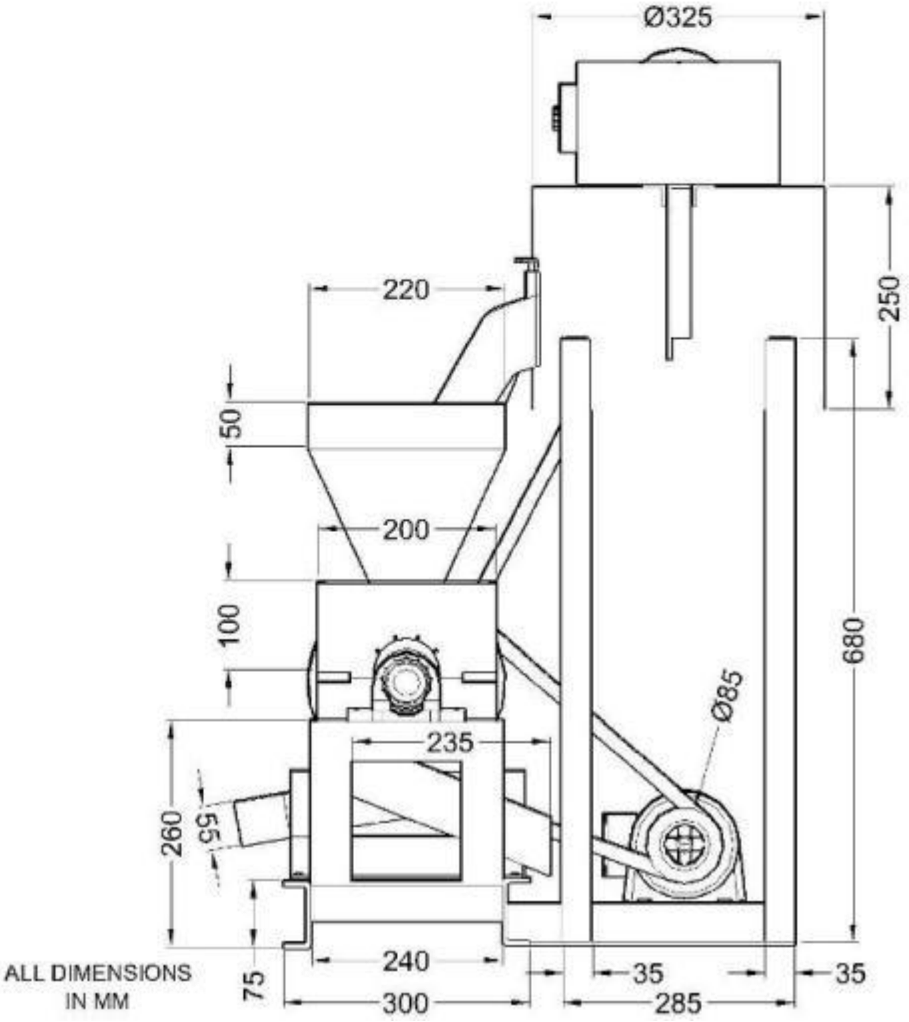


Figure L16. The Right End View

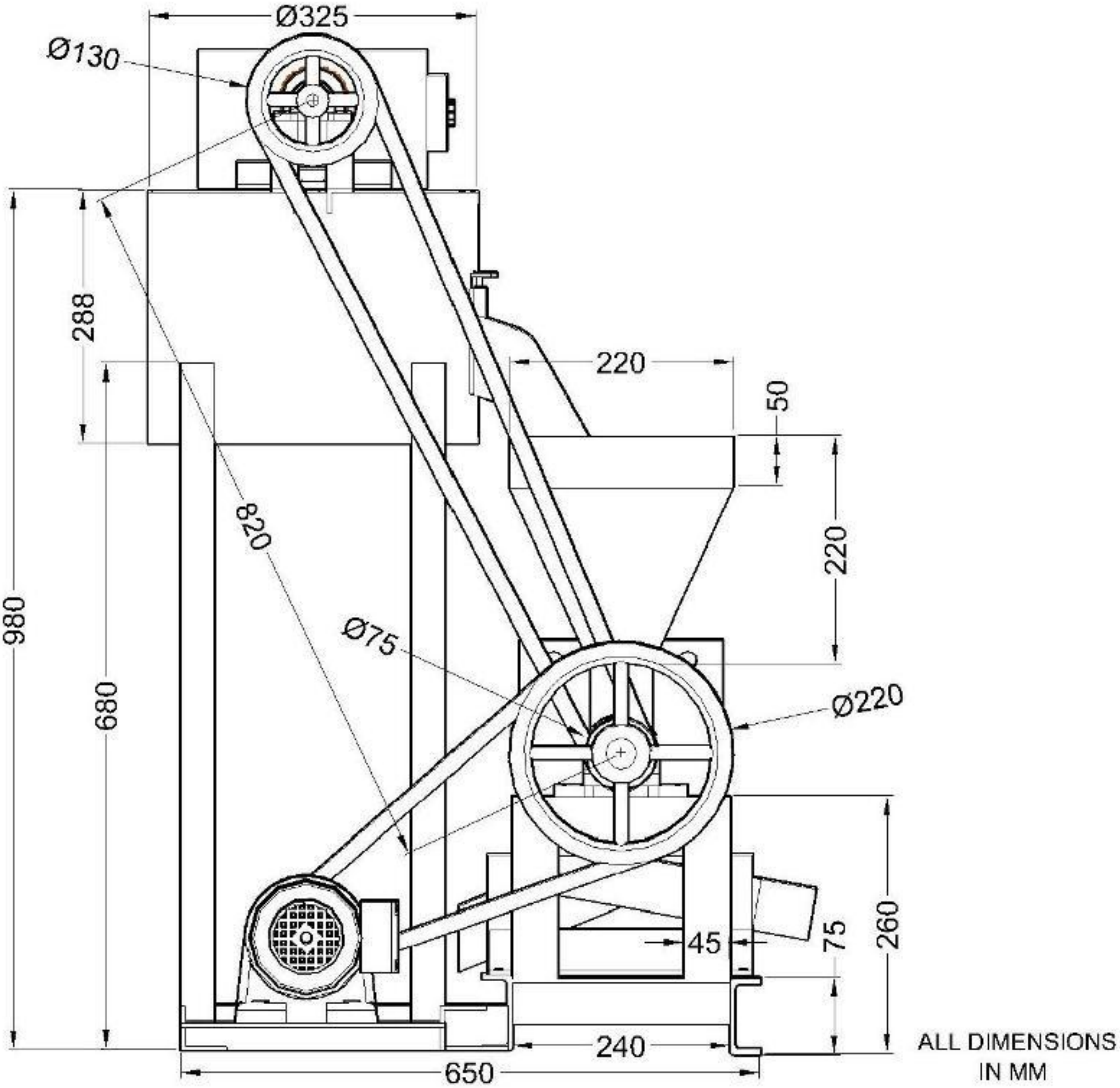


Figure L17. The Left End View

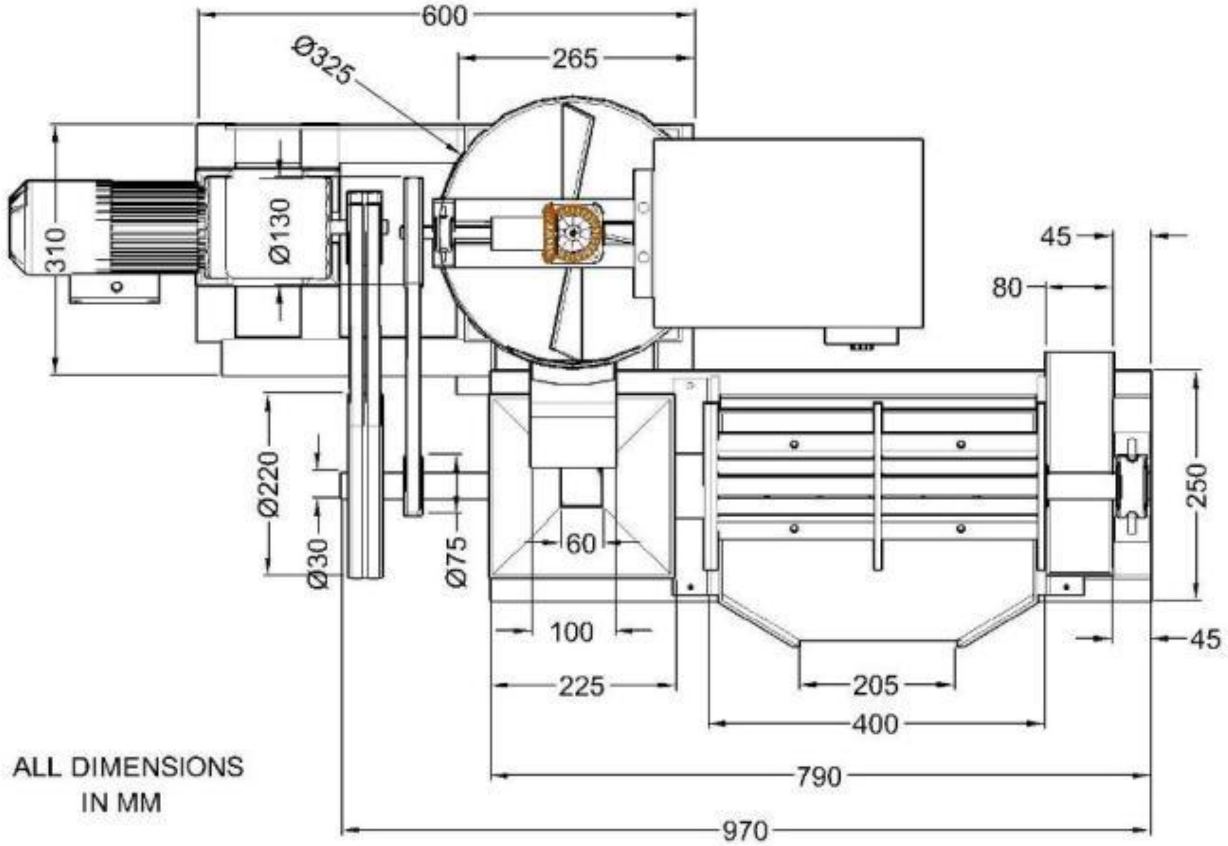


Figure L18. The Plan View

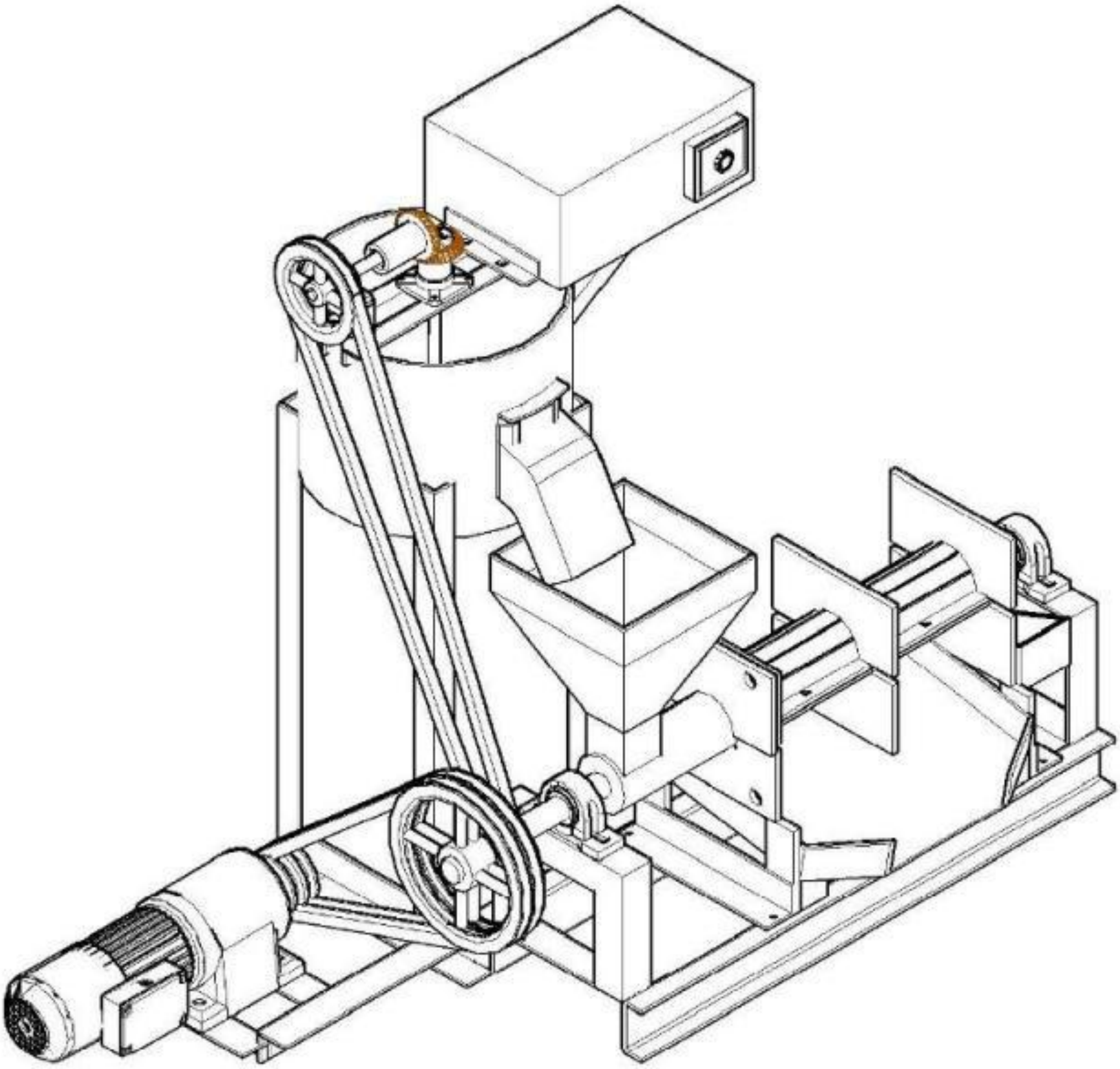


Figure L19. The Schematic View

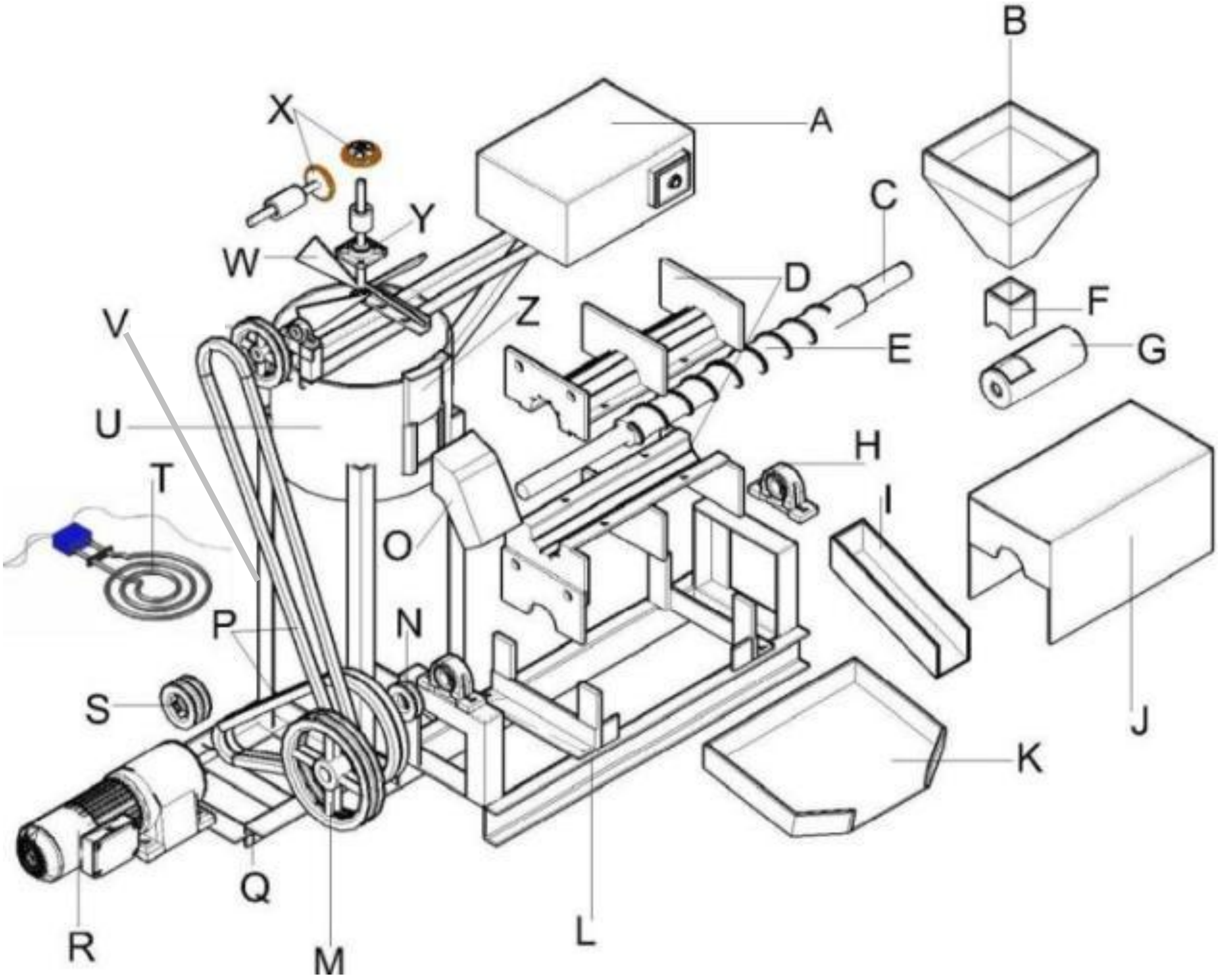


Figure L20. The Schematic Exploded View

PART	DESCRIPTION	PART	DESCRIPTION
A	Temperature Regulator	N	Bolt and Nut
B	Hopper	O	Hopper Passage
C	Wormshaft	P	Belts
D	Oil Barrel	Q	Electric Motor Stand
E	Worms	R	Electric Motor
F	Hopper Base	S	Driving Pulley
G	Mechanism Link	T	Electric Heater
H	Pillow Bearing	U	Roasting Drum
I	Cake Trough	V	Roasting Drum Stand
J	Barrel Oil Cover	W	Stirrer Blade
K	Oil Trough	X	Bevel Gears
L	Machine Frame	Y	Stirrer
M	Driven Pulley	Z	Sliding Gate

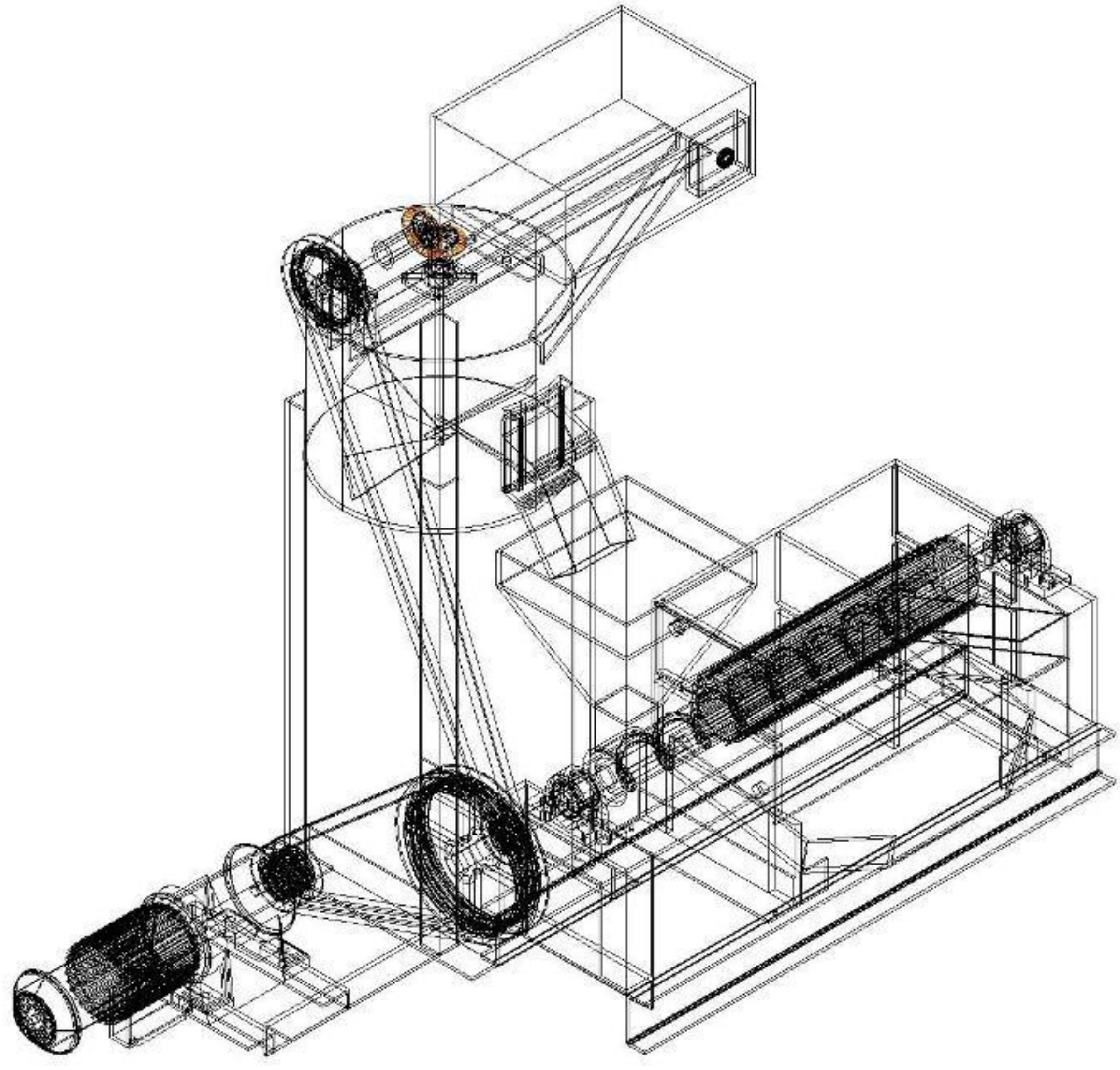


Figure L21. The Wireframe View

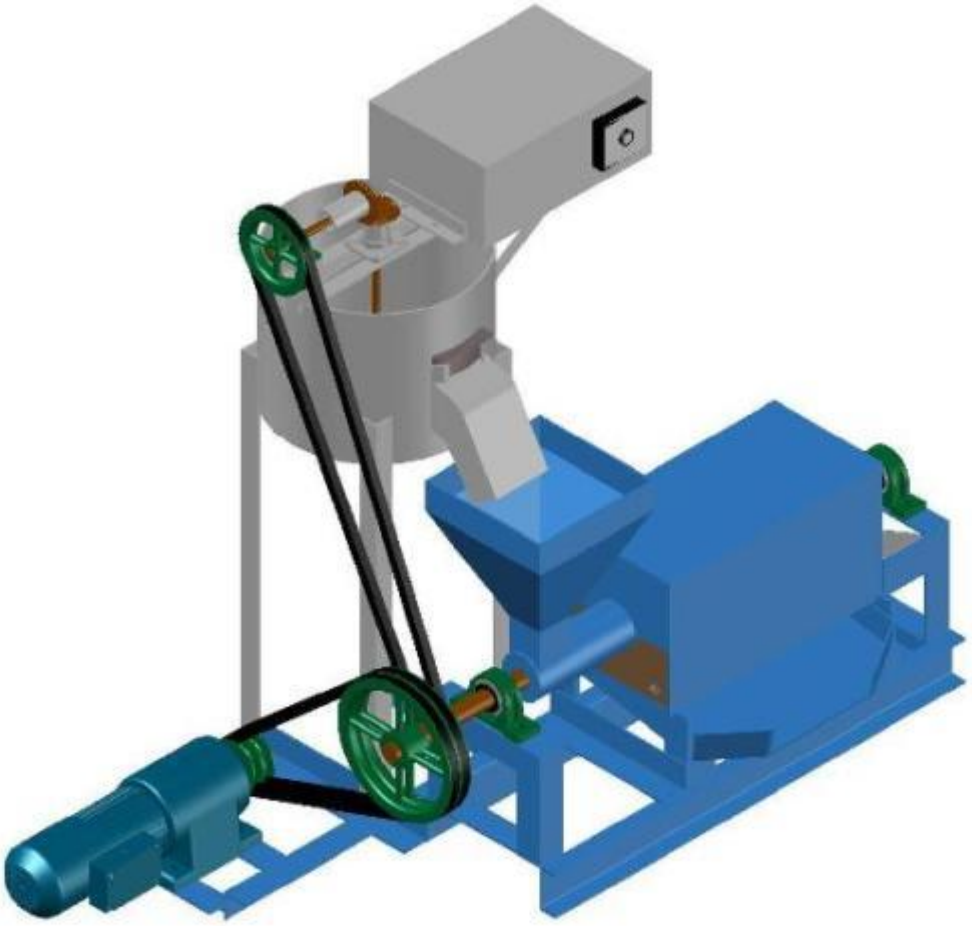


Figure L22. The Main View

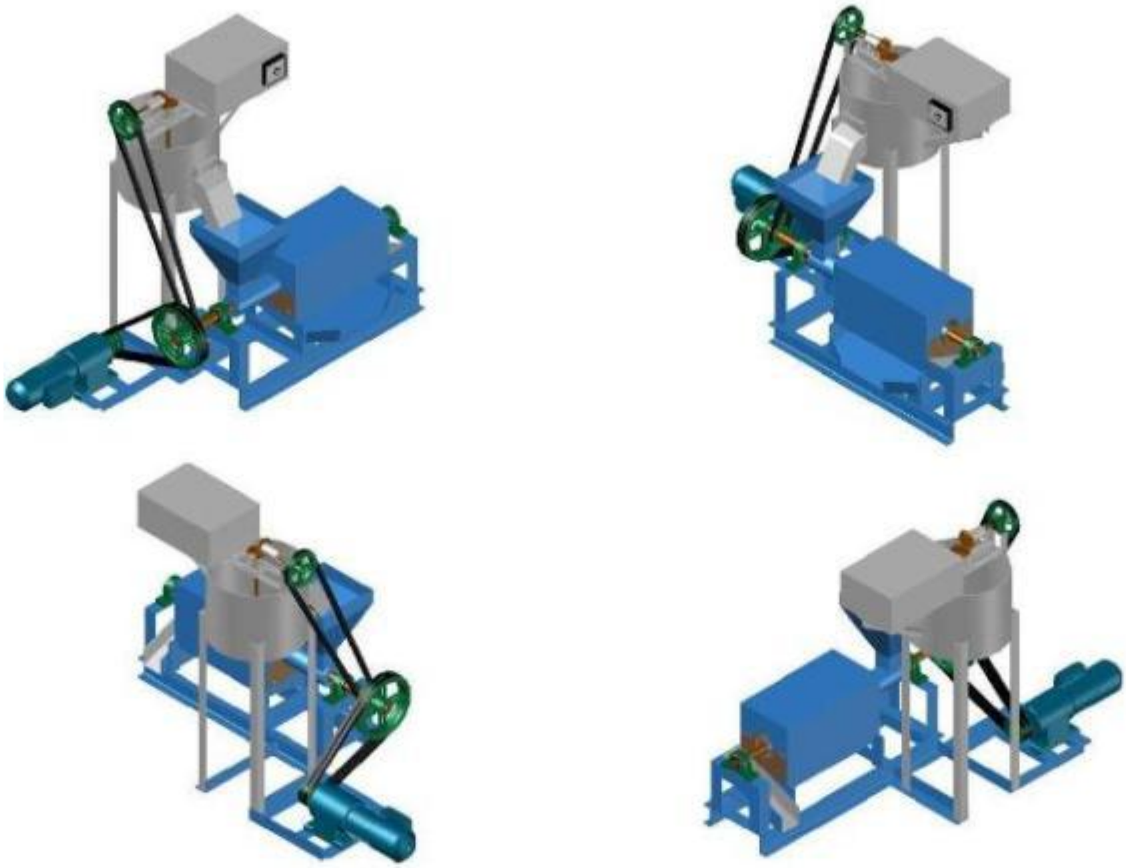


Figure L23. Multiple Views

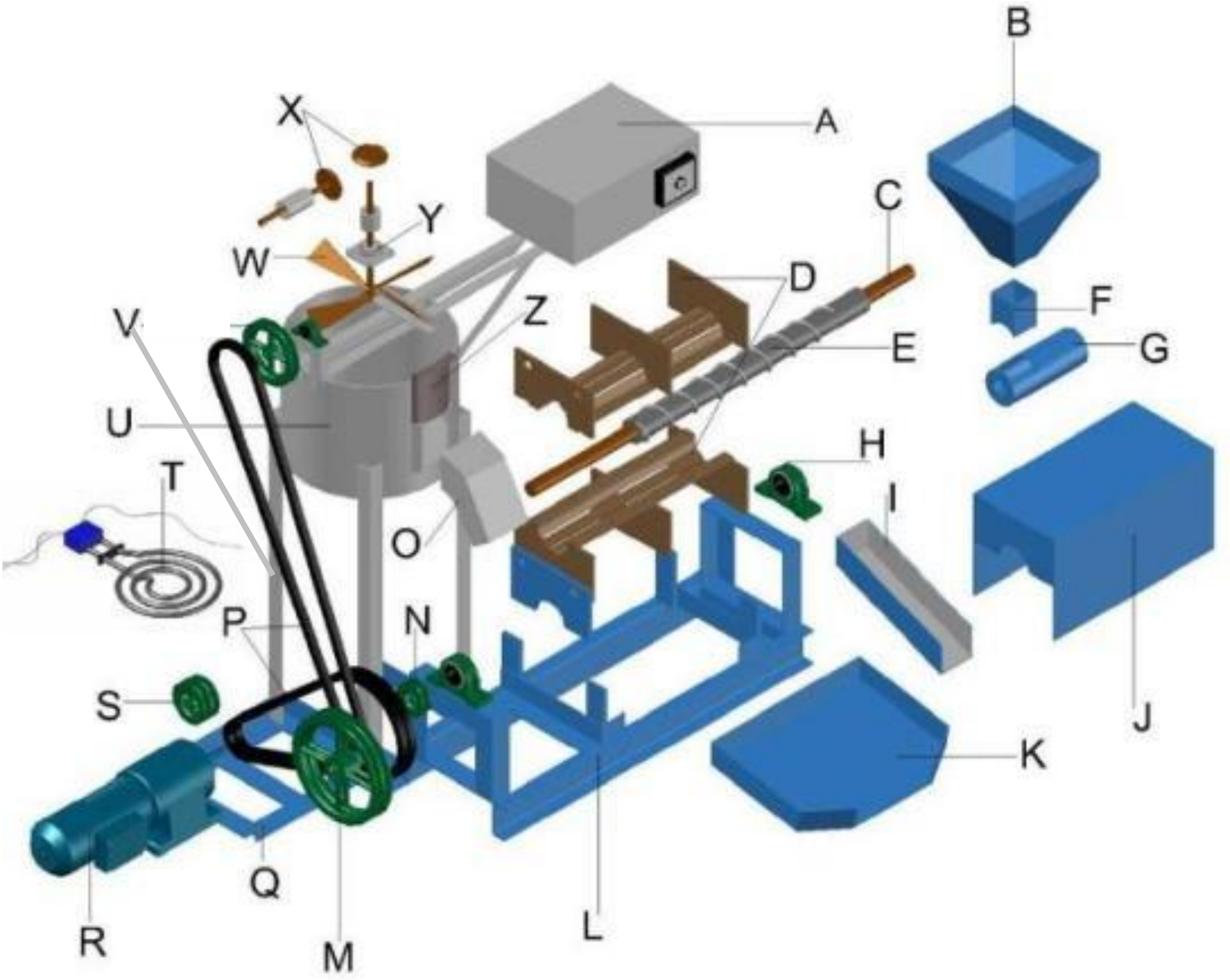


Figure L24. The Exploded View

PART	**DESCRIPTION**	**PART**	**DESCRIPTION**
A	Temperature Regulator	N	Bolt and Nut
B	Hopper	O	Hopper Passage
C	Wormshaft	P	Belts
D	Oil Barrel	Q	Electric Motor Stand
E	Worms	R	Electric Motor
F	Hopper Base	S	Driving Pulley
G	Mechanism Link	T	Electric Heater
H	Pillow Bearing	U	Roasting Drum
I	Cake Trough	V	Roasting Drum Stand
J	Barrel Oil Cover	W	Stirrer Blade
K	Oil Trough	X	Bevel Gears
L	Machine Frame	Y	Stirrer
M	Driven Pulley	Z	Sliding Gate