DEVELOPMENT AND PERFORMANCE EVALUATION OF A *DONKWA* PRODUCTION MACHINE

BY

OKANLAWON, Kunle Jonathan

M.Eng/SIPET/2018/8345

DEPARTMENT OF AGRICULTURAL AND BIORESOURCES ENGINEERING

FEDERAL UNIVERSITY OF TECHNOLOGY,

MINNA

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IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE AWARD

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AUGUST, 2023

DECLARATION

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 Information from other sources (publish or unpublished) has been duly acknowledged.

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OKANLAWON, KUNLE JONATHAN
SIGNATURE/DATE

MEng/SIPET/2018/8345

Federal University of Technology

Minna, Niger State.

CERTIFICATION

The thesis titled**: "Development and Performance Evaluation of a *Donkwa* Production Machine**" by **OKANLAWON, Kunle Jonathan** (M.Eng/SIPET/2018/8345) meets the regulations governing the award of the degree of MEng of the Federal University of Technology, Minna and it is approved for its contribution to scientific knowledge and literary presentation.

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DEDICATION

This project work is dedicated to the Almighty God who is the giver of knowledge, wisdom, understanding, skills in all learning, strength and grace; through Him have I been able to come this far and inspire to go much further.

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ABSTRACT

Donkwa is maize-groundnut based street vended snacks commonly consumed in Nigeria. *Donkwa* is produced from the mixture of roasted groundnut, roasted maize, sugar, salt and pepper, which is then moulded into shapes. The technologies employed in the processing, distribution and storage of *Donkwa* are based on the long established knowledge of traditional processing. *Donkwa* reduces the risk of cancer, helps promote fertility because of the presence of folate, help fight depression, boost memory power and aid in blood sugar regulation. Despite the nutritional and health potential of the product, its production has remained the use of local tools; the mixing of the raw ingredients is done with bare hands, moulding of the snack is also done by rolling the snacks on a tray to produce a spherical shape of the products. Some of other problems associated with the local production of *Donkwa* include non-standardization of equipment, process and raw material, inadequate hygiene during and after production, and little or no packaging which results in poor preservation techniques and high levels of contaminants in the food resulting in food borne illnesses. The aim of this study is to design, construct and conduct a performance evaluation of a *Donkwa* production machine. *Donkwa* production machine was designed and fabricated. The components of the machine are hopper, mixer, screw conveyor, die, frame, shaft, electric motor pulley and cutter. Experimental design was carried out. The study was conducted using a D-optimal design expert 11.1.2.0 to evaluate the effect of three independent variables: screw speeds (400-6000rpm), Feed rate (3-7kg/min) and Mix Ratio (2:1, 2:2 and 1:2) on the *Donkwa* production machine as well as the final product of evaluation the moulded *Donkwa*. The machine performance parameters are actual capacity and efficiency with variables like feed rate, the speed of the machine, mixing ratio of *Donkwa* materials, bulk density, efficiency and the capacity of the machine with the efficiency 78.7% and the capacity 65.1kg/h. Result showed that the produced machine is capable of moulding 65.1kg/hr compared to the traditional methods from the researched which can only produce 20kg/day.

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CHAPTER ONE

1.0 INTRODUCTION

1.1 Background of the Study

Donkwa, is a cereal and groundnut based snack prepared at home by vendors and consumed mainly in the northern parts of Nigeria. *Donkwa* is still locally prepared from mixtures of cereals (maize, millet and sorghum), tiger nuts, groundnut, ground pepper, ginger, sugar and salt (Nkama and Gbenyi, 2001). The ingredients are thoroughly mixed, pounded and moulded into balls that can be eaten without further processing (Abdulrahman and Kolawole, 2006).

In Nigeria, *Donkwa*, like other snack foods, is mainly produced and consumed in areas of its production and is based on art rather than scientific knowledge, varies with people, culture and geographical locations: these lead to possession of variable characteristics. Maize, groundnuts, pepper, salts and sugar, groundnut oil, ginger, and cloves together with Cashew nuts from Roasted maize and groundnuts are milled separately and then, the maize is sieved after which they are blended together with other ingredients and pounded in a mortar. Groundnut oil is added during pounding to increase the firm thickness of the ingredients. Cleaning is done by hand-picking and winnowing by means of metal trays or local trays made from palm fronds (Aroyeun *et al.*, 2017). Roasting of maize, groundnuts and cashew nuts were done using firewood, sand and specially constructed earthenware and aluminium frying pans in production process of *Donkwa. Donkwa* is rich in fat (37mg/g), calcium (302mg/kg) and potassium (364mg/kg) *Donkwa* has some very interesting health benefits such as; i. Promotes weight loss, ii. Boosts fertility, iii. Fights depression by boosting some antioxidants in the human body, iv. Boosts memory, v. Regulates blood sugar, and vi. Reduces risk of cancer (Aletor and Ojelabi, 2007).

The processes involved in making *Donkwa* are as enumerated below;

i. Roasting: Roast a well dried maize and groundnut separately.
ii. Milling: Mill the roasted maize and the groundnut separately.
iii. Sieving: Sieve the maize powder to remove lumps, chaff or other impurities. Inspect and remove any lumps or impurities from the groundnut powder.
iv. Mixing: Combine/mix all the ingredients (except the peanut oil) in a bowl and blend well to ensure even distribution of all ingredients. You can use your hands or a wooden spoon, then add little oil at a time and mix well. On adding the oil, the blend will begin to solidify.
v. Oil addition: Oil continuously until the blend becomes solid enough to be moulded without crumbling/breaking.
vi. Moulding: Mould into any shape of your choice using miniature jelly or cake moulds or simply make them into balls by rolling small portions in your hands. Serve with some crunchy peanut butter which includes blending the groundnut until they are fine then add it to the maize meal along with salt pepper and sugar. Afterwards add the rest remaining ingredients to the maize meal mix and finally shape the mix into small balls on a plate and serve.

1.2 Statement of the Research Problem

Donkwa has not been fully recognized throughout in the country due to the local method of production which has caused the limitation in the quantity being produced. *Donkwa* production manually brings so much daily stress on those producing it, affects the inherent quality due to the presence of unwanted impurities that may be presently available in the surroundings when it is not properly cleaned. With the manual method, large quantity will not be effectively produced to meet the demand (Ocheme *et al.*, 2011)

Despite the nutritional and health benefits of the product, its production is through locally use tools; the mixing of the raw ingredients is done with bare hands, moulding of the snack is also done by rolling the snacks on a tray to produce a spherical shape of the products. Some of other problems associated with the local production of *Donkwa* include non-standardization of equipment, process and raw material, inadequate hygiene during and after production, and little or no packaging which results in poor preservation techniques and high levels of contaminants in the food resulting in food borne illnesses (Lasekan *et al.*, 1996).

1.3 Aim and Objectives of the Study

The aim of this study is to design, construct and evaluate a *Donkwa* production machine. The specific objectives of this project are to:

i. design a *Donkwa* production machine

ii. construct the *Donkwa* production machine.

iii. carry out the performance evaluation of the machine as well as determine the performance indices.

1.4 Justification for the Study

Donkwa lowers risk of weight gain, helps promote fertility because of the presence of folate helps fight depression, boosts memory power, aids in blood sugar regulation (Abdulrahaman and Kolawole, 2006). However, in order to make the general public to be more aware of the benefit, there will be need for the introduction of the mechanical method in producing *Donkwa*. For this to be made available in large quantity, there is need to introduce the mechanical method of production in order to meet its demand. The mechanical if adapted will take care of some lapses such as contamination using the manual method and other factors e.g. time used in production, drudgery, and quantity. However, with the mechanical method of production, there will be massive productions and citizens will be aware of the health benefits of *Donkwa* leading to an improved packaging and sales of *Donkwa*.

1.5 Scope of the Study

This study will focus on the design and develop a *Donkwa* production machine by using local available materials and also test and carried out performance evaluation of the produced machine by using statistical analysis to determine the effects of the independent variables on the dependable variables.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 *Donkwa* Snack

A snack can be considered as a convenient food which can be eaten between meals. A snack is also considered as mobile food, easy to carry and simple to package. Snack can be eaten at any time of the day, (morning, afternoon and evening). In developed countries, snacks can also be eaten as a stop-gap measure to briefly check hunger, provide energy for the body and for enjoyment of the taste. Notable among snacks available in most urban settlements are the meat pies, scotch eggs, biscuits, buns, puff puff, plantain chips, peanuts, potato chips coconut chips, and beef rolls. Most of these foods are considered as junk food, which are dangerous to health. Snacks are used for refreshment and entertainment at home or offices but traditionally, produced snacks are rarely served in offices. Their production serves as a means of livelihood and employment especially for women in developing countries (Oke *et al.*, 1995).

An increasing proportion of the household food budget in Nigeria is spent on snacks in which convenience and quality are perceived imminent. An indication of the growing importance of snack foods is evident from the fact that consumers complain bitterly about increases in the prices of staples such as milk and bread but willingly pay disproportionately large sum for snack items (Lasekan *et al.*, 1996).

Donkwa is a common snack food in Central and Northern Nigeria. It is produced from a mixture of maize flour and groundnut paste, ground pepper, ginger, sugar and salt, these ingredients are thoroughly mixed, pounded together and moulded into balls that can be eaten without further processing (Abdulrahman and Kolawole, 2006).

In Nigeria and many other African countries, traditionally made snacks are also available. For instance, in Nigeria snacks are locally made from different crops such as maize, millet, sorghum, beans, groundnut, and soya beans as a sole component or as a mixture of one or more of the mentioned crops. Notable among popular snacks eaten in Nigeria are *Donkwa* (a cereal/legume based snack), *kulikuli* (legume based snack), *kokoro* (a cereal based snack), *maasa* (cereal-based snack), and *aadun* (a cereal –based snack). The difference in all the listed snacks and the others not mentioned are in their method of processing and packaging. Areas of production also have effect on the quality and type of processing/raw material used. An example is 'Booli' – a roasted ripe plantain, 'Akara' – a fried bean cake, dundu – a fried yam, ojojo – a fried grated cocoyam, all popular in the South Western part of Nigeria (Nkama and Gbeniyi, 2001).

Most of the snacks always contain sweetener, spices and salts to taste. They contain fewer preservatives and they are not meant to store for a long period and as such they are prone to quality degradation. In Nigeria, many snack foods have been produced from blends of different materials. Most important factors used are based on nutritional composition of a material which is directly insufficient in the other. Eneche (1999) produced a biscuit with a blend of millet/pigeon pea flour blends. In most of these cases, products of reasonably good quality have been produced. Some other snacks based on mixture of different raw materials have been produced with different reasons. For example, biscuits have been produced through replacement of wheat flour with mixtures of wheat flour, corn flour and cassava flour with products of reasonably good quality.

Cashew apple has been reported to be a high source of vitamin C higher than those reported in citrus fruits. Cashew kernel, obtained from the removal of the cashew nut from the apple base is rich in protein (Aroyeun *et al.*, 2017). The kernels are roasted usually and sold as a roasted snack by vendors on the street Aroyeun *et al.* (2017) extracted the oil from the kernel and used the addictive in biscuit processing and obtained a good biscuit with good sensory attributes and high protein content. Apart from this work, cashew kernel has not been popularly used in food processing. Cashew kernel paste was replaced with the popular groundnut while making other ingredients constant. The work describes the proximate composition, the mineral composition and the sensory characteristics of cashew *Donkwa*. This is the first report of this kind of work. A sample of *Donkwa* snack is presented in Plate I.

Plate I: *Donkwa* Snack

2.2 Composition of *Donkwa*

The following ingredients are used in making *donkwa*;

i. Groundnut: Groundnut or peanut *Arachis hypogaea* [*Fabaceae/Leguminosae]* Singh, (2009) is a native of Brazil and believed to have been introduced into Africa by the Portuguese (Anyanwu *et al*., 2001). The major groundnut producing countries in West Africa are Nigeria, Gambia, Togo, Republic of Benin, Ghana, Ivory Coast, Liberia, Chad, Niger, Senegal, Mali, Upper Volta and Guinea. As at 2008/2009, Nigeria is the largest producer of groundnut in Africa and fourth in the world. As a legume, it plays a huge role in feeding the world’s people and animals particularly in the third world countries, where they meet as much as two thirds of human nutritional needs. Moreover, because they can pull nitrogen out of air, they do not need much chemical fertilizers. Thus, make it a better bargain for poor farmers who cannot afford fertilizers (Khan *et al*., 2004). A large number of food products are prepared from groundnuts namely, boiled nuts, roasted nuts, salted nuts, groundnut milk, groundnut yoghurt, groundnut bars, groundnut butter, groundnut cheese, bakery product (Opeke, 2006; Abdulrahama *et al.*, 2014).

ii. Fine roasted maize: Maize contains about 72percentage starch, 10percentage protein, and 4 percentage fat, supplying an energy density of 365 kcal/100g compared to rice and wheat, but has lower protein content. Maize provides many of the B vitamins and essential minerals along with fibre, but lacks some other nutrients, such as vita-min B12 and vitamin C, in general, a poor source of calcium, folate and iron. Maize was one of the first plants cultivated by farmers between 7000 and 10,000 years ago (Dary and Imhoff-Kunsch, 2012). The way in which maize is processed and consumed varies greatly from country to country, with maize flour and meal being two of the most popular products by global alliance for improved nutrition (Gain, 2012).

iii. Chili pepper: The chili pepper is the fruit of plant from the genus capsicum which are members of the nightmare family. Chili peppers are widely used in many cuisines as a spice to add heat to dishes. It is originated from Mexico by germplasm resources information network (GRIN). Chili pepper is eaten by a quarter of the earth’s population every day in countries all over the globe. They are perennial shrubs belonging to the capsicum family and where completely unknown to most of the world until Christopher Columbus made his way to the New World in 1492 (Ettenberg, 2019).

iv. Salt: Salt is a mineral composed primarily of Sodium chloride (NaCl) a chemical compound belonging to the large class of salts; salt in its natural form as a crystalline mineral is known as rock salt or halite. Salt is present in vast quantities in seawater where is the main mineral constituent. Salt is essential for life in general, and saltiness is one of the oldest and most ubiquitous food seasoning. Of the annual global production of around two hundred million tonnes of salt, about 6 % is used for human consumption. Ji and Cappucio (2014).

v. Sugar: Sugar is the generic name for sweet-tasting, soluble carbohydrates, many of which are used in food. Table sugar, granulated, or regular sugar, refers to as sucrose; a disaccharide composed of glucose and fructose. Sugar is found in the tissue of most plants. Honey and fruits are abundant natural sources of unbounded simple sugar (Westenhoefer, 2006).

2.3 *Donkwa* Moulding Methods

2.3.1 Traditional method

The processes involved in making *Donkwa* traditionally are enumerated below:

i. Roast a well dried maize and groundnut separately

ii. Mill the roasted maize and the groundnut separately

iii. Sieve the maize powder to remove lumps, chaff or other impurities. Likewise inspect the groundnut powder and remove any lumps or impurities.

iv. Combine all the ingredients (except the peanut oil) in a bowl and blend well to ensure even distribution of all ingredients. You can use your hands or a wooden spoon.

v. Add the oil a little at a time and mix well. On adding the oil, the blend will begin to solidify. Continue to add the oil until the blend becomes solid enough to be moulded without crumbling/breaking (Nkama and Gbeniyi, 2001).

vi. Mould into any shape of your choice using miniature jelly or cake moulds. Or simply make them into balls by rolling small portions in your hands. Serve with some crunchy peanut butter. The steps include, blending the groundnut until they are fine then add it to the maize meal along with salt pepper and sugar. Afterwards add the rest remaining ingredients to the maize meal mix and finally shape the mix into small balls on a plate and serve. The process flow diagram for *Donkwa* preparation is presented in Figure 2.1. While the Pictorial preparation of *donkwa* is presented in Plate II.

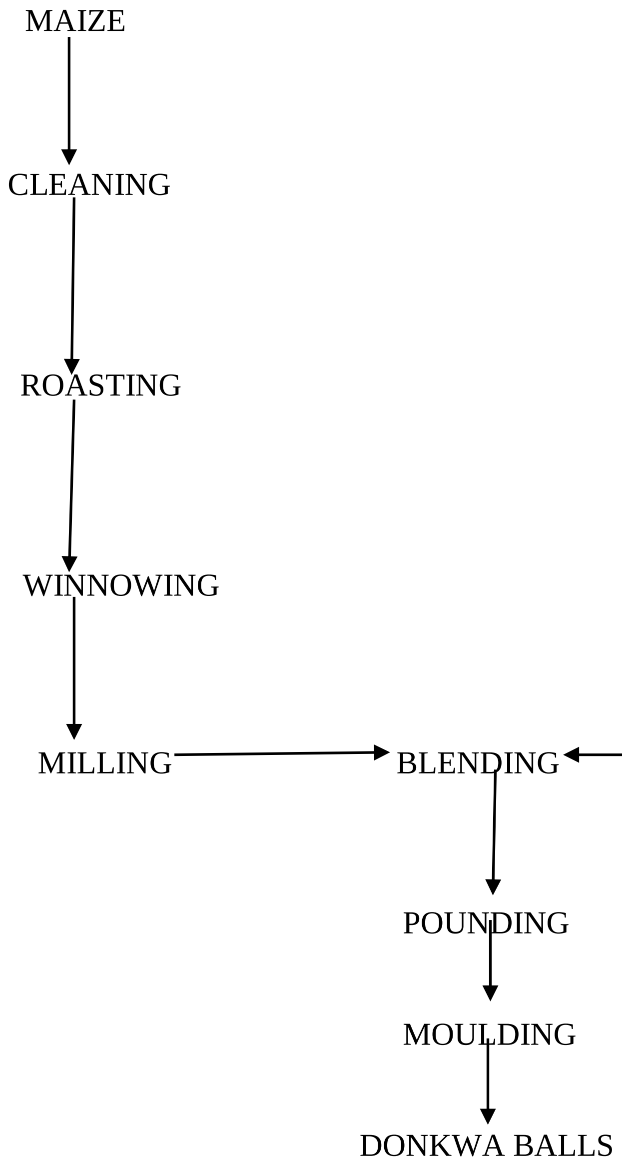

Figure 2.1: Process flow diagram for the production of *Donkwa*
Source: Nkama and Gbeniyi (2001)

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Plate II: Pictorial Procedure for the production of *Donkwa*
Source: Author's Field Work 2022.

2.3.2 Mechanical method/ technological method moulding machine

An injection moulding machine also known as an injection press, is a machine for manufacturing plastic products by the injection moulding process. It consists of two main parts, an injection unit and a clamping unit. Moulding machines are classified primarily by the type of driving systems they use: hydraulic, mechanical, electrical, or hybrid (Berkery, 1993).

i. Hydraulic: Hydraulic process have historically been the only option available to moulders until Nissei Plastic Industrial Co., limited introduced the first all-electric injection moulding machine in 1983. Hydraulic machines, although not nearly as precise, are the predominant type in most of the world, with the exception of Japan.

ii. Mechanical: Mechanical type machines use the toggle system for building up tonnage on the clamp side of the machine. Tonnage is required on all machines so that the clamp side of the machine does not open (i.e. tool half mounted on the platen) due to the injection pressure. If the tool half opens up it will create flash in the plastic product.

iii. Electric: The electric press, also known as Electric Machine Technology (EMT), reduces operation costs by cutting energy consumption and also addresses some of the environmental concerns surrounding the hydraulic press. Electric presses have been shown to be quieter, faster, and have a higher accuracy, however the machines are more expensive. Hybrid injection (sometimes referred to as "Servo-Hydraulic"): Moulding machines claim to take advantage of the best features of both hydraulic and electric systems, but in actuality use almost the same amount of electricity to operate as an electric injection moulding machine depending on the manufacturer. Singha and Vermaa (2016). A robotic arm is often used to remove the moulded components; either by side or top entry, but it is more common for parts to drop out of the mould, through a chute and into a container.

2.4 Review of Literature on *Donkwa* Production

The proximate composition of cashew made *Donkwa* and groundnut based were compared. The percentage protein of the samples varied significantly with protein level ($p < 0.05$) and ranged between 26.28 % and 31.43 % respectively for cashew made *Donkwa* and groundnut based *Donkwa*. There was also a significant difference ($p < 0.05$) in the percentage fat content of the samples which ranged between 9.87 % and 11.42 %. The percentage ash content of the samples ranges from 6.34 % to 7.12 % for both the cashew based *Donkwa* and the regular groundnut based *Donkwa* respectively. The crude fibre for both *Donkwa* were low and differed significantly with 1.06 % for cashew *Donkwa* while the *Donkwa* produced with groundnut has 1.23 % of crude fibre. The variation in both samples was significant at $p < 0.05$ (Ocheme, 2009). The carbohydrate content as calculated also varied significantly at $p < 0.05$. The effect of variation in the raw material used manifested in the percentage carbohydrate level of the *Donkwa*. The values obtained for cashew-based *Donkwa* is 51.66 % while the groundnut based *Donkwa* was 44.22 %. The significant differences observed in the percentage proximate composition of the samples of *Donkwa* produced in this study is probably due to the raw material difference, in the first case (Cashewnut) and the other case (Groundnut). The results observed in the study showed the suitability of cashew nut as a suitable material in the production of *Donkwa*.

The report of Ocheme (2009) who reported percentage protein levels of *Donkwa* produced in Niger State as 15.37, 16.12, 13.42 and 15.68 % for Bida, Doko, Lapin and Minna, respectively. The difference in the percentage protein in the study of Ocheme (2009) might not be unconnected with the initial raw material used and the processing methods. Our result also showed that cashew kernel has a higher percentage protein which reflected in the *Donkwa* sample (Cashew *Donkwa*). The percentage fat content show a low level which is a desirable characteristic as high level of fat in foods may expose the food to oxidative rancidity which is an undesirable condition in processed food and can affect the organoleptic properties of the food, especially of the taste and the odour of the food. The percentage crude fat obtained in this study was lower than the one reported by Ocheme (2009), who reported percentage crude fat which ranged significantly between 25.24 % and 32.43 %. There was a significant difference between the percentage total ash obtained in this study which ranged between 4.90 % - 7.12 % and the ones reported by Ocheme, (2009). According to Ocheme, (2009) the percentage total ash between 9.80- 12.45 % was due to the addition of spices such as Ginger and Pepper which were not added in our own case. The proximate analysis of *Donkwa* is shown in table 2.1. The mineral composition in the different *Donkwa* (Table 2.2) showed significant differences ($p < 0.05$) percentage, sodium, potassium, calcium, magnesium, phosphorus, zinc, copper, iron and manganese values reflected higher values for Groundnut-based *Donkwa* than the cashew based *Donkwa* respectively. This is an indication that Groundnut has higher mineral content than cashewnut and this reflected in its percentage total ash content. From Table 2.3 the result of sensory evaluation showed a significant difference in the organoleptic profiles of all the *Donkwa* samples. The cashew-based *Donkwa* has a better in taste, aroma, colour and overall acceptability than the groundnut based *Donkwa* with significant differences ($p < 0.05$).

Table 2.1: Proximate Analysis of *Donkwa*

Samples	Crude Protein	Crude fat	Crude fibre	Total ash	Dry matter	Moisture	Carbohydrate
Cashew *Donkwa*	26.26	9.87	1.06	6.34	95.21	4.79	51.66
Groundnut *Donkwa*	33.43	1.42	1.23	7.12	95.42	4.58	44.22

Source: Ocheme (2009)

Table 2.2: Mineral Composition of *Donkwa*

Samples	Na	K	Ca	Mg	P	Zn	Cu	Fe	Mn
Cashew *donkwa*	0.183	0.538	0.157	0.27	0.16	23.6	2.9	234.8	42.8
Groundnut *donkwa*	0.195	0.557	0.169	0.31	0.19	25.2	3.1	241.2	46.3

Source: Ocheme (2009)

Table 2.3: Sensory Evaluation of *Donkwa*

Samples	Taste	Aroma	Colour	Crispness	Overall acceptability
Cashew *donkwa*	7.5	6.95	7.45	7.4	7.40
Groundnut *donkwa*	6.95	6.6	6.7	6.95	6.95

Source: Ocheme (2009)

2.5 Main Components of Injection Moulding Machine

2.5.1 Injection unit

This consists of three main components: Screw motor drive, Reciprocating screw and barrel, Heaters, thermocouple, and ring plunger.

2.5.2 Clamping unit

This consists of three main components: Mould, Clamping motor drive, Tie bars, the sender is clamped onto the edge of a workbench

2.6 Moulding Machine Selection

2.6.1 Selection by injection volume

Moulding machine injection volume Q (gr) 1 shot weight W (gr), including the sprue and the runner, within a following range is preferable.

$$Q = (1.3 \sim 1.5)\, W \quad (2.1)$$

If the injection volume is too small, plasticization will not make it, and it will be sent to the end of the screw before sufficient plasticization, which will end up with losing physicality it would have as moulded product. Conversely, if the injection volume is too big, retention time in cylinder will be long, and will likely to cause degradation of resin (Tang *et al*., 2006).

2.6.2 Selection by mould clamping pressure

When moulding, both toggle type and direct pressure type is prefirable. Relationship between moulded product projected area A (cm^2) and required clamp capacity P (ton) as shown in figure 2.2 is preferable (Tang *et al*., 2006).

$$P = (0.5 \sim 0.7)\,A \tag{2.2}$$

2.6.3 Selection by nozzle structure

Open nozzle is commonly used for moulding. There are open nozzle, and shut-off nozzle as in Figure 2.2 and 2.3 respectively, for the nozzle of commercially available injection machine, but with either nozzle, it must have temperature control function. If concerning about drooling from nozzle, use shut-off nozzle. However, it might cause silver streak or burn from retention in slide part, so extra attention is required (Erzurumlu and Babur 2006).

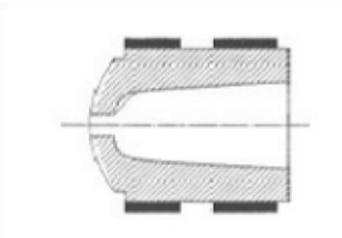

Figure 2.2: Open nozzle
Source: (Erzurumu *et al*., 2006)

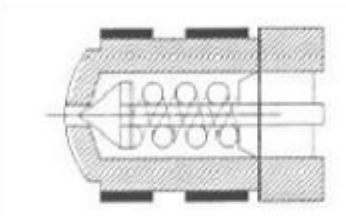

Figure 2.3: Shut-off nozzle
Source: (Erzurumu *et al*., 2006)

2.6.3 Injection mechanism

Normal moulding machine, "determinate injection speed, and injection pressure dual regulation", is sufficient for moulding, but when moulding a product which requires severe measurement, appearance, and formability (flow property, de-mould property), machine with injection speed and pressure control program is effective (Shigley, 2006)

2.6.4 Backflow prevention ring

Backflow prevention ring is necessary for moulding, since melt viscosity is relatively low. If this backflow prevention ring is damaged by friction or corrosion, resin in the cylinder will backflow to the hopper side when injecting (pressure keeping), and might not give injection pressure (hold pressure), described below, properly to the cavity because the cushion volume cannot be kept. Good moulded product cannot be made in this case, so cushion volume and its stability when moulding must be cared from the aspect of maintenance and control. Backflow prevention ring do not need any special corrosion and abrasion resistant steel grade, but when moulding glass fibre, carbon fibre filling grade filled filler, or other corrosive gas generating resin concurrently, usage of corrosion and abrasion resistant steel grade is preferable (Singha and Vermaa, 2016).

2.7 Peripheral Equipment

2.7.1 Material drying

Moulds can be shape formed without preliminary drying of the material, but if putting emphasis on mould deposit cut down, or surface appearance, 3 to 4 hours of material drying in 80 to 90℃ is preferable. Especially, talking about each filler added complex, moisture absorption of filler might affect its physicality and appearance, so enforcement of preliminary drying is necessary. Generally, shelf-type dryer or hopper dryer is sufficient for drying and there is no need to use dehumidifying dryer (Yi-qi, 2013).

2.7.2 Mould temperature control

Mould temperature control must have an ability to keep the mould temperature determinate by promptly getting rid of the heat brought by resin, to gain moulded product with steady measurement and physicality. Table 2.4 shows methods of the mould temperature control system. Select system by product required quality, workability, and mould design, but Heater calefaction is not suitable for general usage (Singha and Vermaa, 2016).

Table 2.4: Mould Temperature Control System

System	Adaptation to polyacetal
Hydronic	Generally used to polyacetal. Be careful when removing scales in flow passage after long term usage.
Pressurized hydronic	Used when mould temperature is over 90℃.
Heated oil circulation	Used when mould temperature is over 90 ℃
Heater calefaction	Irrelevant. Cannot stop mould temperature going to high. Sometimes used for auxiliary heating.
Chiller	Effective as a local overheat protector of the core and the other mould tool.

Source: (Singha and Vermaa, 2016)

2.7.3 Local ventilation equipment

Mould is a resin with a good thermal stability, but by the condition, it will generate formaldehyde by thermal decomposition. Formaldehyde is a gas with a strong acridity against eyes, nose, and throat. It extrudes can be noticed by the irritating smell. Even though there is a personal difference, this can be felt at 0.2 to 0.3 ppm in general. American Conference of Governmental Industrial Hygienists and Japan Industrial Hygiene Academic Society recommend "below 1 ppm" in working atmosphere concentration. Consequently, formaldehyde concentration of the work floor such as around moulding machine should be "below 1 ppm" and try to make it even lower. For this reason, moulding plant need to consider installation of part or general ventilation equipment. Also, formaldehyde detecting tube can be used for concentration measurement (Eastop and McConkey, 2009).

2.8 Moulding Conditions

2.8.1 Preliminary drying

Figure 2.4 shows relationship of drying temperature, drying time and water absorption rate of standard grade. Water absorption rate of mould is small, and moulding without preliminary drying is possible if it is immediate after breaking the seal, but when putting emphasis on mould deposit cut down, or surface appearance, 3 to 4 hours of material drying in 80 to 90℃ is preferable **(**Kale *et al.*, 2021).

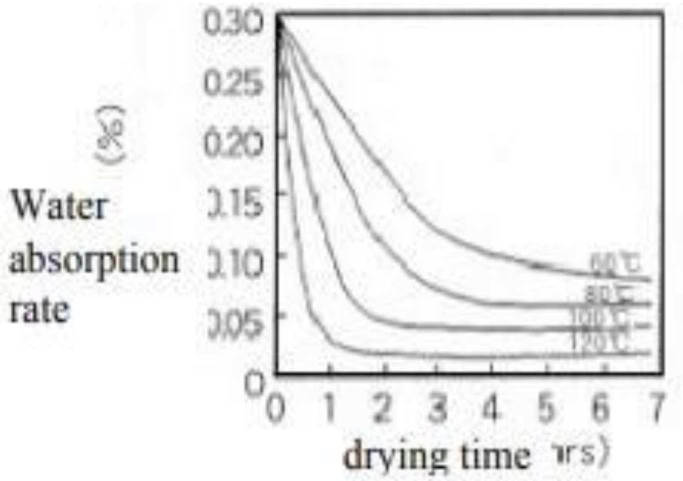

Figure 2.4: Relationship between drying time and water absorption rate
Source: (Kale *et al.*, 2021)

2.8.2 Resin temperature

Table 2.5 indicates standard pre-set temperature of cylinder in typical grade mould. Because mould flow property resin temperature dependence is low, that flow length will not increase as expected even if resin temperature rises, and it can trigger thermal decomposition, which might cause mould deposit increase or silver streak. Conversely, if the resin temperature is too low, mould crystal will be injected before plasticization meltdown, and moulded product physicality might be insufficient, so pre-set temperature of at least 160℃ to 170℃ is necessary (Kale *et al.*, 2021).

Table 2.5: Standard Moulding Condition of Each Grade Mould (unit: ℃)

Grade	**Nozzle**	**Cylinder front section**	**Cylinder middle section**	**Cylinder rear section**
Standard grade		190	180	170
Weather-resistant grade		190	180	170
FC		200	190	180
FT		200	190	180
FL, FW		190	180	170
LO, FX		190	180	170
FA		190	180	170
FS		190	175	170
FU		190	180	170
ET		190	180	170
TC		190	180	170

Source: (Kale *et al*., 2021)

FS: Low screw rotation speed, temperature of the upper limit 220 ℃

FU: Mould temperature below 40℃, temperature of the lower limit 160 ℃

ET: Low injection speed, nozzle temperature adjust so that nozzle will not lock out or drool

2.8.3 Injection pressure

Injection pressure can be considered separately as fill pressure and hold pressure. Generally, fill pressure should be set bigger than hold pressure. In case of crystalline resin, hold pressure is necessary for filling up because big shrinkage will happen when cooling solidification. Increasing hold pressure is effective to resolve sink and void, but if it increases too much, it might cause burr (Singha and Vermaa, 2016).

2.8.4 Injection speed

Faster injection speed is preferable for thin moulded product or multiple-cavity moulded product with strict dimension accuracy. Conversely, slower injection speed is preferable for thick moulded product. Also, program control of injection speed is effective to resolve jetting and flow mark (Singha and Vermaa, 2016).

2.8.5 Mould temperature

Generally, the suitable temperature for mould temperature is 60 ℃ to 80 ℃ and it is important point in moulding condition. Moulding in mould temperature of about 20℃ to 30 ℃ by chiller is possible, for high cycle moulding purpose, but it might cause deformation from moulded product residual strain, and dimension change from after contraction by the usage environment (high ambient temperature) If measurement stability and surface gloss under high ambient temperature are necessary, setting mould temperature up to 120 ℃ is effective (Singha and Vermaa, 2016).

2.9 Moulding Cycle

The moulding cycle time on injector moulding machine consist of the injection time, which depends on the shot size and machine power, but is usually small (1-2 sec) and cooling time usually dominates (Singha and Vermaa, 2016).

2.9.1 Moulding cycle structure

General structure of moulding cycle is shown in Figure 2.6:

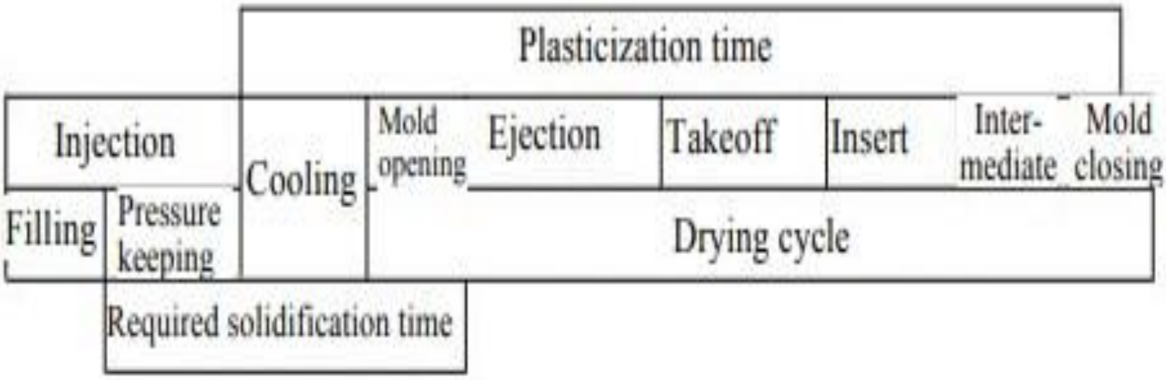

Figure 2.5: Moulding Cycle Diagram
Source: (Singha and Vermaa, 2016)

2.9.2 Injection time (filling time, pressure keeping time)

Setting will vary by the moulding machine. Injection time (filling time + pressure keeping time) ＞ Gate sealing time Gate sealing time is a time which resin stops solidification flow at the gate. As Figure 2.6 show, it can be thought as the injection time where moulded product volume become constant when the injection time is longer. If pressure keeping is stopped before gate sealing, melted Inupiat will backflow, which will end up with measurement and physicality varying widely. War page, sink, and void are caused from this in many cases. To determine the gate sealing time, just measure injection time changed moulded product volume (Dimla, 2006).

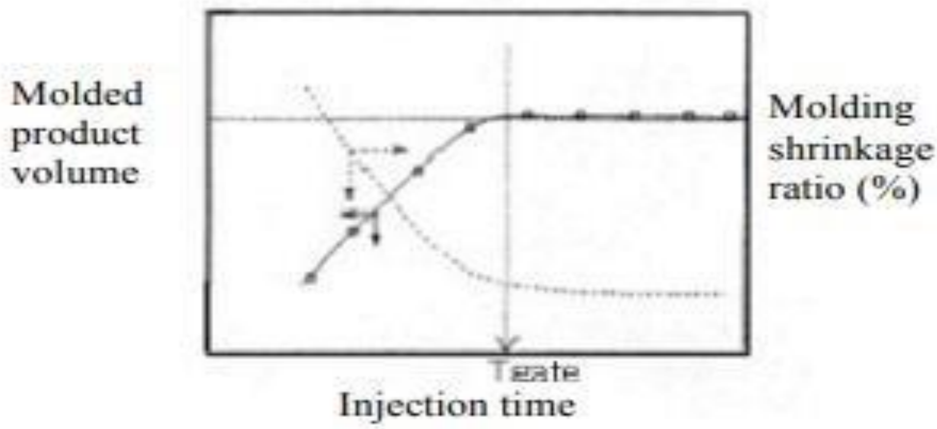

Figure 2.6: Gate Sealing Time
Source: (Dimla, 2006)

2.9.3 Plasticization time

If the plasticization time is longer than required least cooling time, moulding cycle will be longer at the same rate. In this case, raising screw rotation speed or cutting down plasticization time by using bigger plasticization volume moulding machine is effective. Also, some moulding machine can plasticize after mould opening by compounding performance (Erzurumlu and Babur, 2006).

2.9.4 Cooling time

Required solidification time is, minimum time that can extrude without moulded product deforming after the pressure keeping time is over and is solidified. Of course, cooling time will differ by moulded product thickness and draft angle, ejection system, location, hold pressure, and mould temperature. Figure 2.7 indicates computed result of moulded product thickness, mould temperature and required solidification time. Also, required solidification time in the moulding cycle can be estimated from same figure, by calculating required solidification time of moulded product thickest part, which is moulding cycle rate controlling (Li and Li, 2008).

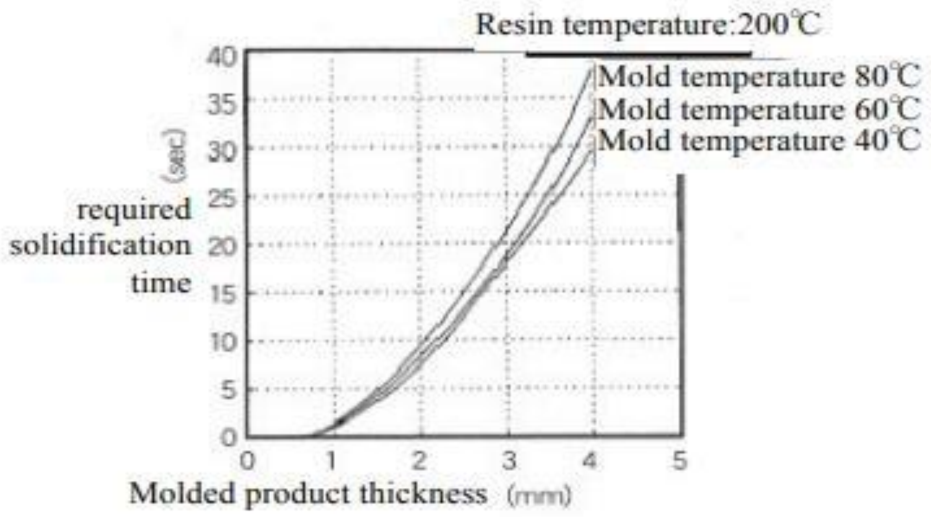

Figure 2.7: Moulded Product Thickness and Required Solidification Time (Standard grade)

Source: (Li and Li, 2008)

2.9.5 Drying cycle

Drying cycle is a total of mechanical time such as mould tool switching time, product ejection time, take-off time, and intermediate time (waiting time). This time is to be controlled by moulding machine model, product figure, mould system and structure, and differs by each moulding condition.

2.10 Start and Finish of Moulding Operation, Interruption of Operation, and Material Change

2.10.1 Material change

When changing material in the heating cylinder, to the other (material that might cause thermal decomposition by moulding temperature, material that might decompose, or material which moulding temperature differs widely), or the reverse, insert a polyethylene or polystyrene with wide moulding temperature range, in the middle (Eastop and Mcconkey, 2009).

2.10.2 Interruption of operation

Aborting the operation, keeping heating cylinder temperature under 150℃ is preferable for security and prevention from carbide mixing in. Also, when aborting operation for long term, resin must be displaced, and polyethylene or polystyrene is preferable as a displacing material. Through a long time moulding operation, decomposed resin layer will be built up, and it will gradually carbonize inside the heating cylinder. This carbonization layer in the heating cylinder will grow thicker and if the decomposition becomes advanced, it will mix in the moulded product, so occasional cleaning by dismantling is preferable (Shigley, 2006).

2.11 Thermal Stability

Thermal stability is an important design characteristic for engineering materials used at elevated temperatures. It may be defined as the resistance of an alloy to degradation of ductility and toughness when subjected to long-term thermal exposure

2.11.1 Thermal analysis

As an evaluation method of plastic thermal stability, there is TGA (Thermogravimetric Analysis) method that examines volume decrease behaviour caused by polymer thermal decomposition under high temperature melting condition (Tang *et al.*, 2006). The mould good thermal stability can be seen in volume decrease behaviour curve by TGA shows in Figure 2.9.

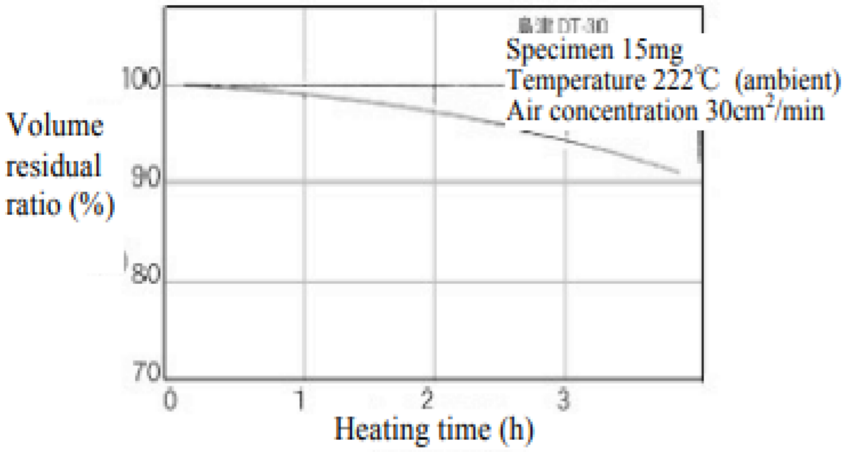

Figure 2.8: Volume Decrease Property by TGA (Standard Grade)
Source: (Tang *et al.*, 2006)

2.11.2 Colour change by retention

Moulding machine retention and colour change property curve is indicated in Figure 2.9. Setting steady mould at resin temperature 190℃ as standard, relationship of resin temperature and residence time in the case of $\Delta E = 2.0$ is indicated.

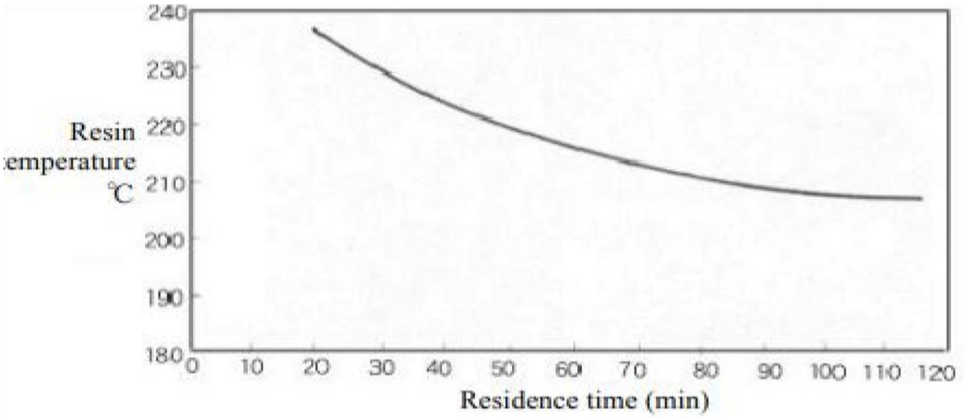

Figure 2.9: Moulding Machine Retention Colour Change Property Curve
Source: (Berkery, 1993)

2.11.3 Reproduction property

Strength, moulding shrinkage ratio, and colour change, in regeneration rate 100 %, 50 % 30 % of standard grade are indicated in Figure 2.10(a) and 2.10(b). Even though repeated for 10 times in regeneration rate 100 %, there was almost no physicality deterioration, but colour tone and moulding shrinkage ratio were changed slightly. There were no changes in strength, moulding shrinkage ratio, and colour tone, if recycled under 50 %, and could say that it is keeping up the same performance with the virgin material. However, there might be foreign material mixed inside, so still need a special attention. Also, mechanical property will decrease by fibre fracture, in filler filling grade, so recycling this is not preferable (Hakimian and Sulong, 2012).

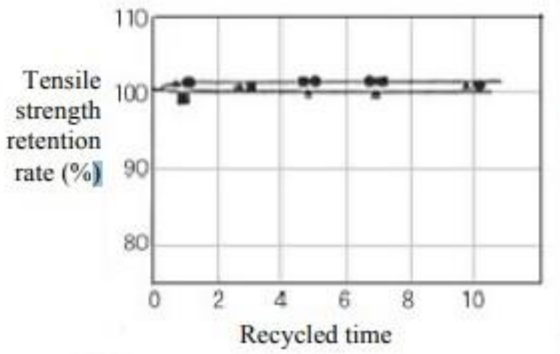

Figure 2.10(a): Change in Tensile Strength

Source: (Hakimian and Sulong, 2012)

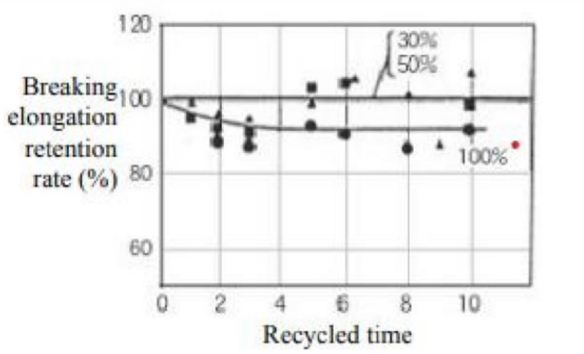

Figure 2.10(b): Change in Breaking Elongation

Source: (Hakimian and Sulong, 2012)

The diagram of Mini-Injection Moulding Machine is shown in plate III

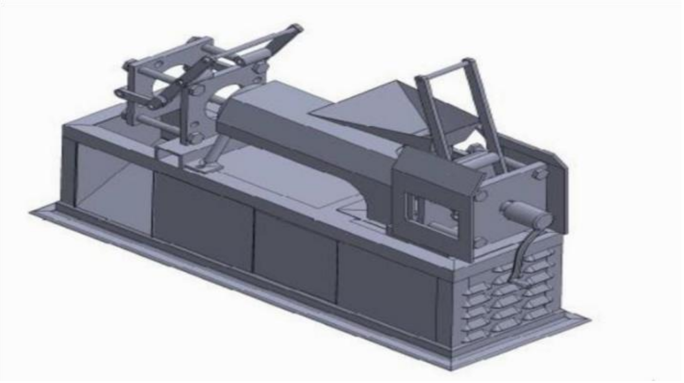

Plate III: Mini-Injection Moulding Machine
Source: (Nwadinobi, 2019)

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Materials

The materials used in making *Donkwa* and equipment used in constructing the *Donkwa* production machine are listed.

3.1.1 Biological materials

The biological materials are roasted groundnut, roasted maize, sugar, and chilli pepper.

3.1.2 Construction materials

The materials used in constructing the *Donkwa* production machine are given as listed.

i. Galvanized Sheet: A galvanized sheet is a piece of metal that has been protected by applying zinc coating to steel or iron, to prevent rusting. The most common method is hot-dip galvanizing, in which parts are submerged in a bath of molten zinc.

ii. Angle iron: An angle iron is a length of iron or steel, having an L-shaped cross section, used as a structural shape. The angle iron forms a right angle when it's about to be used so as to fit into its use.

iii. Rivet pin: A rivet is a permanent mechanical fastener. A rivet consists of a smooth cylindrical shaft with a head on one end. The end opposite the head is called the tail. On installation the rivet is placed in a punched or drilled hole, and the tail is upset, or bucked (i.e. deformed), so that it expands to about 1.5 times the original shaft diameter, holding the rivet in place. To distinguish between the two ends of the rivet, the original head is called the factory head and the deformed end is called the shop head or buck-tail.

iv. Mild steel sheet: This is steel that contains a small percentage of carbon, strong and tough but not readily tempered. It is less brittle than steel and it can be further strengthened through the addition of carbon. Mild steel can be alloyed with chromium, nickel, molybdenum and other elements to improve its mechanical and chemical properties.

v. Cast iron: This is a group of iron-carbon alloys with carbon content more than 2 %. Its usefulness derives from its relatively low melting temperature. The alloy constituents affect its colour when fractured: white cast iron has carbide impurities which allow cracks to pass straight through, grey cast iron has graphite flakes which deflect a passing crack and initiate countless new cracks as the material breaks, and ductile cast iron has spherical graphite "nodules" which stop the crack from further progressing.

3.2 Methods

3.2.1 Design consideration

i. Availability of material: The design considered materials that are easily available in the local markets.

ii. Maintenance consideration: The machine was designed with least complexity in the parts production to aid and ensure easy and assessable maintenance.

iii. Cost consideration: The machine was designed in a way to reduce the production cost and cost efficient.

iv. Ergonomics and convenience: The starting, controlling and stopping levers and buttons were positioned on convenient handling.

v. Safety of operation: the system was designed safe for the operator in a way that it is not dangerous to operate by. The speed moving parts were designed well covered and the electrical wire joined using right insulation tape.

3.3. Design Calculation and Analysis

The design analysis is aimed at evaluating the necessary design criteria and parameters at selecting the various machine parts suitable to achieve the desired end product

3.3.1. Design of the hopper dimensions: Design assumption

The hopper serves as the mixing unit, bulk storage and feeder. In order to determine the hopper capacity. The assumed capacity of the machine must be put into consideration. The sketch of the hopper is shown in Figure 3.1.

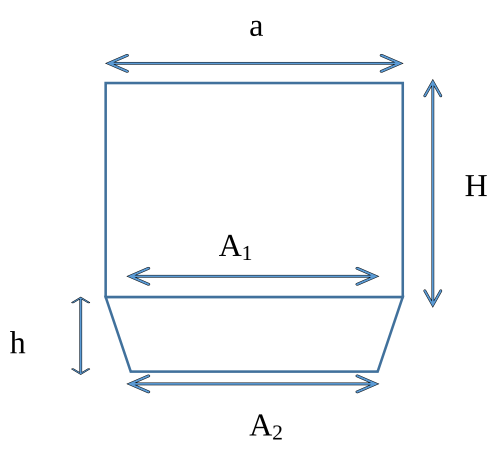

Figure 3.1: Line Sketch for the Hopper

The hopper assumed to be loaded with grinded *Donkwa* materials to fullness, assuming volume of *Donkwa* equal volume of hopper. Mass of *Donkwa* in the hopper is assume 7 kg per run. The volume of the *Donkwa* can then be computed using equation 3.1 (Gbabo *et al.*, 2013).

$$\rho = \frac{M}{V} \tag{3.1}$$

Where:

$V = volume\ of\ thr\ Dokwa\ (cm^3), \rho = Bulk\ density\ of\ the\ Donkwa\ kg/cm^3$

From reviewed literature, the bulk density of *Donkwa* is 0.00051 kg/cm^3 (0.51 g/ml). Therefore volume of the *Donkwa* will be, $V = 13725.5\ cm^3$, this equals the volume of hopper required in the Figure 3.1. The volume of the hoper can be computed using equation 3.1, 3.2, and 3.3 as presented by Fadeyibi *et al*. (2014).

$$V_t = V_b + V_f \tag{3.2}$$

$$V_b = a^2 \times H \tag{3.3}$$

$$V_f = \frac{h}{3}(A_1 + A_2 + \sqrt{A_1 + A_2} \tag{3.4}$$

Where:

V_t = Total volume of the hopper (cm^3), V_b = Volume of the square body (cm^3), V_f = Volume of frustum feed (cm^3), A_1= Bigger area of frustum feed (cm^2), A_2= Smaller area of frustum feed (cm^2) H= Height of the square shape (cm) h = Height of the frustum shape (cm) a = Length of the square hopper (cm) L= Smaller length of the feed (cm) a = 25cm, H =17 cm, h =12 cm, L= 15 cm, A1= 625 cm^2, A2=225 cm^2, V_b = 10625 cm^3, V_f =3518.65 cm^3 and V_t = 14143.65 cm^3

3.3.2 Design for the screw conveyor

The screw conveyor moves the mixed *Donkwa* material to the moulding die. This was design to handle 7kg at a "run" to the moulding die. For the screw shaft diameter, considering 3 as the factor of safety, the maximum shear stress can be calculated using Equation 3.5 (Olaoye, and Olotu, 2015)

$$F.S = \frac{Yield\ stress(\sigma)}{Design\ stress\ (\tau mx)} \tag{3.5}$$

Shaft material considered is stainless steel grade 304 of Yield strength 241Mpa Shaft standard selected from American Society of Mechanical Engineers (ASME).

But yield stress = $\frac{1}{2}$ yield strength

$$\sigma = \frac{1}{2} \times 241 \quad = 120.5 \text{ MPa}$$

$$= \frac{120.5}{3} = 40.1667 \text{ MPa}$$

Therefore, the maximum shear stress considered is τmax (Design stress) = 40 MPa

3.3.3 Torque transmitted by the shaft

The torque transmitted is important in determining the force required by the motor to rotate the connected shaft. The torque transmitted (T_s) can be defined as the product of the forces (F_o) required by the motor to rotate the screw conveyor shaft through the pulley of the shaft and the perpendicular distance from the die to the arm (L_d). This can be computed using equation 3.6 and 3.7 as presented by Gbabo *et al.* (2013)

$$T_S = F_0 \times L_d \tag{3.6}$$

$$F_0 = m \times g \tag{3.7}$$

Where: m is the mass of pulley and g is the acceleration due to gravity. The average weight of the pulley plus the load it carries from the mixing shaft was summed to be 25 kg and a perpendicular distance from the die to the arm taken as 500 mm.

F_o = 25 x 9.81 = 245.25 N

T_s = 245.25 x 500 = 122,625 Nmm

3.3.4 Design of the first pitch of the pitch screw.

The design of the pitch was done to determine what size of the pitch will fit in the barrel and to determine how many fight required to achieve proper moulding of the *Donkwa* material.

The engineering practice states that the pitch of the decreasing pitch of the screw should be between 0.9 and 1.5 times the outside diameter of the screw conveyor. Therefore, the first pitch of the decreasing pitch auger is given in Equation 3.8 (Rauwendaal, 2013).

$$P_S = 1.4D_S \tag{3.8}$$

Where:

Ps = The pitch of the auger (mm), Ds = outside diameter of the auger (mm)

Pitch is therefore 35mm

$$Tan\varphi = \frac{Pitch}{\pi Ds} \quad (3.9)$$

Where:

Helix angle (φ) =? (Unknown), Screw diameter (Ds) = 25mm, Screw pitch (p) = 35mm

φ=54.46°

3.3.5 Design of the barrel

In order to design the barrel, the lower part dimensions of the hopper were considered as well as the quantity to be fed into the barrel per time.

It is horizontal and cylindrical. It is also divided into two for easy maintenance and cleaning of the residue in case it is stuck and stainless steel was selected to ensure quality of the *Donkwa*. It contains a screw conveyor. The screw conveyor is made of stainless steel with reducing decreasing pitch. The total barrel volume can be calculated from equation 3.10.

$$V_{br} = \pi \times r^2 \times L_{br} \quad (3.10)$$

Where:

r = inner radius of the barrel (cm) L_b = length of the barrel (cm) r = 6 cm, L_b = 40 cm,

V= 4524.48 cm^3

3.3.6 Determination of the total length of belt

The length of belt required to transmit power from the motor to the screw shaft as shown in Figure 3.2. Pulley sizes were selected based on recommendation from literature review. The length of an open belt running over two pulleys is given by equation 3.11 in terms of pulley diameter as presented by Khurmi and Gupta (2011).

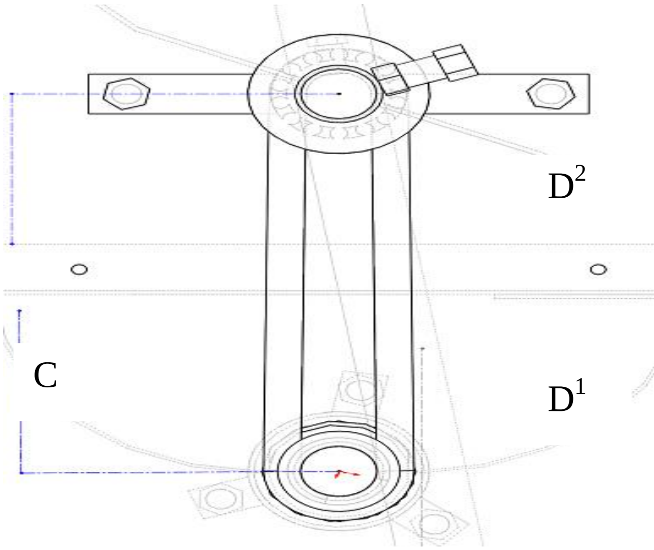

Figure 3.2: Sketch of the Belt

$$L = 2C + \left(\frac{\pi(D_2 + D_1)}{2}\right) + \left(\frac{D_2 - D_1}{4C}\right) \tag{3.11}$$

Where:

L = length of the belt (mm), D_2 = shaft pulley diameter (mm) and, D_1 = motor pulley diameter (mm) D_2 was 60 mm and D_1 was 40 mm (C) = Centre distance of the pulleys was obtained = 250 mm

L = 2(250) + (157.1+0.4) = 22.8” L = 657.5 mm

3.3.7 Speed transmitted from the motor to the screw shaft to the mixing shaft

The motor shaft was connected directly to the screw shaft which transmits the same speed through them but different speed was transmitted to the mixing shaft, as shown in Figure 3.2. The speed transmitted from screw shaft to the mixing shaft was calculated using Equation 3.12 (Khurmi and Gupta, 2011).

$$\frac{N_2}{N_1} = \frac{D_1}{D_2} \tag{3.12}$$

Where:

D_2 = shaft pulley diameter (mm), D_1= mixing shaft pulley diameter (mm), N_1 = motor speed (in rpm), N_2 = mixing shaft speed, (in rpm) Diameter D_1 and D_2 are 60 mm and 40 mm, respectively and the motor used is 960 rpm.

$$\frac{N_2}{960} = \frac{40}{60} = \ 640\, rpm$$

Speed transmitted to the mixing shaft was calculated to be 640 rpm and that of the screw shaft which is same as that of the motor was 960 rpm.

3.3.8 Determination of power requirement

Determination of power requirement was necessary in the selection of motor to drive the machine. This can be obtained using equation 3.13, 3.14 and 3.15 (Khurmi and Gupta, 2011).

$$P_c = T \times \omega \tag{3.13}$$

Where:

$P_c = power\ required, \quad T = torque, \quad \omega = angular\ speed$

The angular speed of shaft is found from Equation (3.14)

$$\omega = \sqrt{\frac{g}{L_P}} \tag{3.14}$$

$$\omega = \sqrt{\frac{9.81}{0.5}} \ = 4.43\, rad/s$$

Therefore, the power required for compression through the screw shaft is found from Equation (3.13)

Pc = 122.625 x 4.43 = 543.2288watt = 0.72hp ≈ 1hp

The angular speed of mixing shaft is computed using Equation (3.14)

$$\omega = \sqrt{\frac{9.81}{0.35}} \ = 5.3\, rad/s$$

The power required for the mixing shaft is computed from Equation

(3.13)

Pm = 122.625 x 5.3 = 649.9125watt = 0.87hp ≈ 1hp

The total power required to operate the machine would be the sum of power to drive the Screw shaft and power to mix as given in Equation 3.15

$$P_T = P_S + P_M \quad (3.15)$$

Where:

P_T is total power required to operate the machine (Watts), P_s is power required to drive the screw shaft (Watts), $P_{\mathbf{m}}$ is power required to mix (watts), P_T = 0.72 + 0.87 = 1.59hp ≈ 2hp

3.4 Fabrication of the Machine

3.4.1 Description of the machine

The *Donkwa* production machine is made up of the following component parts.

i. Hopper: a container for a loose bulk material such as grain, rock, or rubbish, typically one that tapers downward and is able to discharge its contents at the bottom. The one used for the *Donkwa* mould is rectangular in shape. It is also divided into two units. One to mix and the other is to convey the loose bulk *Donkwa* material into the compression barrel through the die (Plate IV).

Plate IV: Hopper

ii. Screw shaft: This is a type of machine press in which the ram is driven up and down by a spiral screw of predetermined pitch and revolution, welded on a steel circular rod (Plate V).

: Plate V: Screw Shaft

iii. Mixer: This stirred the biological materials and mixed together at right proportion to make th mixed *Donkwa* ready for mould. This is made from 1" flat bars, cut into 6 pieces, joined to a round pipe as spline (Plate VI).

Plate VI: Mixer

iv. FRAME: This is a rigid structure that supports and surrounds *Donkwa* production machine components. It is made of mild steel 1.5" angle iron. Each piece joined together with arc welding machine (Plate VII).

Plate VII: Machine Frame

v. Electric motor: This electrical motor converts electrical energy into mechanical energy. This drives the mixing mechanism, the compression mechanism and the cutting mechanism (Plate VIII).

Plate VIII: Electric Motor

vi. Pulley: This is a wheel on an axle or shaft that is designed to support movement and change of direction of a belt, or transfer of power between the shaft and belt. The pulley used for the *Donkwa* production are two both made from cast iron material and are of 60 mm and 40 mm diameters (Plate IX).

Plate IX: Pulley

vii. Cutter: This is the final stage for the *Donkwa* mould. The cutting mechanism cut the compressed moulded *Donkwa* coming out from the die into smaller sizes. The cutter blade is made from mild steel, 1.5" flat bar bolted to a round pipe (Plate VIII). The pictorial view of the competed/assembled *Donkwa* production machine is shown in Plate X

Plate X: Cutting Blade

Plate XI: The Pictural View of the Assembled *Donkwa* Production Machine.

3.4.2 Machine fabrication procedure

Solid Works (CAD) software was used for the drawings of the *Donkwa* production Machine. The working and assembled drawings are presented in appendix. The material were bought as shown in Appendix A, detailing the cost and quantity of the material used for the fabrication. The machine was fabricated in Technology Incubation Centre, Minna, Niger State, Nigeria. Major tools used were welding machine, riveter, angle cutter, drilling machine and measuring tape. The angle iron to which the supporting frame is to be formed was cut into parts according to size and dimension of the components, this was followed by the fabrication of each components. The hopper was formed with sheet metal, considering its function, which is to serve as hopper and also accommodate the mixing mechanism. A pair of bearings was joined to the hopper to support the mixer. Screw conveyor shaft was made and fixed into a cylindrical compression barrel with an opening to receive mixes from the hopper, this setup was welded to the hopper and installed on the frame. Electric motor slot was made on the frame followed by the motor installation. A belt was connected to the two pulleys inserted on the mixing shaft and the screw shaft, ensuring it tensioned. After the assembling of the components, the machine was painted with silver colour.

3.5 Principles of Operation of the Machine

Put on the machine for some minute, the mixed *Donkwa* constituent in the right proportion is fed into the hopper and mixing unit which transport the mixture through a channel into the compressing unit. The compressing unit consists of a screw conveyor, whose action of compression and compaction forms the *Donkwa* mould with the desire compressive strength and compaction density, pressed it through the die for moulding at desired size, a cutter cuts into shapes and channels it to the collector unit

3.6 Technical Characteristics of the Machine

The technical characteristics of the analysis obtained from calculation of the design are given in Table 3.1.

Table 3.1: Technical Characteristics of the Machine

Nos	Parameters	Values
1	Actual machine Capacity	773.2266 kg/h
3	Screw Diameter	35 mm
4	Screw Speed	960 rpm
5	Screw Pitch	56 mm
6	Barrel Volume	4524.48 cm^3
7	Thread	6 (assumed)
8	Compression ratio	1.8
9	Power requirement	2 hp
10	Hopper volume	99 mm^3

3.7 Cost Analysis

The material specification and costing for the construction of the *D*onkwa production machine was determined on the basis of materials cost, labour cost and overhead cost. The total production cost was estimated from the addition of the materials costs (all the parts used were either purchased or fabricated are shown in (Table 3.2).

Table 3.2: Bills of Engineering Measurement and Evaluation

S/N	Materials	Quantity	Rate (#)	Amount
1.	2'' Angle bar	1 length	7,000	7,000
2.	Stainless steel pipe	0.6m	10,000	10,000
3.	Stainless steel 4 mm plate	$\frac{1}{4}$ sheet	20,000	20,000
4.	Stainless steel 25 mm diameter Shaft	0.3m	6,000	6,000
5.	Mild steel 30 mm diameter Shaft	0.6m	2,000	2,000
6.	Bearing	3	1,500	4,500
7.	Gear motor 2hp	1	65,000	65,000
8.	Bolt and Nuts	1 dozen	1,200	1,200
9.	Paint	1 litre	3,000	3,000
10.	Thinner	1 litre	3,000	3,000
11.	Threaded shaft	1m	4,000	4,000
12.	6 mm Diameter rod	2m	4,000	4,000
13.	Electrodes	2 dozen	2,150	4,300
14.	Labour cost		35,000	
	Total		# **160,000 = $ 211**	

3.8 Testing of the Machine/Performance Evaluation of the Machine

A measure of 3 kg, 5 kg and 7 kg of groundnut (grinded), maize (grinded), sugar, salt and pepper mix were weighed and introduced into the mixing unit and stirred. The time for the mixture to completely form the products (*Donkwa*) when it was operated, was noted. The mass of mould produced was measured with electronic weighing balance to ascertain the product consistency. The test was replicated and the average values calculated. The procedure was repeated for 2.5, 3.0, 3.5, 4.0, 4.5, 5.0, 6.0 and 7 kg *Donkwa* mixes. The following parameters: moulding capacity, machine efficiency bulk density and diameter of the *Donkwa* were used to assess the performance of the moulding machine as well as the consistency of product.

3.8.1 Determination of machine capacity

The efficiency of *Donkwa* production machine was evaluated by determining parameters quantity in mass of the moulded *Donkwa* over the specific period of time. Extrusion capacity was calculated using Equation 3.18 (Olaoye, and Olotu, 2015)

$$E_C = \frac{M_e}{T} \tag{3.18}$$

Where;

E_C is the Extrusion Capacity (kg/h),

M_e is the mean mass of the *Donkwa* extruded for each treatment (kg),

T is the mean time taken for the extrusion (min).

3.8.2 Determination of efficiency of the machine

The efficiency of the machine is the weight of the mixture of maize to groundnut feed in to the machine over the weight of moulded *Donkwa* produced. This can be computed using equation 3.19 (Olaoye, and Olotu, 2015)

$$E = \frac{w_i}{w_o} \times 100 \tag{3.19}$$

Where;

E is the efficiency of the machine %, W_i is the weight mixture fed in (kg), W_o is the weight of *Donkwa* mould produced (kg).

3.8.3 Determination of bulk density

Bulk Density (BD) is expressed as g/cm^3, is an inverse measure of expansion. It is measured using the method described by Ding *et al.* (2006) in equation 3.20 by taking a bulk pieces of moulded *Donkwa* into a defined volume jar or cylinder then place it inside a bowl of water and measure the displace volume of water

$$Density\ (\rho) = \frac{M}{V} \quad (3.20)$$

Where;

ρ is the bulk density of *Donkwa* mixture (g/cm^3), M is the mass of the *Donkwa* (g) , V is the volume (cm^3)

The samples were randomly selected and replicated 3 times and the average value taken.

3.9 Experimental Design

The variables considered for the performance evaluation were categorized into the independent and dependent variables. The independent variable was mass of *D*onkwa maize to groundnut mix ratio, machine speed, and feed rate. The response variables measured were machine capacity, machine efficiency and product consistency for evaluation (Bulk density and the diameter) of the *Donkwa*. A response surface methodology was used for the experiment.

The study was conducted using a D-optimal design to evaluate the effect of three parameters; screw speeds (400-6000rpm), Feed rate (3-7kg/min) and Mix Ratio (2:1, 2:2 and 1:2) on the machine as well as the final product of evaluation the moulded *Donkwa* as shown in Table 3.1. A layout was obtained containing 43 run by the process of randomization showing the different combination of dependent and independent variables. All collected data were analyzed with response surface methodology D-optimal design using Design Expert 11.1.2.0.

3.10. Statistical Analysis

The fitness of the model was evaluated and the interactions between the independent and dependent variables were identified by using an analysis of variance (ANOVA). The goodness of fit of the second order equation was expressed by the coefficient of determination (R^2) and its statistical significance was determined by F-test. Significant terms were accepted at $P < 0.05$. The R^2 of 0.6 was accepted for predictive purposes (Anuonye *et al.*, 2007). 3-D response surfaces were used to visualize interactive effects of the independent variables. The experimental design details indicating the levels are shown in Table 3.3.

Table 3.3: Experimental Design Details Indicating the Levels

Factor	**Units**	**Type**	**Mini Max**	**Coded Low**	**Coded High**	**Mean**	**Std. Dev.**
A	A: Speed	Rpm Numeric	400	600 -1 ↔ 7.00	+1 ↔ 10	8.91	1.69
B	B:Mix Ratio	Percentage Numeric	2:1	1:2 -1 ↔ 5.04	+1 ↔ 15	7.04	2.19
C	C: Feed Rate	Numeric	3	7		Levels:	3

CHAPTER FOUR

4.0 RESULTS AND DISCUSSIONS

4.1 Effect of Feed Rate on the Machine Performance

4.1.1 Effect of feed rate on actual capacity of the machine

Figure 4.1 shows the relationship between the feed rate and the actual machine capacity. At a feed rate of 3 kg/min, and 2:1, 2:2, and 1:2 maize-groundnut mixed ratio, the actual machine capacity obtained were; 59.2 kg/h, 58.4kg/h, and 57.2 kg/h respectively. At a feed rate of 5 kg/min, and 2:1, 2:2, and 1:2 maize-groundnut mixed ratio, the actual machine capacity obtained were; 62.4 kg/h, 60.1 kg/h, and 58.1 kg/h respectively. Finally, at a feed rate of 7 kg/min, and 2:1, 2:2, and 1:2 maize-groundnut mixed ratio, the actual machine capacity obtained were; 64.5 kg/h, 62.8 kg/h, and 58.9 kg/h, respectively. These results indicate, that increasing the feed rate increases the actual capacity of the *Donkwa* moulding machine.

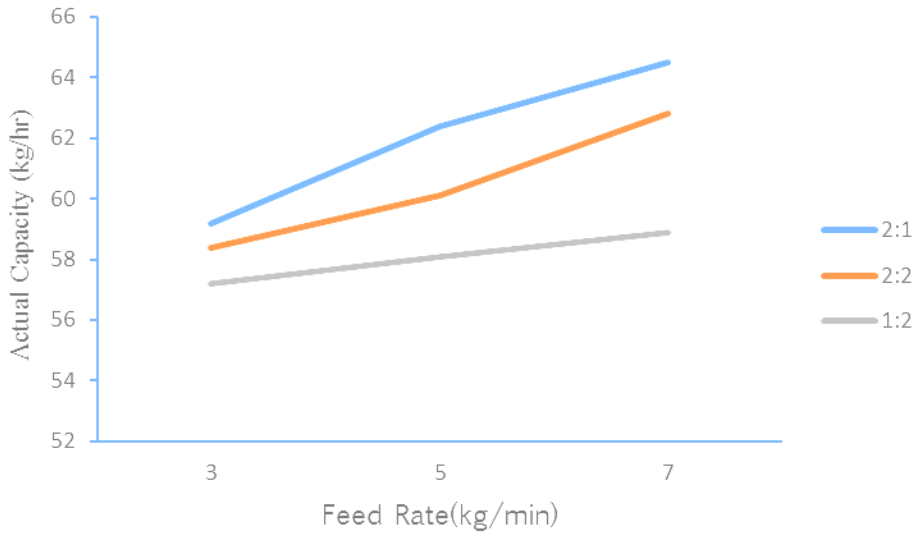

Figure 4.1: Effect of Feed Rate on Actual Capacity of the Machine.

4.1.2 Effect of feed rate on bulk density of the *donkwa*

The result of evaluation of *Donkwa* moulding machine for feed rate on the bulk density of the *Donkwa* produced is shown in Figure 4.2. At a feed rate of 3 kg/min, and 2:1, 2:2, 1:2

maiz-groundnut mixed ratio, the bulk density were; 0.97 g/ml, 1.15 g/ml, and 1.15 g/ml respectively. At a feed rate of 5 kg/min, and 2:1, 2:2, and 1:2 maiz-groundnut mixed ratio, the bulk density were; 0.99 g/ml, 1.18 g/ml, and 1.2 g/ml respectively. Finally, at a feed rate of 7 kg/min, and 2:1, 2:2, and 1:2 maize-groundnut mixed ratio, the bulk density were; 1.01 g/ml, 1.2 g/ml, and 1.2 g/ml respectively. The results indicate that increasing the feed rate generally increases the bulk density of the moulded *Donkwa*.

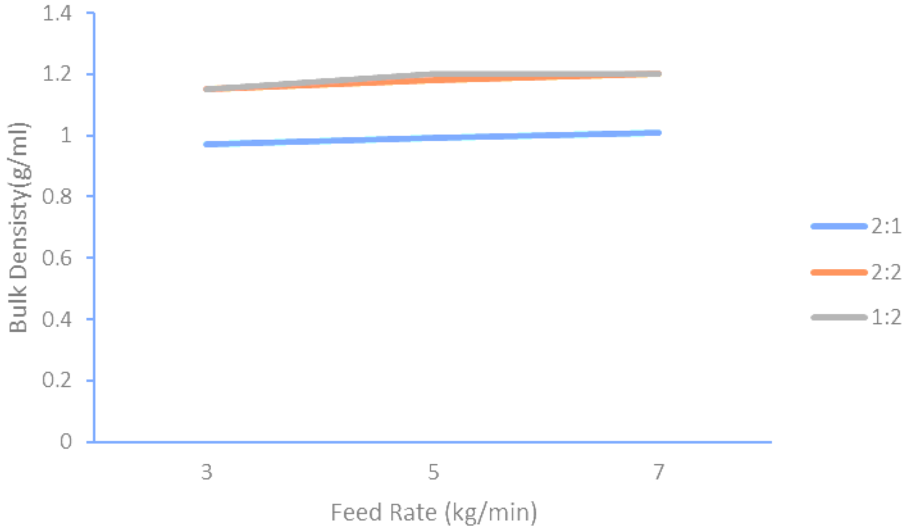

Figure 4.2: Effect of Feed Rate on Bulk Density of the Mould *Donkwa*

4.1.3 Effect of feed rate on the consistency of *donkwa* diameter

The result of evaluation of *Donkwa* moulding machine for feed rate on the bulk density of the *Donkwa* produced is shown in Figure 4.3. At a feed rate of 3 kg/min, and 2:1, 2:2, and 1:2 maize-groundnut mixed ratio, the *donkwa* diameters were; 14.43 mm, 14.97 mm, and 14.98 mm respectively. At a feed rate of 5 kg/min, and 2:1, 2:2, and 1:2 maize-groundnut mixed ratio, the *donkwa* diameters were; 14.45 mm, 15.13 mm, and 15.01 mm respectively while, at a feed rate of 7 kg/min, and 2:1, 2:2, and 1:2 maize-groundnut mixed ratio, the *donkwa* diameters were; 14.44 mm, 14.99 mm, and 15.3 mm respectively. These results suggest that the diameter of the moulded *Donkwa* is relatively consistent across different feed rates and mixture levels of maize to groundnut.

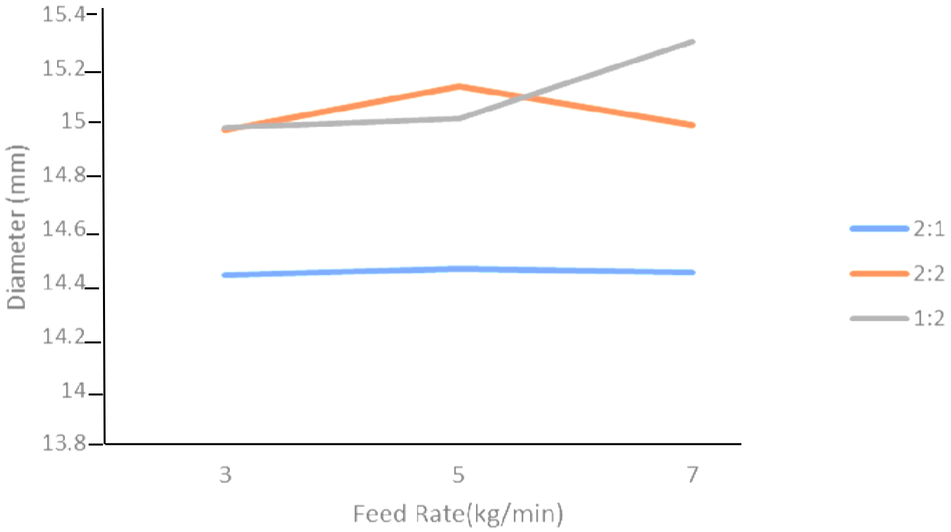

Figure 4.3: Effect of Feed Rate on the Consistency of *Donkwa* Diameter

4.1.4 Effect of feed rate on the machine efficiency

Figure 4.4 show the effect of feed rate on the efficiency of the *Donkwa* moulding machine at three different mixed ratios of maize to groundnut. At a feed rate of 3 kg/min, and 2:1, 2:2, and 1:2 maize-groundnut mixed ratio, the efficiency were; 77.5%, 75.2%, and 74.2% respectively. At a feed rate of 5 kg/min, and 2:1, 2:2, and 1:2 maize-groundnut mixed ratio, the efficiency were; 78.5 %, 76.1 %, and 74.9 % respectively while, at a feed rate of 7 kg/min, and 2:1, 2:2, and 1:2 maize-groundnut mixed ratio, the efficiency were; 78.7 %, 76.2 %, and 75.01 %, respectively. These results suggest that the *Donkwa* moulding machine operates more efficiently at higher feed rates. This could be due to the fact that at higher feed rates, the machine is able to process larger quantities of material in a shorter amount of time, resulting in higher production output and efficiency.

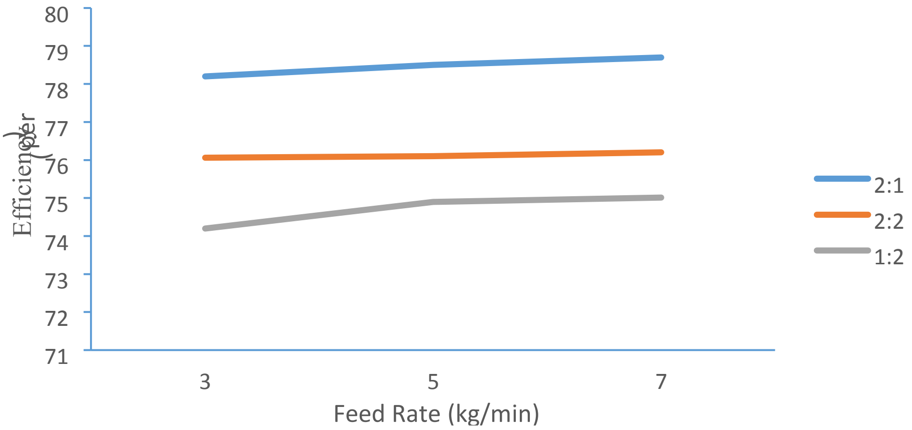

Figure 4.4: Effect if feed Rate on Efficiency of Machine

4.2 Effect of the Machine Speed on Machine Performance

4.2.1 Effect of machine speed on the bulk density of *donkwa*

Figure 4.5 shows the effect of speed (rpm) on the bulk density (g/ml) of moulded *Donkwa* at three different mix ratio of maize to groundnut. At 400 rpm, and 2:1, 2:2, and 1:2 maize-groundnut mixed ratio, the bulk density of the moulded *Donkwa* were; 1.1 g/ml, 1.26 g/ml, and 1.4 g/ml respectively. At 500 rpm, and 2:1, 2:2, and 1:2 maize-groundnut mixed ratio, the bulk density of the moulded *Donkwa* were; 1.07 g/ml, 1.19 g/ml, and 1.25 g/ml respectively. While, at 600 rpm, and 2:1, 2:2, and 1:2 maize-groundnut mixed ratio, the bulk density of the moulded *Donkwa* were; 0.998 g/ml, 1.09 g/ml, and 1.21 g/ml respectively. These results suggest that higher speeds lead to a decrease in the bulk density of moulded *Donkwa*. This could be due to the fact that at higher speeds, the moulding machine is producing moulded *Donkwa* at a faster rate, which may result in less compacted and less dense moulded *Donkwa*.

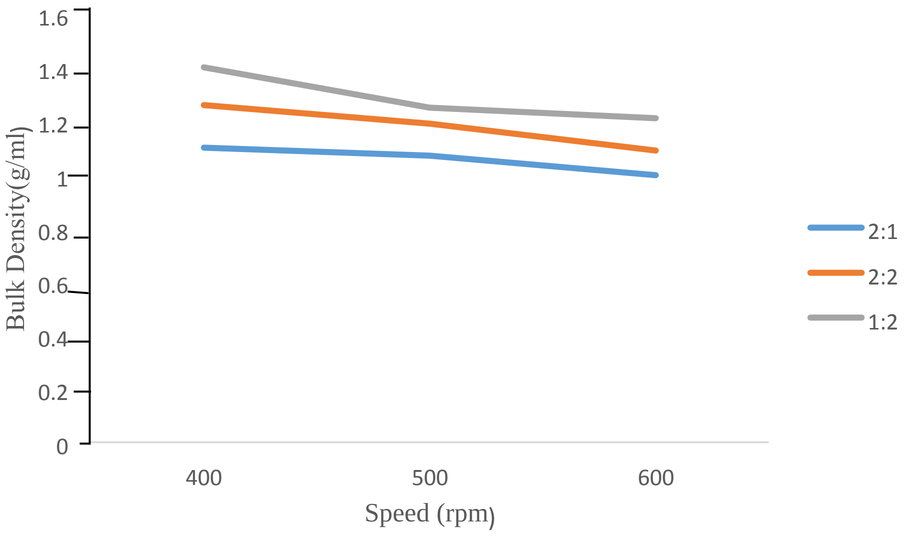

Figure 4.5: Effect of Machine Speed on the Bulk density of *Donkwa*

4.2.2 Effect of machine speed on the actual capacity

The result of evaluation of the effect of speed on the actual capacity of mould as shown in Figure 4.6 indicates that the effect of speed (rpm) on the actual capacity (kg/h) of moulded *Donkwa* at three different mixture levels of maize to groundnut. From the results, we can observe that there is an increase in the actual capacity of moulded *Donkwa* with an increase in the speed of the moulding machine. At 400 rpm, and 2:1, 2:2, 1:2 maize-groundnut mixed ratios, the actual capacity of the machine where; 62.9 kg/h, 60.4 kg/h, and 57.2 kg/h, respectively. At 500 rpm, and 2:1, 2:2, 1:2 maize-groundnut mixed ratios, the actual capacity of the machine were; 64.8 kg/h, 60.1 kg/h, and 58.1 kg/h, respectively. While, at 600 rpm, and 2:1, 2:2, and 1:2 maize-groundnut mixed ratios, the actual capacity of the machine were; 65.1 kg/h, 62.8 kg/h, and 60 kg/h respectively.

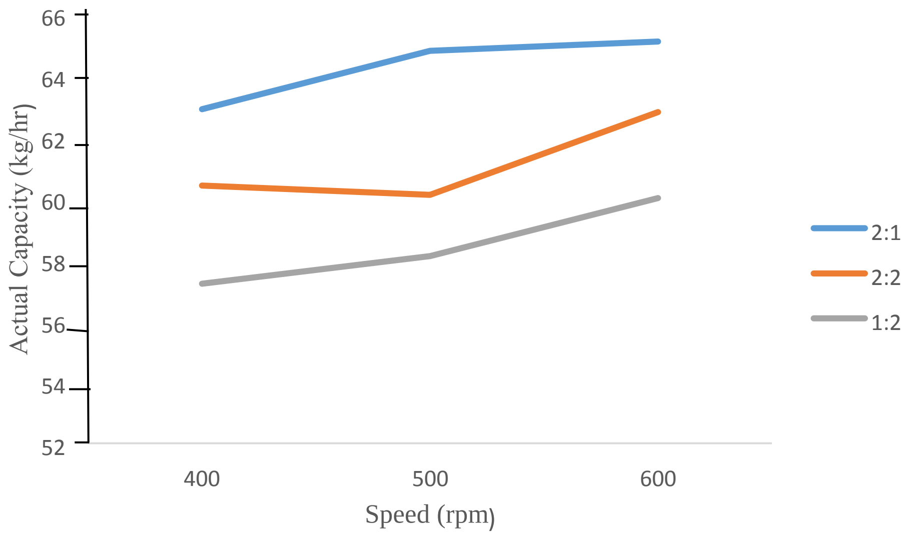

Figure 4.6: Speed of Machine on the Actual Capacity

4.2.3 Effect of machine speed on the efficiency

The result of the effect of speed on the efficiency of the *Donkwa* moulding machine is shown in Figure 4.7. The Figure showed that the efficiency of the *Donkwa* moulding machine increases with an increase in the feed rate and speed. At all three mixture of maize-groundnut ratio, the efficiency increases as the feed rate increases. At a feed rate of 3 kg/min, the efficiency ranges from 74.2 % to 77.5 %. At a feed rate of 5 kg/min, the efficiency ranges from 74.9 % to 78.5 %. At a feed rate of 7 kg/min, the efficiency ranges from 75.01% to 78.7 %. This indicates that the *Donkwa* moulding machine is able to produce more *Donkwa* at a higher feed rate. Similarly, at all three mixed ratio of maize-groundnut, the efficiency increases as the speed increases. At a speed of 400 rpm, the efficiency ranges from 69 % to 72.1 %. At a speed of 500 rpm, the efficiency ranges from 76.1 % to 78.5 %. At a speed of 600 rpm, the efficiency ranges from 76.2 % to 81 %. This also indicates that the *Donkwa* moulding machine is able to produce more *Donkwa* at a higher speed while maintaining a higher efficiency.

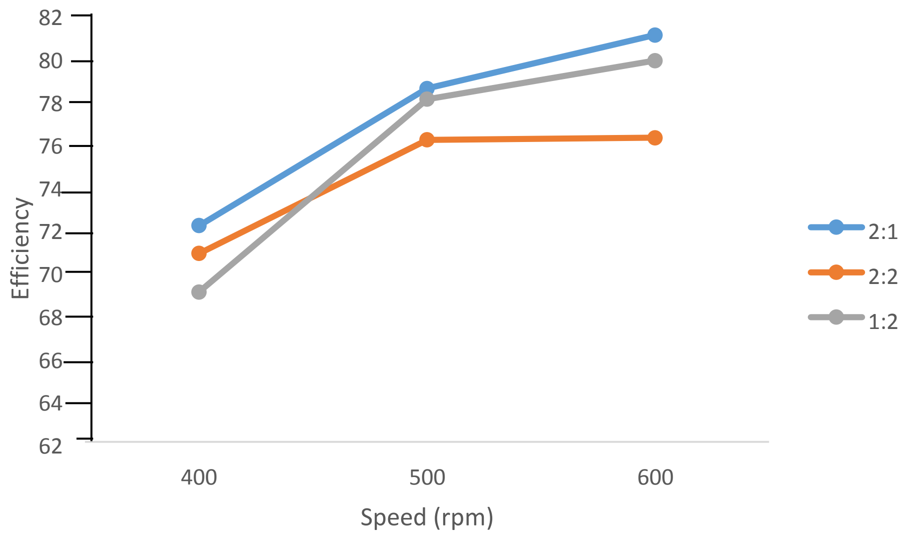

Figure 4.7: Effect of Machine Speed on the Efficiency

The result obtained indicates that increasing the feed rate increase the actual capacity of the *Donkwa* moulding machine and the machine operate more efficiently at high speed rate. This could be due to the fact that at higher feed rate, the machine is able to mould large quantities of *Donkwa* material in a shorter time resulting in high production output and efficiency. Therefore, the highest capacity of the machine 65.1kg/h at efficiency of 78.7 % compared to the local or the traditional method with the capacity of producing 20 kg of *Donkwa* per day Author's Field Work in 2022.

CHAPTER FIVE

5.0 CONCLUSION AND RECOMMENDATIONS

5.1 Conclusions

i. *Donkwa* production machine has been designed, fabricated and evaluated. The machine has a capacity of 65.1kg/h and efficiency of 78.7%.

ii. Increasing the feed rate increases the actual capacity of the *Donkwa* production machine.

iii. Increasing the ratio of maize to groundnut in the mixture also increases the actual capacity of the *Donkwa* production machine, also the efficiency of the *Donkwa* production machine generally increases with an increase in feed rate and mixture level of maize to groundnut, but the effect is relatively small.

5.2 Recommendations

Based on the findings of this study, the following recommendations are made:

i. During the performance evaluation, it was observed that the feed rate of the machine have great impacts on the mould of the *Donkwa.* It is therefore recommended that the feed rate of the *Donkwa* production machine should be optimized to increase the actual capacity and bulk density of the moulded *Donkwa* while maintaining a consistent diameter.

ii. To improve the efficiency of the *Donkwa* production machine, further investigations could be conducted on other parameters such as different mould design, and moisture content of the mixture.

iii. The study also suggests that varying the mixture level of maize to groundnut can have a significant effect on the actual capacity and bulk density of the moulded *Donkwa*. Therefore, it is recommended that manufacturers should experiment with different mixture levels to optimize their production process.

5.3 Contributions to knowledge

A 65.1 kg/h *Dokwa* production machine was successfully developed using locally sourced materials.

The developed machine has an efficiency of 78.7 % under optimal operating condition of 600 rpm, 7 kg/min feed rate and 2:1 of maize to groundnut.

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APPENDICES

Appendix A: Table 1. Result of the Feed rate, Mixed ratio, Machine speed on the Machine Efficiency and machine Capacity.

_Std	Run			Feed Rate	Mixing Ratio	Speed			Efficiency	Capacity
13	1	Block 1	7	5	1:2	600	0.98	11.4	62.9	77.8
22	2	Block 1	3	7	2:2	500	0.98	11.7	64.8	78
36	3	Block 1	5	5	2:1	500	0.998	12.4	65.1	76.5
42	4	Block 1	7	7	1:2	500	1.07	14.43	63.2	74.2
18	5	Block 1	7	5	1:2	400	1.07	14.43	65.8	71.5
25	6	Block 1	5	9	2:1	400	1.07	14.43	63.9	70.2
15	7	Block 1	7	9	2:2	600	1.13	11.7	66.2	76.3
19	8	Block 1	5	5	1:2	500	1.13	11.7	64.2	78.2
33	9	Block 1	3	5	2:2	500	1.1	11.55	61.8	77.2
21	10	Block 1	7	9	1:2	400	1.1	12.3	68.2	78.2
38	11	Block 1	3	9	2:1	400	1.128	15.13	61.2	78.5
34	12	Block 1	3	5	2:1	500	1.124	11.7	62.2	78.7
4	13	Block 1	5	7	2:2	400	1.124	11.7	63.1	76.5
30	14	Block 1	5	9	2:2	500	1.14	12.2	60.4	74.2
23	15	Block 1	5	5	2:1	600	1.14	12.2	60.1	71.5
32	16	Block 1	3	9	2:2	400	1.15	11.6	62.8	70.2
24	17	Block 1	3	7	2:1	600	1.158	12.2	60.5	74.2
27	18	Block 1	7	7	1:2	500	1.18	14.63	63.1	74.9
43	19	Block 1	5	9	2:2	500	1.18	14.97	60.2	75.01

2	20	Block 1 5	9	1:2	400	1.18	15.3	60.2	74.5
7	21	Block 1 7	9	2:1	600	1.2	12.7	60.4	72.3
41	22	Block 1 7	9	2:1	600	1.2	12.7	60.1	77.2
16	23	Block 1 7	7	2:1	400	0.98	11.4	62.8	78.2
29	24	Block 1 3	5	2:2	600	0.98	11.7	57.2	78.5
31	25	Block 1 3	9	2:1	500	0.998	12.4	59.1	77.8
12	26	Block 1 5	7	2:1	500	1.07	14.43	59.8	77.3
39	27	Block 1 5	7	1:2	600	1.07	14.43	60.8	74.2
5	28	Block 1 3	5	1:2	600	1.07	14.43	63.7	74.9
9	29	Block 1 5	5	2:2	400	1.13	11.7	63.4	75.01
20	30	Block 1 5	9	2:2	600	1.13	11.7	57.2	78.2
26	31	Block 1 7	7	2:2	600	1.1	11.55	58.1	78.5
6	32	Block 1 7	5	2:2	500	1.18	12.3	60	78.7
14	33	Block 1 7	7	2:2	400	1.18	15.13	60.1	76.06
37	34	Block 1 3	5	2:2	400	1.18	12.4	62.8	76.1
28	35	Block 1 3	7	1:2	400	1.2	14.43	57.2	76.2
10	36	Block 1 5	7	1:2	600	1.2	14.43	59.1	76.06
3	37	Block 1 3	5	2:1	400	0.98	14.43	59.8	76.1
17	38	Block 1 7	5	2:1	500	0.98	11.7	60.2	76.2
11	39	Block 1 7	9	1:2	500	0.998	11.7	57.2	76.06
40	40	Block 1 7	7	2:2	600	1.07	11.55	58.1	76.1
35	41	Block 1 5	5	2:1	400	1.07	12.3	60	76.2
8	42	Block 1 3	7	1:2	500	1.07	13.15	59.3	78.2
1	43	Block 1 3	9	1:2	600	1.13	12.22	58.2	78.2

Appendix B1: Table 2. Result of the Feed Rate and the Bulk Density

Feed Rate (kg/min)	Bulk Density		
	2:1	**2:2**	**1:2**
3	0.97	1.15	1.15
5	0.99	1.18	1.2
7	1.01	1.2	1.2

Appendix B2: Table 3. Result of Feed Rate and the Average Actual Capacity

	Average Actual Capacity		
Feed Rate (kg/min)	**2:1**	**2:2**	**1:2**
3	59.2	58.4	57.2
5	62.4	60.1	58.1
7	64.5	62.8	58.9

Appendix B3: Table 4. Result of Feed Rate and the Efficiency of the machine

	Efficiency		
Feed Rate (kg/min)	**2:1**	**2:2**	**1:2**
3	59.2	58.4	57.2
5	62.4	60.1	58.1
7	64.5	62.8	58.9

Appendix B4: Table 5. Result of Speed and Bulk Density

Actual Capacity(kg/hr)			
Speed (rpm)	**2:1**	**2:2**	**1:2**
400	62.9	60.4	57.2
500	64.8	60.1	58.1
600	65.1	62.8	60

Appendix B5: Table 6. Result of Speed and the Actual capacity of the machine

Bulk Density (g/ml)			
Speed (rpm)	**2:1**	**2:2**	**1:2**
400	1.1	1.26	1.4
500	1.07	1.19	1.25
600	0.998	1.09	1.21

Appendix B6: Table 7. Result of the Feed Rate and Efficiency of the Machine

Efficiency			
Feed Rate (kg/min)	**2:1**	**2:2**	**1:2**
3	78.2	76.06	74.2
5	78.5	76.1	74.9
7	78.7	76.2	75.01

Appendix C1: Response 1 Bulk Density ANOVA for selected factorial model

Analysis of variance table (classical sum of squares Type-II)

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	0.18	32	5.69E-03	1.51	0.2484	not significant
A-Feed Rate	5.04E-03	2	2.52E-03	0.67	0.5326	
B-Mix time	7.05E-03	2	3.53E-03	0.94	0.4231	
C-Mix Ratio	0.013	2	6.35E-03	1.69	0.2331	
D-Speed	7.67E-03	2	3.83E-03	1.02	0.3951	
AB	0.015	4	3.69E-03	0.98	0.4597	
AC	0.023	4	5.85E-03	1.56	0.2595	
AD	2.83E-03	4	7.08E-04	0.19	0.939	
BC	0.012	4	3.07E-03	0.82	0.5427	
BD	0.016	4	3.95E-03	1.05	0.4284	
CD	0.081	4	0.02	5.38	0.0142	
Residual	0.038	10	3.76E-03			
Lack of Fit	0.022	5	4.36E-03	1.38	0.3649	not significant
Pure Error	0.016	5	3.15E-03			
Cor Total	0.22	42				

Appendix C2: Response 2 Diameter ANOVA for selected factorial model

Analysis of variance table (classical sum of squares Type-II)

Source	Sum of Squares	Df	Mean Square	F Value	p-value Prob > F	
Model	64.21	32	2.01	2.07	0.1117	not significant
A-Feed Rate	1.14	2	0.57	0.59	0.5731	
B-Mix time	4.68	2	2.34	2.41	0.1396	
C-Mix Ratio	10.98	2	5.49	5.66	0.0227	
D-Speed	7.55	2	3.77	3.89	0.0563	
AB	8.37	4	2.09	2.16	0.1477	
AC	10.07	4	2.52	2.59	0.1009	
AD	7.49	4	1.87	1.93	0.182	
BC	9.22	4	2.3	2.38	0.1218	
BD	6.96	4	1.74	1.79	0.2065	
CD	4.89	4	1.22	1.26	0.3479	
Residual	9.7	10	0.97			
Lack of Fit	5.84	5	1.17	1.52	0.3297	not significant
Pure Error	3.86	5	0.77			
Cor Total	73.91	42				

Appendix C3: Response 3 Capacity ANOVA for selected factorial model

Analysis of variance table (classical sum of squares Type-II)

Source	Sum of Squares	Df	Mean Square	F Value	p-value Prob > F	
Model	231.37	32	7.23	1.16	0.4236	not significant
A-Feed Rate	14.42	2	7.21	1.16	0.3532	
B-Mix time	6.36	2	3.18	0.51	0.6152	
C-Mix Ratio	6.29	2	3.14	0.5	0.6183	
D-Speed	38.47	2	19.24	3.09	0.0903	
AB	39.01	4	9.75	1.57	0.2572	
AC	15.58	4	3.89	0.63	0.6553	
AD	12.84	4	3.21	0.52	0.7267	
BC	37.75	4	9.44	1.51	0.2702	
BD	54.88	4	13.72	2.2	0.1419	
CD	28.4	4	7.1	1.14	0.3923	
Residual	62.3	10	6.23			
Lack of Fit	60.79	5	12.16	40.12	0.0005	Significant
Pure Error	1.51	5	0.3			
Cor Total	293.67	42				

Appendix C4: Response 4 Efficiency ANOVA for selected factorial model

Analysis of variance table (classical sum of squares Type-II)

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	174.3	32	5.45	1.21	0.3918	not significant
A-Feed Rate	7.56	2	3.78	0.84	0.4597	
B-Mix time	5.19	2	2.59	0.58	0.5791	
C-Mix Ratio	2.98	2	1.49	0.33	0.7254	
D-Speed	23.82	2	11.91	2.65	0.1191	
AB	11.85	4	2.96	0.66	0.6338	
AC	30.88	4	7.72	1.72	0.222	
AD	15.76	4	3.94	0.88	0.5112	
BC	45.43	4	11.36	2.53	0.1068	
BD	20.87	4	5.22	1.16	0.3837	
CD	56.69	4	14.17	3.15	0.064	
Residual	44.92	10	4.49			
Lack of Fit	27.73	5	5.55	1.61	0.3062	not significant
Pure Error	17.19	5	3.44			
Cor Total	219.22	42				

Appendix D: Table 1. Cause and Remedy of mould defect phenomenon, which can be seen in mould defect.

Defect	Cause	Remedy
Silver streak	• Fluid in the pellet • Air engulfment when plasticizing • Resin decomposition by overheat (cylinder or nozzle part overheat, or existence of retention part)	• Drying pellet (80℃ to 90℃ for 3 to 4 hours) • Increase back pressure f better degassing wh plasticizing • Lower the temperature where overheated • Clean the retention part or exchange to the parts with has no retention part.
Tarnish or burn	• Resin decomposition by overheat • Too long residence time • Air engulfed by pellet	• Check cylinder, nozzle retention part, and fitting part. • Adjust cylinder temperature • Use moulding machine with appropriate injection volume

		• Increase back pressure for better degassing
Partial tarnish or burn	• Heat production by adiabatic compression from insufficient degassing in mold tool.	• Place air vent in the mould. • Lower the injection speed
Dark brown or black coloured dot or small piece mixed in	• Peeled off decomposed resin film which was built inside the wall of the cylinder	• More cylinder purge cleaning before molding
Sink on the surface or bubble (void) inside	• Shrinkage is not filled by pressure keeping sufficiently, when plasticizing melted resin • Lack of material feeding	• Make holding pressure higher • Make the pressure keeping time loner (longer than gate sealing time) • Avoid nozzle block • Make thickness thinner • Make gate thicker • Place a gate at thick part

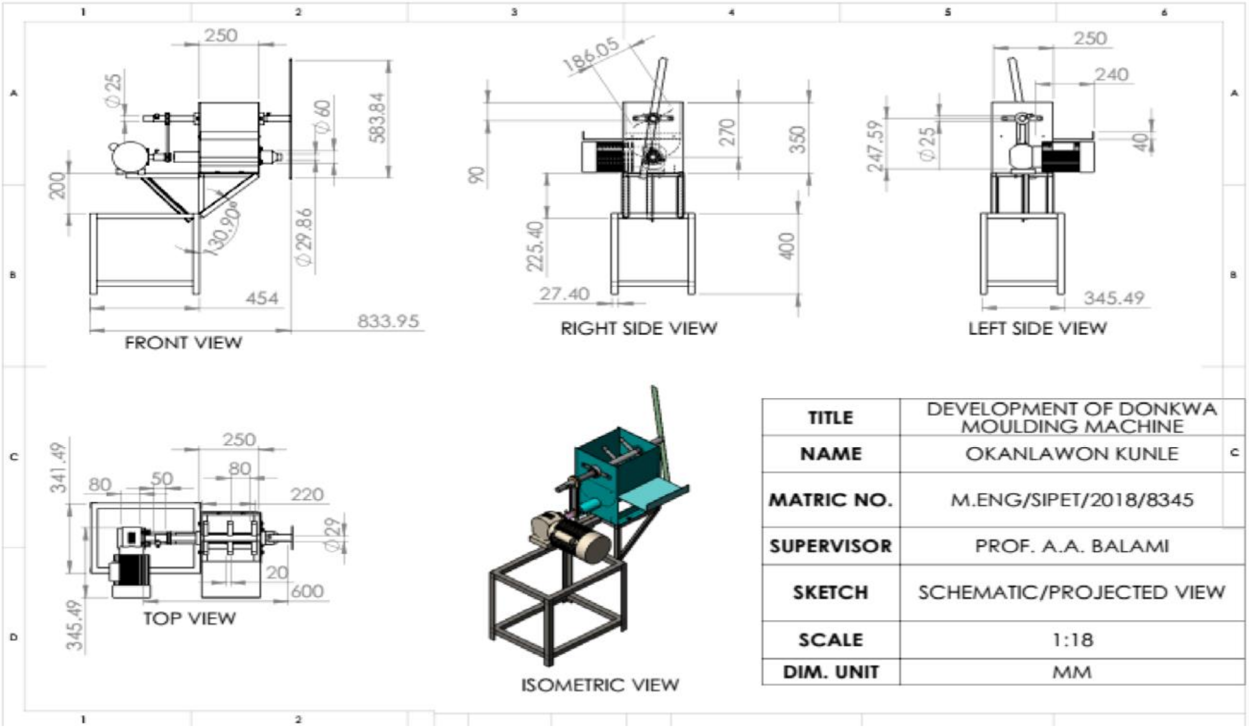
		• Confirm the cushion volume
Burr	• Lack of mould locking force • Injection pressure too high • Injection speed too fast • Wear of the mould • Resin melt viscosity too low	• Increase mould locking force • Lower the injection pressure and the holding pressure • Lower the injection speed • Fix or renew the mold • Change to high viscosity resin
De-mould defect or deformation when demolding	• Requires high de-mould power • Pressure reduction between the mould and the moulded product • De-mould power is not working at moulded product and mould contact point • Moulded product is not cooled enough when de-moulding	• Lower the injection pressure • Make draft angle • Polish the mould • Place device that avoids decompression at the mould • Make the mould opening slow enough • Increase ejector pin • Lower the mould temperature

		• Make cooling time longer
Lack of filling	• Cylinder temperature too low • Runner solidification too fast • Mould temperature too low • Uneven filling to each cavity • Lack of melted resin feeding volume • Degassing defection in the mould	• Raise cylinder temperature • Make runner size larger • Raise mould temperature • Change flow path, check-up gate balance • Increase plasticization volume • Improve degassing effect within the mould (like gas vent)
Circular arc stripe and pock pattern at the edge part	• Low resin temperature • Low mould temperature • Low injection pressure and holding pressure • Slow injection speed • Lack of resin flowability	• Raise resin temperature, raise nozzle temperature • Raise mould temperature • Make injection pressure and holding pressure higher • Improve the injection

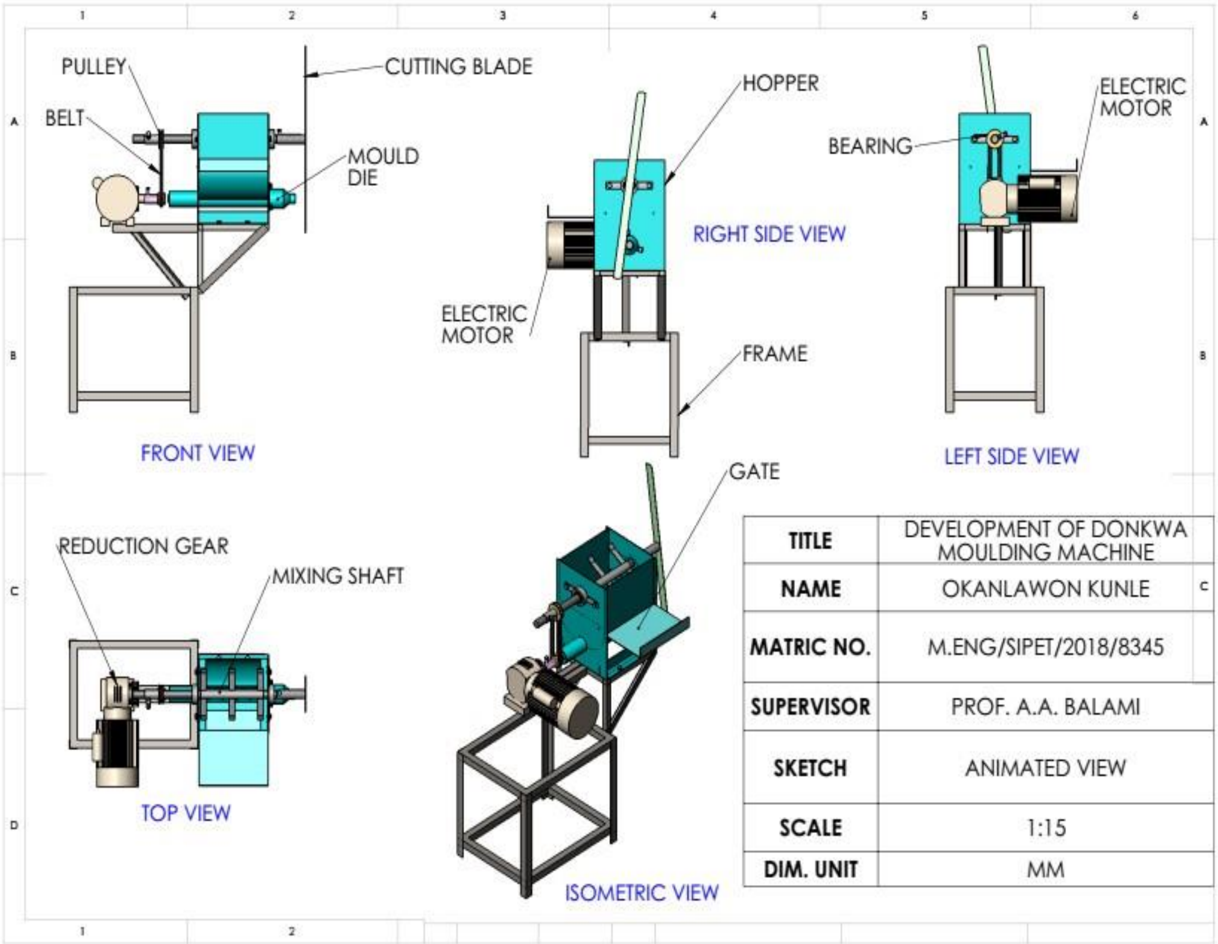
		speed • Improve the resin flowability
Flow mark (jetting, tarnish around the gate)	• By injected resin cooled down in the mould and solidified part swept again by melted resin	• Make the gate larger • Lower the injection speed • Change the gate location • Raise mould temperature and resin temperature • Improve resin flowability
Matter fleck	• Inappropriate melted resin flow • Drastic change in moulded product section area • Inappropriate resin flow at the sharp corner	• Change section area not in a staircase pattern, and do it smoothly • Round out the sharp corner
Weld mark	• Occurs when melted resin join together at flow end • Furthered by exhaust air defect in the mould	• Occurs when melted resin join together at flow end • Furthered by exhaust

		air defect in the mould
Wrinkle around the gate	• Resin get cooled down before the pressure keeping, and design when filling get frosted	• Make the gate larger • Consider appropriate injection speed
Camber deformation	• Uneven shrinkage of melted resin • Uneven moulded product thickness • Uneven mould temperature • Uneven mould inner pressure • Anisotropy of moulding shrinkage ratio	• Increase the injection pressure and holding pressure • Make consideration so that mould temperature equalizes (cooling ditch number and location) • Equalize moulded product thickness, and symmetrize the design • Consider appropriate injection speed • Extend binding hour in the mould • Consider gate location and make gate section area larger

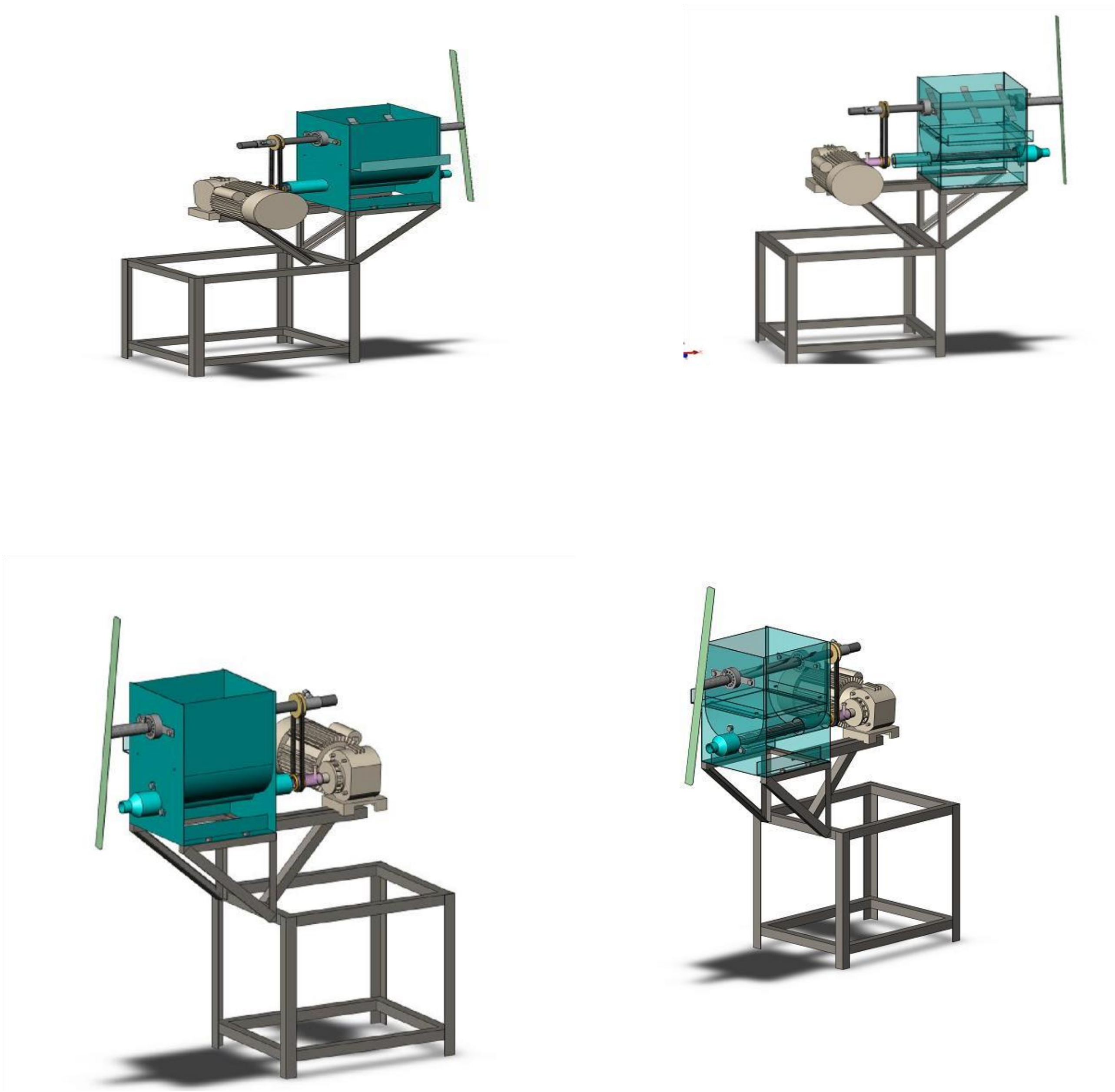
APPENDIX E: Machine Design of *Donkwa* Production Machine



Detail Isometric Dimension of the Machine



Multi-view Isometric and Label of the Machine



Detail Isometric View of the *Donkwa* Production Machin

Fabricated View of *Donkwa* Production Machine