FEDERAL UNIVERSITY OF TECHNOLOGY MINNA

ENGINEERING PROPERTIES OF AGRO-MATERIALS AND THEIR LINKS TO AGRICULTURAL MACHINERY DESIGN AND DEVELOPMENT

By

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PREAMBLE

I am honoured today by the Grace of the Almighty Allah to deliver the 85th Inaugural Lecture of this great University, Federal University of Technology, Minna.

Mr. Vice-Chancellor sir, members of the University community and invited guests, the main theme of this lecture: "**Engineering Properties of Agro-Materials and their Links to Agricultural Machinery Design and Development**". This theme is chosen to bring out the salient issues of the unavailability of efficient, adaptable and affordable indigenous agricultural machines as it concerns the production of agricultural crops and the efforts being made to address this challenge so as to ensure food security.

Mr. Vice-Chancellor Sir, may I crave your indulgence and permission to present today's lecture.

1.0 INTRODUCTION

Brief on Engineering: The concept of engineering has existed since ancient times as humans devised fundamental inventions such as the pulley, lever, and wheel. Each of these inventions is consistent with the modern definition of engineering, exploiting basic mechanical principles to develop useful tools and objects.

Engineering (a term derived from the Latin *ingenium*, meaning "cleverness" and *ingeniare*, meaning "to contrive, devise) broadly speaking deals with the sets of techniques, systems and machines for production of goods and services (Makanjuola, 1977). It is therefore the bridge between new knowledge, the product of research in the sciences and the fulfillment of the needs of the society by putting this knowledge to work. Different sub–disciplines have emerged based on the area of application of the engineering technology in question. These include Agricultural, Chemical, Civil, Electrical, Electronics, Mechatronics, Mechanical, Metallurgical, Petroleum, Production Engineering etc (Oluka *et al.,* 1999). Our interest here is Agricultural and Bioresources Engineering, which leads to the question: What is Agricultural and Bioresources Engineering (ABE)?

Agricultural and Bioresources Engineering (ABE) deals with integration of engineering, science and design with applied biological science for solution of problems involving plants, animals and natural environment (Odigboh, 1985; Mijinyawa *et al.,* 2000; Idah,2017). It involves the design, development, testing, manufacturing, marketing, operation, maintenance and repair of all agricultural tools, implements, machines and equipment which are used in mechanising agricultural operations, with objective of raising the productivity of human labour and the land (Makanjuola, 1977).

Areas of Specialization in Agricultural and Bioresources Engineering

Agricultural Engineering can be divided into nine major areas of specializations (Onwualu *et al.,* 2006):

Farm Power and Machinery Engineering - This area deals with the design, construction, operation and maintenance of power and machinery systems needed for all aspects of Agricultural Mechanization.

Bioresources Engineering - uses machines on the molecular level to help the environment.

Soil and Water Engineering - This aspect of Agricultural Engineering deals with the harnessing and management of the soil and water resources of the ecosystem.

Processing or Post Harvest Systems Engineering - This aspect of Agricultural Engineering deals with all the activities, processes, structures and machines which convert agricultural raw materials (plants and animals) into finished consumer goods.

Farm Structures and Environmental Control Engineering - This option in Agricultural engineering deals with the design and construction of all structures that are used in agricultural production and also understanding and controlling the environment within the structures.

Wood Products Engineering - This field of specialization deals with the machines required for exploiting forest products such as timber and non-timber forest products.

Food Engineering - This is a specialized area of Agricultural Engineering which deals with the processes and machinery that are required for processing agricultural products into consumable foods.

Farm Electrification - refers to a wide range of application of electric energy in the field of agricultural production and rural life.

Emerging Areas in Agricultural and Bioresources Engineering - This discipline of Agricultural Engineering is currently undergoing major and important changes as it responds to new developments and challenges. These Emerging areas include: Information and communication Technology (ICT); Biotechnology; Environmental Engineering, Renewable Energy, Ecological Engineering.

Contributions of Agricultural Engineering to National Development

Agricultural Engineering plays a pivotal role in the development of Nigeria. These are in the area of food security, reduction of drudgery in agricultural work, rural infrastructural development, soil and water resources management, and environmental management, improvement in the quality of life of farmers, sustainable agriculture and industrial development.

At this juncture we are going to look at briefs on the Engineering Properties of Agro-Materials and their Links to Modern Agricultural Machinery Design and Development.

2.0 AGRICULTURAL MACHINERY DEVELOPMENT

Agricultural machinery is machinery used in farming or other agricultural production. There are many types of such equipment, from hand tools and power tools to tractors and the countless kinds of farm implements that they tow or operate in order to save labour. Diverse arrays of equipment are used in farming varying from simple hand-held implements used since prehistoric times to the complex harvesters of modern mechanized agriculture.

Since the advent of mechanised agriculture, agricultural machinery is an indispensable part of how the world is fed. Agricultural machines have been designed for practically every stage of the agricultural process. They include machines for tilling the soil, planting seeds, irrigating the land, cultivating crops, protecting them from pests and weeds, harvesting, threshing grain, livestock feeding, sorting and packaging the products.

People who are trained to solve agricultural problems concerning power supplies, the efficiency of machinery, the use of farm structures and facilities, pollution and environmental issues, the storage and processing of agricultural products are known as **Agricultural and Bioresources Engineers**.

2.1 Evolution of Agricultural Machinery

The first people to turn from the hunting and gathering lifestyle to farming probably relied on their bare hands, perhaps aided by sticks and stones. Once tools such as knives, scythes, and ploughs were developed, they dominated agriculture for thousands of years. During this time, most people worked in agriculture, however each family could barely raise enough food for themselves with the limited technology of the day (Adam *et.al.,* 1998).

2.1.1 Pre - Industrial Revolution

Throughout most of its long history, agriculture particularly the growing of crops was a matter of human sweat and draft animal labour. Oxen, horses, and mules pulled ploughs to prepare the soil for seed and hauled wagons filled with the harvest up to 20 percent of which went to feed the animals themselves. The rest of the chores required backbreaking manual labour: planting the seed; tilling, or cultivating, weeding; and ultimately reaping the harvest, itself a complex and arduous task of cutting, collecting, bundling, threshing, and loading. Still, even as late as the 19th century, farming and hard labour remained virtually synonymous, and productivity had not shifted much across the centuries (Adam *et al.,* 1998).

The Pre-Industrial Revolution led to advances in agricultural technology that greatly increased food production allowing large numbers of people to pursue other types of work. With the coming of the Pre-Industrial Revolution and the development of more complicated machines, farming methods took a great leap forward. Instead of harvesting grain by hand with a sharp blade, wheeled machines cut a continuous swath. Instead of threshing the grain by beating it with sticks, threshing machines separated the seeds from the heads and stalks. These machines required a lot of power, which was originally supplied by horses or other domesticated animals.

2.1.2 Industrial Revolution (Steam power)

With the invention of steam power came the steam-powered tractor, a multipurpose, mobile energy source that was the ground-crawling cousin of the steam locomotive. Agricultural steam engines took over the heavy pulling work of horses. They were also equipped with a pulley that could power stationary machines via the use of a long belt. The steam-powered behemoths could provide a tremendous amount of power, because of their size and low gear ratios.

2.1.3 Internal combustion engines

The next generation of tractors was powered by gasoline and (later) diesel engines. These engines also contributed to the development of the self-propelled, combined harvester and thresher. Instead of cutting the grain stalks and transporting them to a stationary threshing machine, these combines could cut, thresh, and separate and clean the grain while moving continuously through the field (Pripps, 2001).

2.2 Agricultural Machinery Industry in Nigeria

At the time of independence, most farm operations were performed with hand tools, farm productivity then was very low, but the population was low and basic food needs of the country were met through importation. Increasing population, decreasing agricultural land, increasing demand for food, extensive land degradation and inadequate infrastructure have been the major factors of the agriculture sector in Nigeria (Ladeinde *et al.,* 2009). This situation has forced all stakeholders in the private and government sectors to pay attention to agricultural mechanisation. Mechanised systems are often categorized into man, animal and engine powered technology. Takeshima *et al.* (2014) reported that 85% of human power, 11% of animal power and 4% of engine power accounts for the overall sources of power for agricultural production in Nigeria. There is no realistic change since the National Development Plan on agricultural mechanization was launched. The over reliance on hand tool technology (over 70%) for agricultural production is one of the greatest technical problems facing the past and present generation of Nigerian farmers. However, the key to mechanisation lies in raising agricultural productivity that directly involves the utilization of more energy resources (Takeshima *et al.,* 2014) as compared to previous years of National Development Plan.

Nigeria's agriculture has not made any tangible progress because there has been very little engineering input by government, agricultural engineers and farmers. Table 1 presents some of the agricultural developmental activities that took place in Nigeria between 1946 and 2018.

Table 1: Agricultural Developmental Activities that took from 1946 to 2011& 2012-2018

Period covered	Activities	Source
1946 - 1956	▪ The Colonial masters emphasized commodity crop production mainly oil palm, cocoa, rubber, cotton and groundnuts. The document contained very little or no proposal for increased food production. Majority, 90% of the labour are human power, followed by animal power and few engine powers. Establishment of Tractor Hiring Service (THS) in 1952.	Asoegwu and Asoegwu (2007)
1962 - 1968	▪ Increase in the number of animals from 7,052 to 36,000. ▪ Government established loan scheme for farmers to purchase bulls and implements. ▪ 437 tractors were imported to assist the farmers. ▪ Human and animal power sources are predominant; agricultural mechanization and labour productivity levels were low	Asoegwu and Asoegwu (2007)
1970 - 1974	▪ Increase in the number of animals from 5,600 to 16, 400. ▪ Increase in the number of tractors from 460 to 1,699. ▪ Human and animal power sources are predominant; agricultural mechanization and labour productivity levels were low	Takeshina *et al.* (2014)
1975 - 1980	▪ Establishment of the National Centre for Agricultural Mechanization (NCAM) in 1978. ▪ Establishment of Nigeria Machine Tools Limited (NMTL) in 1980. ▪ Establishment of River Basin Development Authority (RBDAs) in 1976. ▪ Decrease in the number of animals from 5,600 to 3,300. ▪ Increase in the number of tractors from 1,699 to 3,256.	Takeshina *et al.* (2014)
1981 - 1992	▪ Establishment of the National Agency for Science and Engineering Infrastructure (NASENI) in 1992. ▪ Establishment of the National Agricultural Research Project (NARP) in 1991. ▪ Decrease in the number of animals from 3,300 to 470 due to Structural Adjustment Programme (SAP) which led to lack of purchasing power to replace these animals.	

	▪ Decrease in the number of tractors from 3,256 to 320 due to Structural Adjustment Programme (SAP) which led to the devaluation of our local currency and high number of tractor breakdowns.	Onwualu and Pawa (2004)
1993 - 2007	▪ Decrease in the number of animals from 470 to 120 due to availability of mechanical power. ▪ Increase in the number of tractors from 320 to 1,538.	Ladeinde *et al.* (2009)
2008 - 2011	▪ Establishment of the National Food Reserve Agency (NFRA) in 2011. Nigeria has adopted a policy that 15% of the total annual grain harvest should be held in reserve, individual should reserve 5% and each state is to hold another 10%. ▪ Decrease in the number of animals from 120 to 47 due to availability of the mechanical power. ▪ Increase in the number of tractors from 1,538 to 1,643.	Ladeinde *et al.* (2009)
2012 - 2018	▪ Increase in the number of tractors from 1,643 to 114,820	PrOpCom (2018)

Figure 1: presents the number of tractors in use in Nigeria within the period covered.

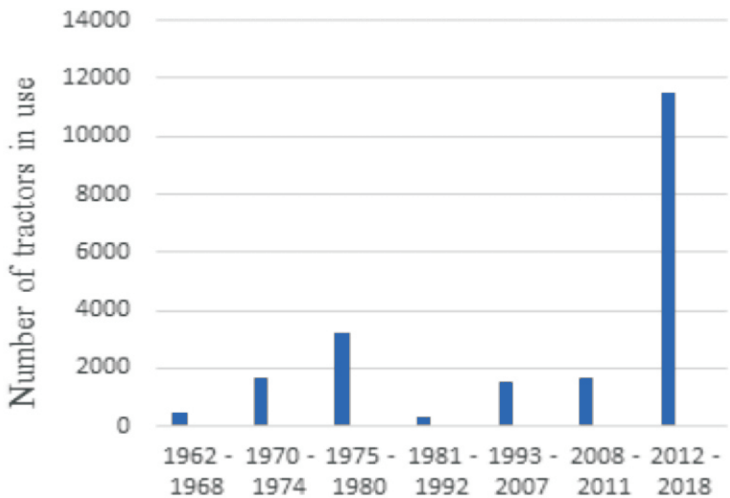

Fig. 1: Year period of tractors in use in Nigeria within the period covered

Source: Ladeinde *et al.,* 2009; PrOpCom, 2018

Some other past policies or National Development Plan (NDP) on agricultural mechanization in Nigeria is itemized as follows: Tractor and Equipment Hiring Units (TEHU), Tractor and Equipment Subsidy Schemes (TESS), Tractor Assembly Plants (TAP), National Agency for Science and Engineering Infrastructure (NASENI), Project Development Institute (PRODA), National Centre for Agricultural Mechanization (NCAM), National Machine Tools (NMT), Federal Institute of Industrial Research (FIIRO), etc.

Under the National Development Plan (NDP), tractors and associated equipment were purchased and made available to farmers at subsidised rates (sometimes with subsidies of up to 80 %) (Sangodoyin & Ogedengbe, 1987).

2.2.1 Present status of agricultural machineryindustry

Nigeria agricultural machinery production at the beginning of 2007 has not met the National demand (Ladeinde *et al.,* 2009). Farm power sources such as human, animal or mechanical power for crop establishment, irrigation, harvesting, processing, and transport has become a critically important input for agricultural production. Agricultural machinery is a major agricultural input in Nigeria. Farm Power machineries developed for agricultural production in Nigeria under the farm power source includes tractor, track laying tractor, crop thresher and combine harvester. Under implements, there are disc plough, mouldboard plough, disc harrow, mouldboard harrow, disc ridger, mouldboard ridger, boom sprayer, gun sprayer, seed planter, cassava planter, fertilizer spreader and mower. Those for crop processing operation include threshing machine (Rice and Soybean); shelling machine (Maize) and cassava peeler (Ladeinde *et al.,* 2009).

- The status of agricultural machinery development in Nigeria still remain deplorable as it was almost a decade ago despite spending huge amount of money in implementing the various agricultural machinery development programmes.

- It is worthy to note too that most of these programmes have been abandoned or neglected apart from the private sector driven which are struggling to survive under the harsh Nigerian developmental environment.

Institutions and enterprises involved in agricultural machinery are described in 2.2.2.

2.2.2 Agricultural machinery manufacturers in Nigeria

Agricultural machinery such as tractor and majority of its associated implements for large scale production had not been manufactured in Nigeria for small and medium scale production. Implements such as seed planter, cassava planter, threshing machine for rice and soybean, shelling machine for maize, cassava peeler, pellet machine, hammer mills, livestock feed mixers, plants shredder and cassava graters are being manufactured in the country.

Some of the top companies/agencies involved in the manufacturing of farm equipment in Nigeria (Ibukun & Ifiok, 1996) are:

National Agency for Science and Engineering Infrastructure (NASENI): NASENI was established in 1992. It is located at Idu Industrial Layout, Garki, Abuja. The Mandate of NASENI is specifically in the area of capital goods research, production and reverse engineering with respect to the following six broad areas: Engineering materials (notably irons, steel, non-ferrous metal and alloys, plastics, glass, ceramics, polymer, electronics and nanotechnology); Industrial and analytic chemical materials including industrial gases; Scientific equipment and components for education, research and industry; Engineering accessories (mechanical, hydraulic, pneumatic, electrical and electronic); Power equipment (generation, transmission, distribution, prime movers); and Mechanical Engineering tools (power tools, hand tools, cutting tools and machine tools).

Project Development Institute (PRODA): PRODA is an institution established by the Federal Government of Nigeria to aid the fabrication of farm machines locally in Nigeria. It is located in Emene Industrial Layout, Off Enugu/Abakaliki Expressway. The agricultural equipment and plant produced by PRODA includes Garri production machines and equipment, Cassava Chipping Machine, Palm Produce Processing Machine and Plant Setup, Fish Feed Pelleting Machine, Maize Sheller, Soya Bean Flour Processing Machines/Plant, Industrial Electric Dryers, Mechanical Kneading Machine and Industrial Juice Extractor.

National Centre for Agricultural Mechanization (NCAM): This centre is located at KM 20, Ilorin – Lokoja Road, Idoflan, Ilorin, Kwara State. NCAM is only devoted to mechanisation of agriculture by conducting adaptive research in all areas of agricultural engineering. They also work on standardization and testing of agricultural machinery of all types. In addition they coordinate research activities in agricultural engineering nation wide and conduct training programmes.

National Machine Tools (NMT): Nigeria Machine Tools is also government owned Organisation and has two branches in Nigeria. The branches of Nigeria Machine Tools are located in Osogbo and Lagos. Its major activity is the assembly of farm machines and implements. The farm machinery assembled by Nigeria Machine Tools includes tractors, tipping trailers, disc harrows, disc ploughs and ridgers.

Federal Institute of Industrial Research (FIIRO): FIIRO is another institute established by the Federal Government of Nigeria in 1956. Its functions are similar to that of PRODA but its activity is not limited to the production of machines used for farming activities. FIIRO is located at 3, FIIRO Road, Off Agege Motor Road Oshodi. The agricultural equipment/machine manufactured by FIIRO are Cassava Chipping Machine, Pelletizer, Cabinet Tray Dryer, Cassava Mash Homogenizer, Cassava Mash Stirrer, Screen Separator, Garri Fryer, Cowpea Dehuller, Beniseed Air Cleaner, Melon Sheller, Sesame Seed Oil Expeller, the Cassava Peeling Machine, Cashew Nut Roaster and Groundnut Processing Plant.

Niji-Lukas Nigeria Limited: Niji-Lukas Nigeria Limited is one of the foremost agricultural equipment manufacturers in Nigeria. It is located at 10 Kufisile Street, Niji-Lukas Bus Stop IsheriIdimu, Lagos State. This company is involved in the fabrication and manufacture of many farm tools and equipment such as Cassava Stainless Steel Grater, Automated Garri Fryer, Stainless Steel Hammer Mill, Vibrating Sifter, Pneumatic Press, Flash Dryer, Smoking Kiln, Beans Separator, Multipurpose Deep Fryer, Cabinet Dryer, Pastry Oven, Bone Crusher, Stainless Steel Wet Miller M150 and Stainless Steel Wet Miller M80, Automated End to End Cassava Flour Processing Plant, Automated End to End Cassava Starch Processing Plant etc.

Techo-Quip Nigeria Limited: Techo-Quip Nigeria Limited is located at No. 14–16 OlusolaIkare Street, IdimuIkotun Road, Lagos State. It is another versatile company involved in the manufacture of agricultural equipment and local farm tools and involved in the establishment of agricultural processing plants. The agricultural equipment manufactured by Techo-Quip Nigeria Limited can be divided into three divisions which are Fruit Processing Machines, Food processing machines and the processing machine used in the wood industry etc (Ibukun & Ifiok, 1996).

NOVA Technology Limited: This Company is situated in Oyo State located on New Ibadan Oyo Expressway, Opposite PW yard, Akinleye, Ibadan. It is a privately owned company. This company is involved in the manufacture of Flash Dryer, Cabinet Dryer, Steam Tube Dryer, Automatic Garri Fryer, Stainless Granulator, Chipping Machine and Sifter.

Eldorado Nigeria Limited: Located at No. 27, Henry Carr Street, Ikeja, Lagos. Eldorado Nigeria Limited is involved in the fabrication of a major farm structure which is the Grain Silo. Eldorado is located at 27, Henry Carr Street, Ikeja, Lagos, Nigeria.

Adiss Agricultural Engineering Limited: Adiss Agricultural Engineering Limited is located at KM 10 Ibadan-Lalupon Road, Oya State and solely dedicated to the manufacture of farm machines. The agro-processing machines manufactured by this company are Fish Pellet Processing Machine, Cassava Processing Machine, Chicken Processing Machine, Palm Kernel Oil Processing Machine, Grain Processing Machine, Rice Processing Machine, Palm Oil Processing Machine and Soap Processing Machine. Another machine fabricated by S. Adiss Agricultural Engineering Limited is the Soya Beans Processing Machine.

Starron Nigeria Limited: This Company is located at No. 27, Layi Oyekanmi Street, Ikeja, (area), Lagos.Starron Nigeria Limited aside from industrial activities also involved in the manufacture of agro-allied machines. The agro-processing machine produced by this institution is the Cassava Processing Machine.

Aluframes Nigeria Limited: This Company is located at No. 27

Godi, Love Street, Lagos State.Aluframes Nigeria Limited specializes in the Manufacture of food processing equipment such as mobile rotary dryer, vibrasieve, plantain slicer, pine apple crusher, wet hammer mill, spice mill, garri fryer and pedal garri press among others (Ibukun & Ifiok, 1996).

Allamit Nigeria Limited, Odo Ona, Ibadan: This Company is located at Odo Ona, Ibadan, Oyo State and leading in spare parts manufacturing in Nigeria. Spare parts of tractor, diesel engine, threshers and power tiller are both imported and locally produced. The spare parts sub-sector is employing a significant number of skilled and semi-skilled labour forces.

Hanigha Nigeria Limited, Kaduna: Located at No. 9, Ahmed Talib Avenue, Behind Crittal Hope, Kakuri Kaduna. Its mandate is also in spare parts manufacturing of tractor and diesel engine, threshers and power tillers.

John-Holt Agricultural Engineers Ltd (HOLTAG): It is located at No. 2 Yero Avenue, Zaria, Kaduna State. It is into manufacture of Emcot ploughs, maize threshers, trailers etc. It is a major supplier of the animal drawn ploughs in the North.

Steyr Tractor Plant, Bauchi: It is located at Fritz Felsinger Road, Industrial Estate, Bauchi, Bauchi State. This company is into production/manufacturing of steyr tractors, trucks, buses, and motorcyles but now almost moribund.

2.2.3 Import of agricultural machinery

Basically, it can be said that Nigeria depends on importation of agricultural machinery. These machines could be in full or parts. Imported agricultural machinery include tractor, power tiller, diesel engine, plough, harrow, ridger, combine harvester, self-propelled transplanter, rice transplanters, threshing machine.

The main importers of these machines are Niji-Lukas Nigeria Limited, Famousil Rich Enterprises, Base Bond International Limited, Bertola Machine Tool Limited, Dizengoff West Africa Nigeria Limited, El-Hanan-Ventures Limited, MantricNigeria Limited, Jopfack International Limited, Centro Machinery Nigeria Limited, TaboV Nigeria Limited and ATC Nigeria Limited. The two leading importers in Nigeria are Dizengoff West Africa Limited and Bertola Machine Tool Limited (Ibukun & Ifiok, 1996).

2.2.4 Effects of importation of agricultural machinery on the Nigerian Economy

The dire effects of importation of agricultural machinery on the Nigerian Economy are high forex scarcity as a result of increase in the demand for dollar by importers which will in turn bring depreciation in the value of naira as well as high tax value on import of agricultural machinery which will lead to unfavourable trade balance, terms of trade and even trade policies for the country. Since Nigeria even import agricultural machinery that can be easily produced locally, many thriving local factories have folded up and are still folding up which had caused many Nigerians lost their jobs. Dumping has affected local production due to heavy inflow of foreign agricultural machinery not suited to our conditions which is pushed out of imported countries into Nigeria.

2.2.5 Problems of agricultural machinery industry

Generally the industrialized countries manufacture agricultural machinery and implements while most of the developing countries like Nigeria import this machinery from these industrialized countries. As a result, imported machinery is expensive and their operating cost is higher. For economic development it is very important to promote mechanization and status of the manufacturing industry. Mechanizing Nigeria agriculture by using only imported implements may not have the desired impact on unemployment reduction. Foreign exchange could be saved through local manufacture of farm machine. Moreover, it also creates technical knowledge among people and sufficient job opportunity for local skilled and unskilled labour.

The problems confronting agricultural machinery industry in Nigeria are many. Farm machinery manufacturers in Nigeria face capital problems. Lack of infrastructure is another problem faced by manufacturers. Bureaucratic complexity is another major problem for installing large industry in Nigeria. Labour is available but skilled labour scarcity is also a major problem. Complexity in taking bank loan, unhealthy political environment and erractic electric power supply affect all manufacturers in Nigeria. Lack of technical know-how is also a serious challenge (Onwualu *et al.,* 2006). Cost of production is also affected due to the increased price of raw materials. Raw material supply is not left out too. Several manufacturers produced farm machinery using low quality materials resulting in poor performance of the product. Almost all the manufacturers use scrap as raw materials due to their cheapness. Seasonal demand of farm machinery affects the manufacturing industry. Heavy taxation system on raw materials and value added tax on the locally produced machinery also increase the price of the locally made machinery compared to imported machinery and thus discouraged the local manufacturer (Aurangzeb, 1991).

It is also worthy to note that one of the first consideration in any engineering design and development is the study of properties of materials. This is applicable to all agricultural machinery as well. Fan-Gangjuan *et al.* (1998) also mentioned the constraints facing the adoption of agricultural mechanisation to include capital, technological adaptability, and product pricing structure, marketing, infrastructure, training and education as well as basic information on ***agro-ecological needs or in-situ properties of agricultural materials.***

Locally made machines could be modified according to **agro-ecological needs** of various regions of the country (Soomro & Bukhari, 1985; Guntz & Morries, 1991). Although in any engineering design and development the study of properties of materials is the first consideration, local agricultural machines manufacturers in Nigeria, rarely, put into **consideration the in-situ properties of agricultural machines when designing these machines** when designing these machines. Basic information on these properties are of great importance and help the design engineers, food scientists and processors towards efficient process and agricultural machinery development.

2.3 Agro-ecological needs or in-situ properties of Agricultural Materials

Agricultural materials especially those that are consumed as food or feed undergo various unit operations right from the pre-harvest to post harvest processing, formulation, preservation, packaging, storage, distribution, retailing, domestic storage and finally consumption. Each of these unit operations has unique characteristics and need special tools and equipment. Designing and selecting such tools and equipment require information regarding various engineering properties.

The engineering properties such as physical, mechanical, frictional, thermal, electrical, aero and hydro-dynamic and rheological properties of the various agricultural materials needs to be understood and are very important in the design of machine, structure, process and control. All these properties are very useful in handling, storage, processing, preservation, quality evaluation distribution and marketing of agricultural products. The knowledge of properties aids in engineering design and development of agricultural machinery and also gives information about the product quality, its acceptability by the consumer of different groups and its behaviour at post production, during storage, during consumption and post consumption (Mohsenin, 1986; Sahin & Sumnu, 2006; Sharma *et al.,* 2012).

Physical Properties

The knowledge of some important physical properties such as shape, size, volume, surface area, thousand grain weights, density, and porosity of different grains is necessary for the design of various separating, handling, storing and drying systems. The function of these types of machines is influenced decisively by the size and shape of the product. The size and shape are, for instance, important in their electrostatic separation from undesirable materials and in the development of sizing and grading machinery (Mohsenin, 1986). 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 also affect the rate of heat and mass transfer of moisture during aeration and drying processes; the knowledge of density is used to separate materials with different densities or specific gravities. It plays an important role in other applications that include the design of silos and storage bins and the maturity and quality of paddy, which are essential to grain marketing. Some of the important physical properties are described below.

Shape and size: The following parameters may be measured for describing the shape and size of the granular agricultural materials (Mohsenin, 1986).

(i) **Roundness:** It is a measure of the sharpness of the solid material. The most widely accepted methods for determining the roundness of irregular particle are given in the Equations 1 and 2 (Mohsenin, 1986):

$$Roundness = \frac{Largest\ projected\ area\ of\ the\ particle\ when\ it\ is\ in\ natural\ restposition,\ A_p}{Area\ of\ smallest\ circumscribing\ circle,\ A_c} \quad (1)$$

$$Roundness\ ratio = \frac{Radius\ of\ curvature,\ r,\ of\ the\ sharpest\ corner}{Mean\ radius\ of\ the\ particle,\ R} \quad (2)$$

(ii) Sphericity: Sphericity may be defined as the ratio of the diameter of a sphere of the same volume as that of the particle and the diameter of the smallest circumscribing sphere or generally the largest diameter of the particle. This parameter shows the shape character of the particle relative to the sphere having same volume. The sphericity can be expressed as in Equations 3 and 4 (Mohsenin, 1986):

$$Sphericity = \frac{D_e}{D_c} \quad (3)$$

The sphericity can also be defined as:

$$Sphericity = \frac{D_i}{D_c} \quad (4)$$

Where: De = diameter of a sphere having same volume as that of the particle; Dc = diameter of the smallest circumscribing sphere; Di = diameter of the largest inscribing circle.

Density and specific gravity: The density of any material may be expressed as given in equation 5 (Mohsenin, 1986):

$$Density = \frac{Weight\ of\ the\ material,\ kg}{Volume\ of\ the\ material,\ m^3} \quad (5)$$

The specific gravity of grain is calculated by the following as expressed in equations 6.

$$Specific\ gravity\ of\ grain = \frac{Specific\ gravity\ of\ toluene\ x\ weight\ of\ grain}{Weight\ of\ the\ toluene\ displaced\ by\ the\ grain} =$$

$$= \frac{Specific\ gravity\ of\ toluene\ x\ weight\ of\ grain}{\left[(weight\ of\ sample) - (weight\ of\ toluene + sample + bottle) - weight\ of\ toluene + bottle)\right]} \quad (6)$$

But the specific gravity of toluene is determined as the ratio of the weight of toluene in the bottle and weight of distilled water in the bottle at same temperature (equation 7).

$$\text{Specific gravity of toluene} = \frac{\text{Weight of toluene}}{\text{Weight of water}} \qquad (7)$$

Frictional Properties

Frictional properties such as angle of repose and coefficient of friction are important in designing equipment for solid flow and storage structures and the angle of internal friction between seed and wall in the prediction of seed pressure on walls. The coefficient of static friction plays also an important role in transports (load and unload) of goods and storage facilities (Sahin & Sumnu, 2006). Coefficient of friction is important in designing storage bins, hoppers, chutes, screw conveyors, forage harvesters, and threshers. The material generally moves or slides in direct contact with trough, casing, and other components of the machine. These various parameters affect the power requirement to drive the machine. The frictional losses are some of the factors, which must be overcome by providing additional power to the machine. Hence, the knowledge of coefficient of friction of the agricultural materials is necessary (Amin *et al.,* 2005).

Coefficient of friction: The coefficient of friction may also be given as the tangent of the angle of the inclined surface upon which the friction force tangential to the surface and the component of the weight normal to the surfaces are acting.

If F is the force of friction and W is the force normal to the surface of contact, then the coefficient of friction 'f' is given by the relationship in Equation 8.

$$f = \frac{F}{W} \qquad (8)$$

There are two types of friction (i) static friction and (ii) kinetic friction:

Static friction: The friction may be defined as the frictional forces acting between surfaces of contact at rest with respect to each other.

Kinetic friction: It may be defined as the friction forces existing between the surfaces in relative motion.

Angle of internal friction: The value of angle of internal friction is equal to the tangent of the coefficient of friction for the material. The angle of internal friction is an important property which helps to estimate the lateral pressure in storage silos, also used in designing of storage bins and hopper for gravity discharge. The coefficient of friction between grains is required as a design parameter for design of shallow and deep bins.

Angle of repose: The angle of repose is the angle between the base and the slope of the cone formed on a free vertical fall of the granular material to a horizontal plane. The size, shape, moisture content and orientation of the grains affect the angle of repose.

There are two angles of repose, (1) static angle of repose, and (2) dynamic angle of repose.

Static angle of repose: It is the angle of friction when a granular material slides upon itself.

Dynamic angle of repose: It comes in picture when bulk of the grain is in motion like discharge of grain from bins and hoppers. The dynamic angle of repose is more important than static angle.

The angle of repose, Ø, is obtained from the geometry of the cone as given in Equation 9 (Mohsenin, 1986):

$$Ø = \tan^{-1} \frac{2(H_a - H_b)}{D_b} \quad (9)$$

Table 2: Angle of repose of some grains

Grain	Angle of repose
Wheat	23 – 28
Paddy	30 - 45
Maize	30 - 40
Barley	28 – 40
Millet	20 – 25
Rye	23 - 28

Source: Krishnakumar (2019)

Mechanical and Rhelogical Properties

Mechanical properties may be defined as those which affect the behaviour of the agricultural material under the applied force. The mechanical properties such as hardness, compressive strength, impact and shear resistance and the rheological properties affect the various operations of agricultural processing. Data on these properties are useful for application in designing equipment for milling, handling, storage, transportation, and food processing.

The mechanical damage to grain and seed in threshing and handling operations causes reduction in germination power and viability of seeds, increases the chances of insect and pest infestation and also affect the quality of final product. The hardness of the grain affects the milling characteristics and it is also useful to live stock feeders and plant breeders.

The impact and shear resistance are important for size reduction of food grains. This information is useful in determination of the appropriate methods of crushing, breaking or grinding the grains. These properties also play important roles towards seed resistance to cracking under harvesting and threshing conditions.

Aero and Hydro-dynamic Properties

The aerodynamic and hydrodynamic properties like terminal velocity and drag coefficient of agricultural products are important and required for the designing of air/ hydro conveying systems and the separation equipment (Table 3 and 4). The physical properties, such as density, shape, and size are required for calculating the terminal velocity and drag coefficient of the agricultural produce (Sharma *et al.,* 2012). In the handling and processing of agricultural products, air is often used as a carrier for transport or for separating the desirable products from unwanted materials, therefore, the aerodynamic properties, such as terminal velocity and drag coefficient, are needed for air conveying and pneumatic separation of materials. The fluidization velocity for granular material and settling velocity are also calculated for the body immersed in viscous fluid.

Terminal velocity: The terminal velocity of a particle may be defined as equal to the air velocity at which a particle remains suspended in a vertical pipe. Air velocity, terminal velocity and drag coefficient requirement for air borne of some agricultural crops is shown in Tables 3 and 4.

Table 3: Air velocity requirement for air borne of some of the agricultural materials

Grain	Unit density, kg/m^3	Terminal velocity, m/s
Wheat	998 - 1238	9-11.5
Rye	1158 - 1218	8.5-10
Oats	738 - 968	8-9
Corn	1138 - 1198	34.9
Soybean	1029 - 1152	44.3

Source: Krishnakumar (2019)

Table 4: Terminal velocity and drag coefficient of groundnut and soybean

Grain	Terminal velocity, m/s		Drag coefficient	
	Range	Mean		
Groundnut kernel (RS-1)	12.31 - 13.78	13.23	0.52 - 0.64	0.58
Soybean (Punjab-1)	12.30 - 13.92	13.40	0.38 - 0.62	0.47
Soybean (Lee)	13.30 - 14.55	14.17	0.33 - 0.51	0.41

Source: Krishnakumar (2019)

Thermal Properties

The knowledge of the thermal properties of foods is essential in the analysis and design of various food processes and food processing equipment involved in heat transport, with respect to heat transfer or energy use, such as in extrusion cooking, drying, sterilization, cooking etc. The most important thermal properties in food processing are specific heat capacity (Cp), thermal conductivity (k), enthalpy (a) and thermal diffusivity (µ) (Lan *et al.,* 2000).

(i) Specific heat capacity: The specific heat capacity may be defined as the amount of heat in kilocalories that must be added to or removed from 1kg of a substance to change its temperature by 1°C. The specific heat of wet agricultural material is the sum of specific heats of bone dry material and its moisture content and is as given in Equation 10 (Mohsenin, 1986; Krishnakumar, 2019):

$$C_m = (\frac{100-m}{100})C_w + (\frac{100-m}{100})C_d, \quad kcal/{}^{\circ}C \qquad (10)$$

Where: C_d and C_w are the specific heats of bone dry material and water respectively, and m is the moisture content of the material in percent wet basis.

Note: The above relationship exists above 8% moisture content of the grain only.

The specific heat of bone dry grain varies from 0.35-0.45 kcal/kg °C.

The specific heat is measured by calorimeter, generally a simple thermos vacuum bottle.
The differential scanning - calorimeter (DSC) is suitable for measuring the specific heat.

(ii) Thermal conductivity: The thermal conductivity may be defined as the rate of heat flow through unit thickness of material per unit area normal to the direction of heat flow and per unit time for unit temperature difference. It is a measure of ability of the material to conduct heat. The thermal conductivity can be expressed by Equation 11 (Mohsenin, 1986; Krishnakumar, 2019):

$$Q = K\ A\ \Delta T \tag{11}$$

Where: Q = amount of heat flow, kcal; A = area, m^2; ΔT = temperature difference in the direction of heat flow, °C; K = thermal conductivity, kcal/m.hr.°C

If the moisture content of the grain is known, then the thermal conductivity of wheat can be expressed as shown in equation 12 (Mohsenin, 1986).

$$K = 0.564 + 0.0858\, w,\ W/m.{}^{\circ}C \tag{12}$$

Where: w = fraction of moisture present in material

The thermal conductivity of single grain ranges from 0.3-0.6 kcal/m.hr.°C and bulk grain varies from 0.10-0.15 kcal/m.hr.°C. The difference is due to the air spaces present in the bulk grain. The thermal conductivity of air is 0.02 kcal/m.hr.°C.

(iii) Enthalpy: Enthalpy is the total heat content or energy level of a material. The enthalpy data are required for frozen foods that freeze over a range of temperatures below 0 °C and for those substances that freeze in a narrow temperature limit, as the case of pure substance like water. The enthalpy (a) of the material can be estimated by using the expression presented in Equation 13 (Mohsenin, 1986; Krishnakumar, 2019):

$$a = h_2 - h_1 = m_p C_p (T_2 - T_1) + mX_w L \tag{13}$$

Where: $a = h_2 - h_1$ = enthalpy difference; m_p= mass of the product C_p = Specific heat of the product; X_w = Water fraction; $T_2 - T_1$ = temperature difference; L = latent heat of fusion for water.

(iv) Thermal diffusivity: The thermal diffusivity may be calculated by dividing the thermal conductivity by the product of specific heat and mass density. It may be expressed as shown in Equation 14 (Mohsenin, 1986):

$$\mu = \frac{K}{\rho C_p} \tag{14}$$

Where, μ = thermal diffusivity, K = thermal conductivity, ρ = mass density, C_p = specific heat.

Thermal diffusivity is important in determination of heat transfer rates in solid food materials of any shape. Physically it shows the relationship between the ability of a material to conduct heat to its ability to store heat.

Electrical Properties

Some electrical properties which are of importance in agro processing are electrical conductance, resistance, impedance. Electrical conductance or capacitance has been used for determining the moisture content of grain. Electrostatic separation of grains is also used for separating grains, based on the ability of the grain to hold electrostatic charge. Electrical conductivity of the grain decides the ability of the material to hold electrostatic charge. Recently ohmic heating has been in use for drying, pasteurization, blanching and other thermal processing of foods, based on resistance heating (Mohsenin, 1986; McKenna *et al.*, 2006).

In any engineering design and development the study of properties of materials is the first consideration.This is applicable to all agricultural machinery as well. The study of these properties (agricultural materials) that is their determination is very important in the determination of the necessary machine construction parameters.

2.4 Prospect of agricultural machinery development in Nigeria

Prospect of agricultural machinery development is bright, if the following points are implemented (Anazodo, 1982; Onwualu *et al.,* 2006):

i. Ensure that agricultural machinery development policy in the country is an integral part of the general economic development policy of the country.
ii. Encourage indigenous development of machinery instead of importation.
iii. Increase funding and revitalisation of the specialised agencies such as National Centre for Agricultural Mechanization (NCAM), Rural Agro-Industrial Development Scheme (RAIDS), Agricultural Mechanics and Machinery Operators Training Centre (AMMOTRAC), etc.
iv. Streamline, harmonise and revitalise the engineering divisions of the Federal and State Ministry of Agriculture and such other bodies as the River Basin Development Authorities.

v. Implement in-service training programmes for the development and improvement of the technical competence of agricultural engineers, technologies and technicians.
vi. Ensure that the right attention is given to infrastructural development.
vii. Provide enough, easily accessible and interest free loan to indigenous private agricultural machinery manufacturing companies.
viii. Ensure synergy between researchers, industries and the end-users for a better result.

Consequently, once these points are implemented, agricultural machines will be available and affordable. Foreign exchange revenue by exporting these machines and increased participation of the populace in farming activieswill drastically improve the economic well-being of the country. Likewise food sufficiency and reduction in hunger and poverty will be attained in the country.

3.0 MY CONTRIBUTIONS

Mr. Vice-Chancellor Sir, my contributions in Agricultural Machinery Development focused mainly in the areas of engineering properties of agricultural materials and their links to design and development of agricultural machines. Summaries of some of the researches carried out on determination of engineering properties of agricultural materials and their link to design and development of agricultural machines and our findings over the past 25 years are as given below:

3.1 Studies in the Areas of Engineering Properties of Agro-Materials, Design and Development of Agricultural Machinery

3.1a Determination of some engineering properties of sweet potato (*Ipomoea batatas*)

This work presents the determination of some engineering properties of sweet potato (shape, size, colour, volume, particle density, sphericity, weight, surface area and compressive strength) at moisture contents of 81.2% (ASAE, 2003; Mohsenin, 1986; AOAC, 2002). The highest value of compressive strength for sweet potato when placed horizontally and vertically are 7.07 kN and 5.62 kN respectively, so in bagging and sorting of sweet potato special care should be taken in placing the sweet potato in a horizontal position due to the compression of the weight of the sweet potatoes. The mean values of the Major, Intermediate and Minor Diameter of sweet potato are 74.33mm, 41.04mm and 38.77mm respectively. These values were used for sorting, grading and construction of sieve to separate the values below the mean obtained. These results are important for maximum efficiency in designing equipment required for further processing of sweet potato and the reduction of mechanical damage to agricultural produce during postharvest handling and processing (Balami *et al.,* 2012).

3.1b Design and fabrication of a sweet potato (*Ipomoea batatas)* peeling machine

A sweet potato peeling machine was designed and fabricated by considering the earlier determined physical and mechanical properties as outlined by ASAE (2003), Balami *et al.* (2012) and Khurmi and Gupta (2012). The technical characteristics of the developed sweet potato peeling machine is shown in Table 5.

Table 5: Technical characteristics of the machine

S/No.	Technical characteristics	Values
1	Power required to operate machine	0.75 kW (1 hp electric motor selected)
2	Diameter of peeling drum shaft	20 mm
3	Speed of operation	1400 rpm
4	Volume of peeling drum	0.019 m3
5	Volume of hopper	0.045 m3
6	Angle of wrap	1st Pulley, Q_A85.34 = rad; Q_B274.66 rad = 2nd Pulley, Q_A128.64 = rad; Q_B205.68 rad = 3rd Pulley, Q_A101.67 = rad; Q_B258.33 rad =
7	Length of belts	Belt 1 = 740 mm; Belt 2 = 700 mm
8	Arc of contact correction factor	Belt 1, F_A= 0.96 when coef. of arc contact factor = 0.3 Belt 2, F_A=0.94 when coef. of arc contact factor = 0.4
9	Diameter of camshaft	20 mm
10	Tortional deflection of shaft	0.1°
11	Peeling efficiency, %	81 %
12	Machine throughput	82.87 kg/hr.
13	Manual throughput	13.2 kg/hr.
14	Peeling weight proportion	0.22

Source: Balami *et al.*, 2012; Balami *et al.*, 2016

The developed sweet potato peeling machine (Fig. 2) has a rotating drum which is eccentrically placed on a shaft and powered by 1 hp electric motor. Peeling of the tubers takes place as a result of the abrasion caused by the perforated drum as the potatoes rotate inside the peeling drum (Balami *et al.*, 2012). The developed machine could reduce the drudgery involved in manual peeling of sweet potato. Production cost of machine is N50,070:00.

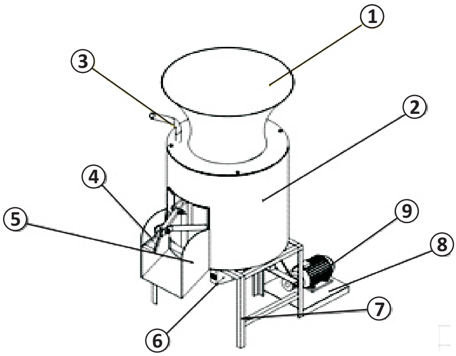

Figure 2: Developed Sweet Potato Peeling Machine
Source: Balami *et al.*, 2016

Legend: 1 - Hopper, 2 - Peeling drum casing, 3 - Handle, 4 - Lever, 5 - Tray outlet, Water outlet 7 - frame, 8 - Eletric motor seat and 9 - Electric motor.

3.2a Engineering properties of palmyra palm (*Borassus aethiopum*) seeds

Despite the numerous uses of palmyra palm, information on its engineering properties is not much available in Nigeria. Palmyra palm (*Borassusa ethiopum*) trees, fruits and seeds (Fig. 3) are useful in food production, such as: oils, timber, dyes, ? bres, wine, and raw materials.

Figure 3: Palmyra palm *(Borassus aethiopum)* trees and fruits and seeds

The objective of the research was to determine some physical and mechanical properties of the seed at three levels of moisture contents (8.09 %, 7.04 % and 5.50 %) using standard methods (ASAE, 2003; Mohsenin, 1986; AOAC, 2002). The mechanical properties such force, stress and deformation both at peak and at break were determined using InstronUniversal testing machine. The seed had major, intermediate, minor and geometric diameter at 8.09 % moisture content as 10.89 ± 1.65, 7.76 ± 1.93, 9.14 ± 1.84 and 9.11 ± 1.53 while that of kernel are 8.14 ± 1.37, 5.08 ± 1.19, 2.96 ± 0.93 and 4.92 ± 1.07 respectively. The mechanical properties of seed and kernel evaluated at 8.09 % moisture content for force at peak, force at break, stress at peak, stress at break, deformation at peak and deformation at break were 8.03 ± 1.87 kN, 10.82 kN ± 0.23 kN, 0.46 ± 0.07 kN/mm, 1.46 ± 0.19 kN/mm, 3.98 ± 0.19 mm, 4.10 ± 0.16 mm and 17.14 ± 1.66 kN, 36.44 ± 8.24 kN, 0.14 ± 1.37 kN/mm, 10.96 ± 8.24 kN/mm, 5.21 ± 1.28 mm and 5.53 ± 1.33 mm respectively. The coefficient of static friction was highest on wood with 0.36 ± 0.06 and 0.44 ± 0.03 for seeds and kernel, respectively. It was found that the seed's coefficient of static friction is of paramount importance in determining the steepness of the storage container, hopper or any other loading and unloading device. The results obtained will contribute immensely to the existing knowledge aimed at solving the problems of equipment design to handle the processing of seeds (Balami *et al.,* 2015).

3.2b Development and performance evaluation of a palmyra palm seed cracking machine

The most common method of seed cracking still widely used in some parts of Nigeria is by manually breaking the seed one at a time between the palms or using hard objects, which is tedious, time consuming and ineffective (Eric *et al.,* 2009). In view of that, a palmyra palm seeds cracking machine (Fig. 4) was developed and evaluated taking into cognisance the results of engineering properties of palmyra palm seeds earlier determined (Balami *et al.,* 2016).

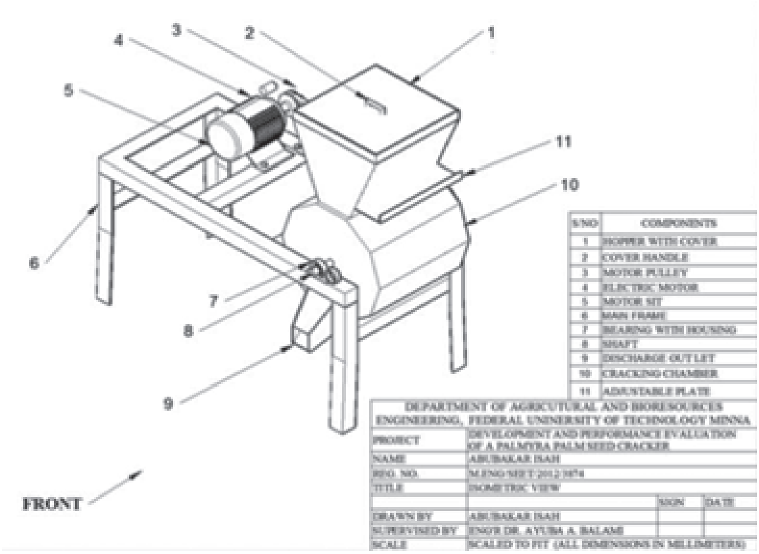

Figure 4: Developed Palmyra Palm Seed Cracking Machine
Source: Balami *et al., 2016*

Cracking of the seeds takes place as a result of the impact caused by the fast rotating beaters against the concave. The machine was evaluated using palmyra seeds at three different moisture content levels of 8.09, 7.04 and 5.50 % and machine speeds of 1100, 1200, and 1480 rpm respectively at a cracking clearance of 7.32 cm and replicated thrice. A model regression equation was also developed to help predict the optimum performance of the machine. Analysis of variance results indicate that, the interaction between the speeds and moisture content has significant effect on the cracking efficiency ($P = 0.005$).

At a cracking clearance of 7.32 cm, the optimum cracking efficiency predicted by the model is 90 % which is 2 % higher than the actual value. The developed machine has a throughput capacity of 160 kg per day as against the hand cracker of 4 kg per day, which is a great improvement. The interaction between the two factors has significant effect on the cracking efficiency at $P = 0.05$. Production cost of machine is N46,100:00.

The response surface plot (Fig. 5) presents the simulated data.

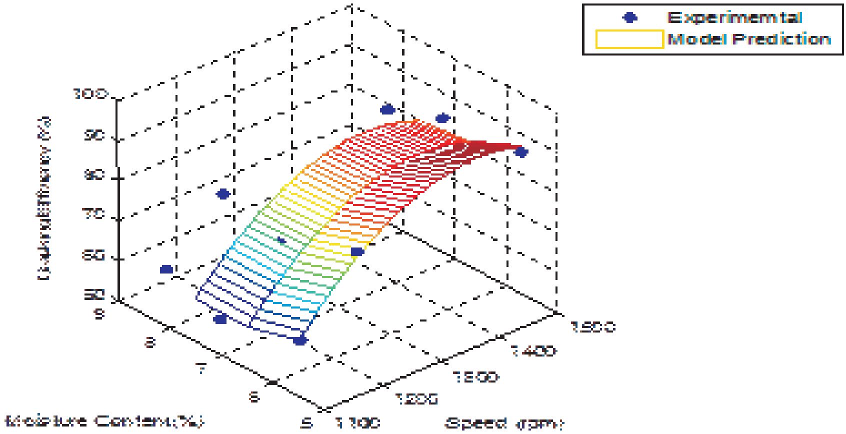

Figure 5: Response Surface Plot for the Cracking Efficiency
Source: Balami *et al.,* 2016

3.3a Determination of some engineering properties of cassava tubers grown in northern Nigeria

Several cassava processing operations have been mechanized successfully, but cassava peeling is still largely carried out manually; however, in this work some selected engineering properties of 5 cassava varieties (TMS 82/00661, TMS 81/00110, TMS 30001, TMS 4(2)30572 and TMS 82/0249) mostly grown in northern part of Nigeria were determined (Balami *et al.,* 2014; Agbetoye, 2003; IITA, 1990) to provide basic data for the design of cassava peeling machine.

The properties include thickness of the peel, the length, and axial dimensions - major, intermediate and minor diameters and the strength of peel (peeling force per unit area), and bioyield (breaking force per unit area). The average length of the tubers measured is in the range of 15.4 – 68.51 cm while the maximum and minimum thickness of the peel is 6.01 and 0.54 mm respectively. The peel reduces in thickness from the radicle towards the apex and the larger the diameter of the tuber, the thicker the peel. The highest and lowest values of the peeling force per unit area are 2248 kN/m^2 and 401 kN/m^2 respectively. It was observed that the peeling force per unit area increases as the cassava tuber slides along the cutting surface while it reduces with time of harvest of the tuber. This could be due to the deterioration of the tuber with time. The major, minor and intermediate diameters of the tubers determined are in the range of 3.00 – 10.35 cm, 2.15 – 10.05 cm and 0.87 – 6.04 cm respectively. The maximum bioyield force per unit area was 3880 kN/m^2 and minimum was 769.3 kN/m^2. All these are important in the design of the cassava peeling machine (Balami *et al.,* 2014).

3.3b Development and performance characteristics of a serrated cylinder cassava peeling machine

In this study, the development of a cassava peeling machine with serrated peeling mechanisms as well as a model to predict the performance of the machine was undertaken considering the earlier determined engineering properties of the common varieties of cassava tubers grown in Niger State, Nigeria, (Balami *et al.,* 2014; ASAE, 2003; Gupta and Das, 1997; Sahay and Singh, 1994). The developed cassava peeling machine (Fig. 6) is powered by a 1HP electric motor using a belt and pulley drive system.

Figure 6: Developed Serrated Cassava Peeling Machine
Source: Balami *et al., 2016*

The peeling mechanism which is a cylinder made up of stainless steel with serrated knives attached to its surface is rotated by the drive on the machine shaft initiated by the electric motor. This arrangement was housed in a stainless steel casing and supported by a frame tilted at 35° to the horizontal so that cassava tubers can glide easily and be discharged from the outlet of the machine. The variation in speed was achieved by varying the pulley on the driven shaft. A certain amount of pressure, which varies from 5 to 17 kN/m^2, on the cassava tubers was required for effective peeling. The machine can be used in small and medium scale cassava processing industries. The cost of constructing the machine is N125,000:00.

The machine has a capacity of 450 kg/h. The highest peeling efficiency of 89.5 % was obtained at an operating speed of 770 rpm, load of 17 N and tuber diameter 71-100 mm. The percentage of cassava flesh loss by the machine was 3.01 – 4.05 %. The models developed for predicting the percentage of peel removed and peeling efficiency are adequate and valid between the predicted and the observed values.

3.4a Engineering properties of Tiger nut seeds relevant to the design of cleaning and sorting machine

Despite the huge economic importance of tiger nut crop, the crop is yet to assume its full potentials (Birma, 2012). Therefore in this study, selected physical and frictional properties (size and shape, volume and density, surface area, weight, spherecity, coefficient of friction, angle of repose, as well as terminal velocity) of the brown type of tiger nut seed were determined using standard procedures (ASAE, 2003; Henderson *et al.,* 1997; Mohsenin, 1986; AOAC, 2002). The results of the physical and mechanical properties are presented in Table 6.

Table 6: The results of the Physical and Aerodynamic Properties of tiger nut seed

S/No.	Properties		Value
1	Mass of one piece of tiger nut seed		4.3×10^{-4}, g
2	Diameter	Major	9.01 mm
		Intermediate	6.80 mm
		Minor	5.26 mm
3	Density (ρ) of tiger nut seed		1.4×10^{-9} kg/m^3
4	Volume (Vm) of tiger nuts seed		0.6×10^{-6} mm^3
5	Moisture content of tiger nut seed		17 % (wb)
6	Coefficient of friction (μ) (wood; glass; metal)		0.37; 0.32; 0.26
7	Angle of repose of tiger nut seed		25.4°
8	Spherecity of tiger nut seed		74.39 %
9	Surface area of tiger nut seed		206.12 mm^2
10	Specific gravity of tiger nut seed		9.3
11	Terminal velocity of tiger nut seed		17.60 mm/s^2

Source: Balami *et al.,* 2014

These data are important for designing of cleaning and sorting machines of Tiger nut seeds.

3.4b Development of a Tiger nut cleaning and sorting machine

Based on the earlier determined engineering properties of tiger nut seeds relevant to the design of cleaning and sorting machine, a tiger nut cleaning and sorting machine was designed, constructed and evaluated. The developed Tiger nut cleaning and sorting machine (Fig. 7) basically consists of the hopper, sieves, frame, collector base, cam and camshaft, springs and belts and pulleys. A blower was also incorporated to facilitate easy and proper cleaning and separation of the nuts from foreign materials. The machine is operated by a 1hp electric motor.

The performance evaluation of the machine was carried out using the brown type weighing 50 kg at a moisture content of 17

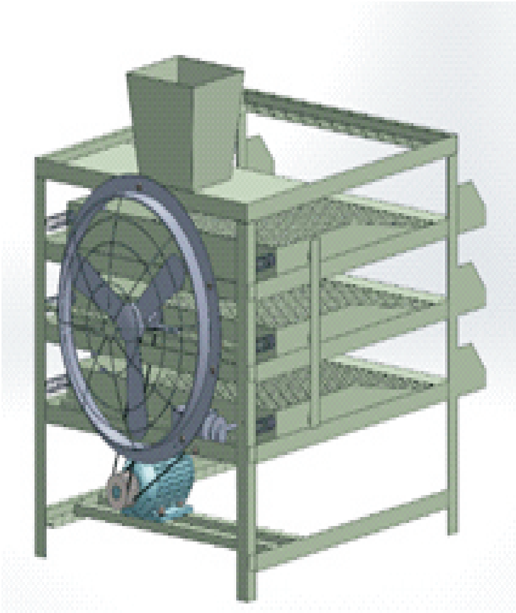

Figure 7: Developed Tiger Nut Cleaning and Sorting Machine

Source: Balami *et al., 2014*

% (ASAE, 2003; Donahue *et al.,* 1999) and sieves diameters of 12, 8 and 6 mm respectively. The developed machine has a throughput of 66 kg/h and a sorting efficiency of 94.7 % as against the manual sorting which has 13.2 kg/h throughput and 18.94 % sorting efficiency. The developed machine drastically reduces the drudgery involved in manual sorting and saves about 76 % operating time. Production cost of machine is N87,200:00.

3.5 Design, Modification and performance evaluation of a dibble for transplanting dry season sorghum *(Masakwa)* seedlings in Nigeria

The parameters considered in the design of the manually and tractor operated Sorghum (*Masakwa*) seedlings transplanting dibble (Machine) are as follows:

Distance between two adjacent rows and successive plant in row (i. e. inter and intra row spacing) (m), Allowable plant deviation from the axis of the row (m), Transplanting depth (cm) and Diameter of hole (cm), Quantity of water required in each hole (ml),Pressure kN/m^2 needed to penetrate the soil to a depth of 20 cm, Height of convenient holding position (mm), Water application and regulating device, Massey Ferguson MF 260 of 60 hp, Three point linkage (ASABE S217.12 DEC01 (ASABE ISO + 730 - 1:1994), Hollow square beam, Cylinder, Piston, Connecting rod, Actuator, Actuator support, Water tank (663 liters and has a weight of 650 Kg), Gusset plate, Dibble (9 in numbers) and Pipe, Machine area of 5 m^2 with area having dibble as 4 m^2.

The design is based on the wooden dibble. The wooden dibble, its measurement, modified manually and tractor operated dibbles are shown in Figure 8.

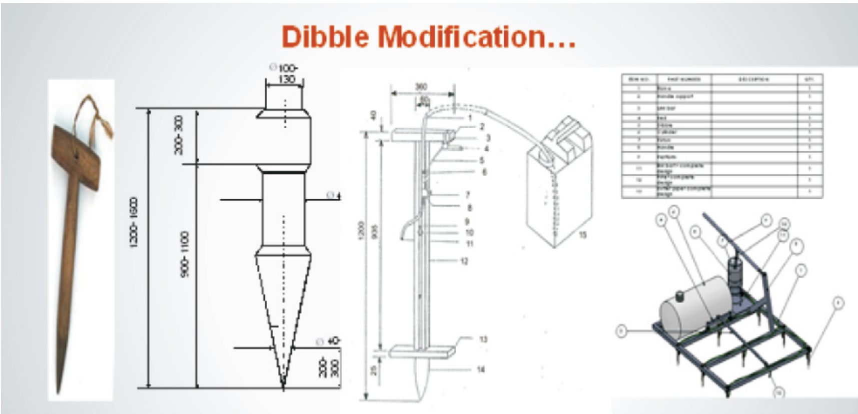

Fig. 8: (i)Wood Dibble; (ii) Dibble Measurement; (iii) Modified Dibble; (iv) Tractor Operated Dibble

***Source**:* BOSADP, 1998; Haque and Audu, 1998; Smekhounov, 1998; Balami and Zanna, 2005; ASABE, 2006; Dada, 2012; Balami *et al.,* 2012

Principle of operation of the Modified manually operated Dibble: Two persons usually work together as a team to carry out the job. One person carries the Dibble with the water device and digs the holes at an interval of about 100 to 120cm along and between the rows, while the second person put two seedlings into the hole. The holes are not covered with soil after transplanting the seedlings but just firmly pressed by foot.

Performance indices: The modified manually operated dibble could transplant a hectare within 40 - 42 hours as compared with the traditional dibble which transplant a hectare within 60 - 80 hours. The modified Dibble is 40% more efficient than the traditional. Production cost of machine is N7,650:00.

Principle of operation of the Tractor operated Dibble: The machine is basically operated through the tractor three point linkages, with the help of two persons, one driving and operating the pump while the second put two seedlings into the holes. At a speed range of 1 – 7 m/s and effective working time of 3.4 – 7 hours, a hectare (10, 000 holes) could transplanted.

Performance indices: Transplanting efficiency of the tractor operated dibble is 82% which is two times greater than the efficiency of the modified dibble.
The production cost = N95,000:00.

3.6 Development and optimization of a disc type peanut skin decorticating machine

The engineering properties used in the design of the Disc Type Peanut decorticating machine are as follows: Weight of 1000 seed (g/1000seed), Volume of 1000 seeds (mm^3), major, intermediate and minor diameters, AMD, GMD, SMD, ED (mm), Coefficient of friction (dec.), Bulk density (g/mm^3), Aspect ratio (dec.), Spherecity (dec.), Surface area (mm^2), Particle density (g/mm^3), Moisture content (%), Angle of repose (°) as well as Compressive load at break (N) of 3 varieties of shelled and unshelled Peanut (SAMNUT, 10, 11, 22).

The developed disc type peanut skin decorticating machine is shown in Figure 9. Production cost of machine N175,000:00.

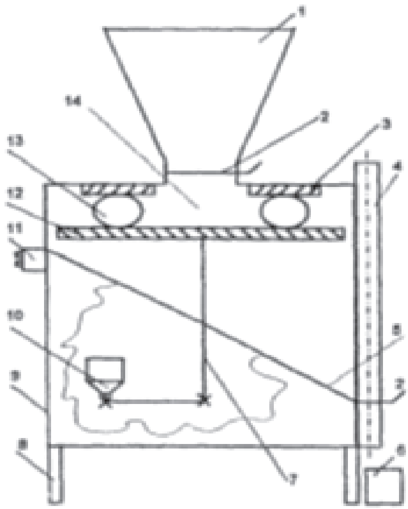

Figure 9: Developed disc type peanut skin decorticating machine

Source: Balami, 2007

Legend: 1 – hopper; 2 – dampers; 3 – upper disc; 4 – aspirating channel; 5 – tray; 6 – receiving box; 7 – turntable drive of lower disk; 8 – stand; 9 –frame; 10 – electric motor; 11 – switch; 12 – lower disk; 13 – peanut seed; 14 – tube.

Principle of operation: The disc type Peanut decorticating machine consists of two discs placed at adjustable distance from one another and powered by a 2 hp electric motor. Decortication of seeds occurs due to frictional and inertia forces and frictional forces created as the lower disc revolves against the upper stationery disc.

Performance indices: The machine has a throughput of 75 kg/h and maximum decorticating efficiency of 97.87% was obtained at optimal values of $n = 620rpm$, $z = 8mm$ and $p = 0.13Pa$ while the percentage coefficient of peanut kernel wholeness is equal to 17.62 %.

3.7 OTHER DEVELOPED AGRICULTURAL MACHINERY

NEEM SEED DECORTICATING MACHINE

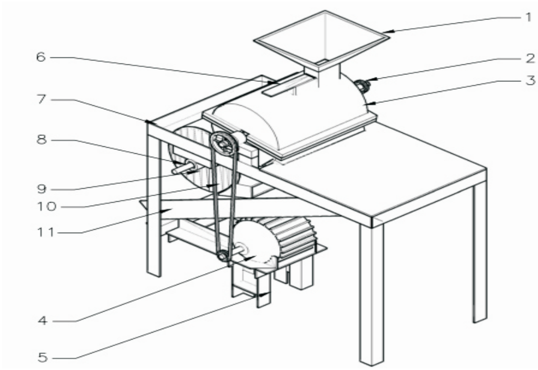

Figure 10: Developed neem seed decorticator

Source: Balami *et al.,* 2015

- The decorticator is powered by 2 hp electric motor.
- Production cost of machine = N59, 300:00.

Performance indices:

- Decorticating efficiency = 97.95 %
- Cleaning efficiency = 62.00 %
- Average blower loss = 2.56%
- Average undecorticated seeds = 2.43 %
- Average kernel recovery efficiency = 97.23 %.

COCOYAM PEELING MACHINE

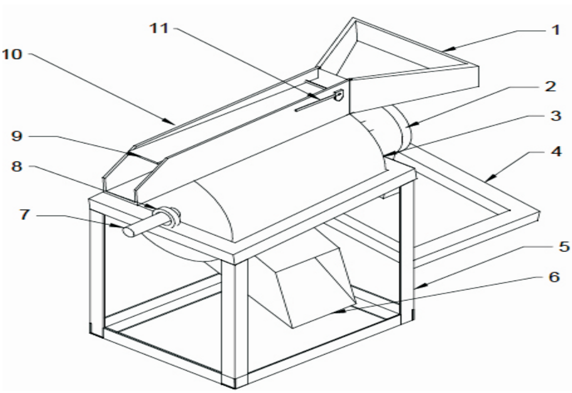

Figure 11: Developed Cocoyam Peeling Machine

Source: Balami *et al.,* 2016

- The machine is powered by 2hp electric motor through a V-belt.
- Production cost of machine = N48, 260:00.

Performance indices:

- Decorticating efficiency = 97.95 %
- Cleaning efficiency = 62.00 %
- Average blower loss = 2.56%
- Average undecorticated seeds = 2.43 %
- Average kernel recovery efficiency = 97.23 %.

RICE WINNOWING MACHINE

Figure 12: Developed Rice Winnowing Machine

Source: Balami *et al.,* 2012; Ogunlowo and Adesuyi, 1999

- The machine operated by 2 hp electric motor.
- Production cost of machine = N49, 050:00.

Performance indices:

- Separation efficiency of 92.11 %
- Throughput capacity of 115 kg/h.

MORINGA *Oleifera* SEED DECORTICATING MACHINE

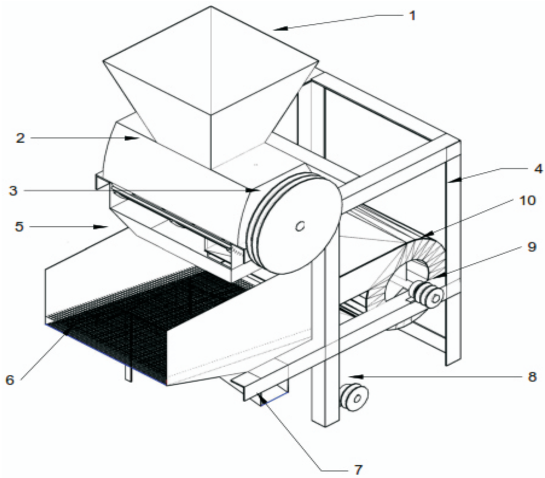

Figure 13: Developed *Moringa oliefera* seeds decorticating machine

Source: Balami *et al.,* 2015

- ➢ The machine is operated by a 5 hp electric motor.
- ➢ Production cost of machine = N65, 520:00.

Performance indices:

- ➢ The machine has a through put capacity 480 kg per day as against the hand decortication of 15 kg per day.
- ➢ Decorticating & cleaning efficiencies of 95.07 % and 92.20 % respectively.

ANIMAL FEED MIXING – PELLETING MACHINE

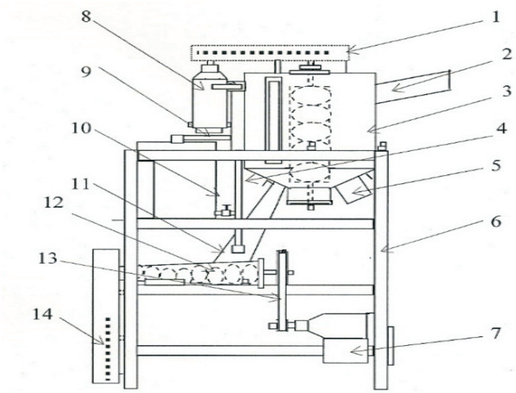

Figure 14: Developed animal feed mixer-pelleting machine

Source: Balami *et al.,* 2013

- The machine is powered by 5 hp electric motor.
- Production cost of machine = N47, 290:00.

Performance indices:

- Throughput of 60 kg/h.
- Mixing performance of up to 95.31% in 20 min &
- Complete evacuation in 9 min.
- Extrusion efficiency of 96.80 %.
- Machine can mix feed ingredients & then extrude pellets of different shapes (i.e. circular and bars) and sizes (5mm, 7mm, 20mm x 20mm and 40mm x 40mm).

CASTOR SEED DEHUSKING MACHINE

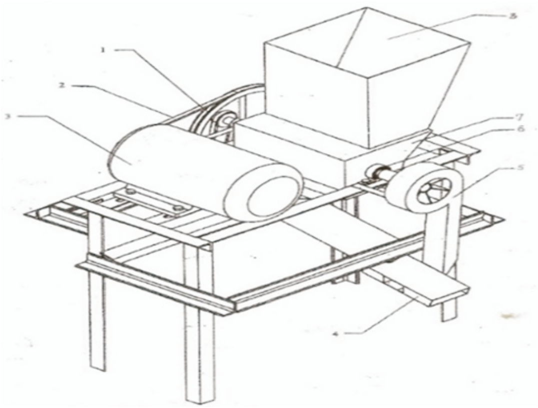

Figure 15: Developed Castor Fruits and Seeds Dehusking and Shelling Machine

Source: Balami *et al.,* 2012; Onyechi *et al.,* 2014

- The machine is operated by 1 hp motor.
- Production cost of machine = N52, 400:00.

Performance indices:

- Average shelling efficiency of 79.33 %,
- cleaning efficiency of 48.74 %,
- seed recovery rate of 99.6 %,
- Throughput of 895.8 kg/h,
- % losses of 0.40 %,
- Could reduce drudgery involved in manual shelling with saving in operating time of about 70 %.

4. Concluding Remarks and Recommendations

Engineering properties are the properties which are useful and necessary in the design and operation of equipment employed in the field of agricultural production and processing. They are also useful for design and development of other farm machinery. In handling of grains and other commodities the properties which play important role are physical, mechanical, frictional, rheological, aero and hydrodynamic, electrical and optical properties of the agricultural materials. Basic information on these properties is of great importance and help the engineers, food scientists and processors towards efficient process and equipment development. An attempt has been made to describe some of the engineering properties usually encountered in post-production handling of agricultural crops.

From the study conducted, it was deduced that:

1. The status of agricultural machinery development in Nigeria is deplorable despite Government's huge spending in implementing the various agricultural machinery development programmes.
2. Most of these programmes have been abandoned or neglected apart from the private sector driven which are struggling to survive under the harsh Nigerian developmental environment.
3. Most of the local agricultural machines manufacturers in Nigeria, rarely, put into **consideration the in-situ properties of agro-materials** when designing these machines.
4. Basic information on these properties are essential to design engineers, food scientists and processors towards efficient process and agricultural machinery development.

Undoubtedly, the problem of agricultural machinery development is great and is actually affecting the mechanisation of agriculture. The following are hereby **recommended** for efficient process and agricultural machinery design and development in Nigeria.

1. Agricultural machinery development policy should be an integral part of the general economic development policy of the country.
2. There should be proper funding and revitalisation of the government specialised agricultural development agencies.
3. Mandatory and proper consideration of in-situ properties of agricultural materials (engineering properties) in the design and manufacture of agricultural machinery in Nigeria as practiced by the developed manufacturing countries should be enforced.
4. Sufficient, easily accessible and interest free loan to indigenous private agricultural machinery manufacturing companies should be provided.
5. There should be proper synergy between researchers, industries and the end-users for better results.

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Finally, the audience, I will not forget to say thank you all for being here today to listen to me without which this gathering wouldn't have been possible.

Mr. Vice-Chancellor Sir, that is the Engineering Properties of Agro-Materials and their Links to Agricultural Machinery Design and Development.

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A Brief Profile Of The Inaugural Lecturer

Ayuba Audu Balami was born on 13th August, 1964 to the family of Late Audu Tapchi and late Mrs.Lami Mayadima in Shaffa, Hawul Local Government Area (LGA) of Borno State.

He had his early education in Shaffa Primary School now Shaffa Central Primary School, Hawul Local Government of Borno State. Thereafter, he was admitted into Government Technical School Benisheikh from 1978–1980 before moving to Yerwa Science Secondary, Maiduguri, Borno State. In the school he served as the class monitor and assistant house captain. He completed his secondary education in 1983.

He was admitted into Ramat Polytechnic, Maiduguri in 1983 and had his National Diploma in 1986 and worked briefly before gaining a scholarship to study in the USSR (Russia) in 1989. He graduated with Master Degree in Agricultural Engineering in 1995 and returned to Nigeria that same year. Upon his arrival to Nigeria, he got employed with the Department of Mechanical Engineering, University of Maiduguri as Assistant Lecturer and steadily rose to the position of Lecturer I in 2002. He joined the service of Federal University of Technology, Minna in 2003. In 2004 he got another opportunity for a scholarship still in Russia for his PhD study. He graduated in 2007 and came back that same year.

Among the awards received by him in his career are the following:

1. Bureau External Aid (BEA) i.e. a Bilateral Agreement Scholarship between Russia and Nigeria for B. Sc and M. Sc in 1989.

2. Bureau External Aid (BEA) i.e. a Bilateral Agreement Scholarship between Russia and Nigeria for PhD in 2004.

3. Certificate of Russian and French Languages in 1995; 2001 and 2007.

At the Federal University of Technology, Minna, he rose through the ranks and became a Professor of Agricultural and Bioresources Engineering in October, 2015. Professor A. A. Balami has held a number of administrative positions including Head of Agricultural and Bioresources Engineering Department (2009 - 2012).

He is a member of several professional bodies among which are Nigerian Institution of Agricultural Engineers (NIAE), Nigerian Society of Engineers (NSE), Council for the Regulation of Engineering in Nigeria (COREN) and American Society of Agricultural & Biological Engineers (ASABE).

He has published many papers in his area of specialization in both National and International Journals and has contributed a chapter in a textbook. Professor A. A. Balami has supervised several undergraduate, PGD, M. Eng. and PhD students and is still supervising many. He has served as External Examiner for both undergraduate and postgraduate to several Institutions. He has assessed many candidates for promotion to professorial ranks at many Universities. He has served as reviewer to several National and International Journals.

Prof. A. A. Balami is happily married and blessed with children.