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TRANSFORMATION OF FIELD TO FOOD MATERIALS: AGRO-FOOD PROCESS ENGINEERING APPROACH

By

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(Professor of Food Engineering)

DEDICATION

This inaugural lecture is **dedicated to**

the loving memory of my late very dearly dad:

Pa Timothy Adedeji ADEWUMI (Alias Baba Taden),

who passed away on Monday October 25th, 2011

at an age of 79 years (1932 – 2011).

TRANSFORMATION OF FIELD TO FOOD MATERIALS: AGRO-FOOD PROCESS ENGINEERING APPROACH

The Vice Chancellor, Sir,
The Deputy Vice-Chancellor (Academic),
The Deputy Vice-Chancellor (Development),
The Registrar,
Other Principal Officers of the University,
The Dean, College of Engineering,
The Dean, Postgraduate School,
Other Deans and Directors,
Heads of Departments/Units,
Other Members of Senate here present,
Distinguished Academic and Professional Colleagues,
Invited Guests and Friends of the University,
All members of FUNAAB Family,
All members of my Family, Friends and Well Wishers,
Gentlemen of the Press,
Distinguished Ladies and Gentlemen,
Great F*UNAABITE*.

1.0 INTRODUCTION

I am grateful to God today for the privilege to deliver the 36th

Inaugural Lecture of this great University, the 2nd Inaugural Lecture from the College of Engineering and the 1st from the Department of Agricultural Engineering titled, '***Transformation of Field to Food Materials: Agro-food Process Engineering Approach'***. I am indebted to my highly respected Vice Chancellor, Professor Oluwafemi Olaiya Balogun, the University Management and my Dean, Professor Samuel Adejuyigbe, for giving me the opportunity to present this lecture.

My choice of Agricultural Engineering was ordered by God through the guidance of a great academic father and grandfather, Prof. E. B. Lucas in 1981 when he encouraged me to select the course, while my choice of crop and food process engineering was guided by my academic mentor, Prof. Emeritus J. C. Igbeka, who was my academic supervisor at first and Master's degrees. My choice of Agricultural Engineering and specializing in food process engineering has taken me into the deep ocean of knowledge in science, agriculture, technology and engineering, which has spotted me out today by the mercy of God. The ocean of knowledge is indeed too deep and cannot be completely explored but the little we are able to acquire should be made relevant and useful to mankind.

I shall echo two common Yoruba songs related to this discussion to drive home the lessons and stimulate our appetite:

1. Ise agbe, nise ile wa
   Eni ko sise, a ma jale
   Iwe kiko, lai si oko, ati ada
   Ko'i pe o, ko'i pe o.

'Oko' (hoe) and 'ada' (cutlass), in this song, must be seen now as the state of the art engineering equipment to facilitate agricultural operations.

2. Ki isu to d' yan
   A gun isu lodo
   Ki agbado to deko
   A loo papo

The processing of yam to pounded yam and maize to pap, in this song, are simple age-long processing operations, representing complex and sophisticated agricultural processing systems.

These two opening songs give a traditional information and insight into the food chain. The first song identifies crop agriculture and the tools involved (i.e., engineering component) while the second song links crop agriculture (yam) with agro-food processing (transformation of yam to pounded yam, and maize to pap). Food chain includes and integrates all forms of agro-food production systems. The food chain starts with agricultural production system and includes harvest and post harvest activities (handling, processing, and packaging), added value component (such as food formulation) and the distribution and marketing of food materials.

'***Transformation of Field to Food Materials: Agro-food Process Engineering Approach***' is one of the main thrusts of my academic and professional career in the last 25 years. To ensure a good grasp of the issues of my discussions today, I shall endeavor to define the basic terminologies in the title of the lecture.

1.1 Field Materials

Field materials are raw agricultural materials from the farm. Field materials in the context of my discussion could be either of crop or animal origin. They are naturally rich in moisture and highly perishable. Except fruits and some vegetables, field materials cannot be consumed directly by human beings and are not readily digestible. They have to necessarily pass through some processes before they can be fit for human consumption. Examples include raw yam, cassava, beef, beans seed and melon seed.

1.2 Food Materials

Food materials are processed or transformed form of field materials that are near to consumption or readily consumable. They are digestible without harm to man. They could be in the near-final product form, requiring only minimal processing or in a readily consumable form. They must have undergone either primary or secondary processing or both. Examples include bread from wheat or cassava, extruded products such as indomie from cereals, poundo-flour from yam, bean powder or 'moin-moin' from beans seeds, condensed and powdered milk from raw cow milk,' suya' from raw beef and so on.

1.3 Transformation

This is a process that allows change of nature, phase or state of a matter. Several field materials are not in the consumable form by mankind because of the raw nature or the form in which they occur. They need to be changed or converted to food materials that are easily or readily digestible via biological, chemical, mechanical or physical means. The main concern of this lecture is the physico-mechanical means of transformation which involves a lot of engineering applications, especially agro-food processes. The engineering processes in the transformation may include separation, cleaning, size reduction, heat treatment, mixing, etc, and the forces/ energy involved may include mechanical, thermal or electrical.

1.4 Agro-food Process Engineering

Agricultural engineering is generally concerned with the application of scientific and engineering principles in solving all forms of agricultural problems and extends to the following areas of specialization (Oluka *et al*, 1999, Oduwole, 2006, Igbeka, 2010, Mijinyawa, 2011):

Farm Power and Machinery
Soil and Water Conservation
Agro-food Process or Post harvest Engineering
Farm Structures and Environment
Farm and Rural Electrification

Adewumi (2009) idenutified that agro-food process engineering has its applications in the following areas:

Engineering properties of biological materials
Drying of agricultural materials
Material handling technology
Agro-food packaging
Development of agro-food equipment
Process and production technology
Quality evaluation and control
Value addition
Agricultural and food distribution systems

Agro-food processing minimizes losses during the handling of agricultural and food materials. Agro-food losses up to 50% were recorded in Africa (Kazembe, 2005; Adewumi, 1998a). This is a serious threat to food security. Reduction of agro-food losses is achieved via techniques that ensure the reduction of moisture content of agro-food materials; effective storage and storage conditions; conversion of agricultural materials to stable and durable forms and value addition by effective processing.

2.0 AGRO-FOOD PROCESS ENGINEERING: HISTORIC AND PRESENT PERSPECTIVES IN NIGERIA

Adewumi (2009) explained that agro-food process engineering started in Nigeria with the use of traditional tools/ methods and indigenous knowledge. Fermentation technology, being an aspect of agricultural and food process engineering, was used extensively in the processing of cocoa bean, rice, locust bean ('Iru' – Yoruba, and 'Dawadawa' – Hausa), cheese ('Wara' – Yoruba), condiment and spices (like 'Ogiri' - Yoruba) and pap ('Ogi' or 'Eko' – Yoruba). Winnowing with air, thermal treatments via boiling, sun drying and evaporative coolant system using padded materials and pot in pot, practised locally, are all forms of indigenous practices of agro-food process engineering (Odunfa, 1982, Macmillan, 1999). Agro-food process engineering is applicable in various areas in local agriculture and food production, including photometric, aerodynamics, hydro-dynamics, rheology and storage (Adewumi, 1997a, b, 2005a; Adewumi *et al* 2001a, 2006a, b, Kurien *et al*, 1993).

The use of modern machine started in agricultural and food processing industries in Nigeria via the efforts of Cocoa Research Institute of Nigeria, Ibadan and the establishment of large scale food processing industries such as Cadbury, FANS, Peak Milk, Cocoa Industry Ltd. and Food Specialties, all located at Lagos, Lisabi Mills, Abeokuta and rice mills located in strategic areas all over Nigeria in the 1960s and 70s. Most of the equipment used by those large scale industries were imported and managed by foreign experts. Small and medium scale agricultural and food processing industries thereafter started in the 1980s and local manufacturers of machines for food products emerged in Nigeria (Jabagun, 1965; Faborode and Oladosun, 1991; Adewumi, 1997c, d).

In the mid 1990s, as the problems of economic recession became intensified, entrepreneurships in small and medium scale food industries drastically increased as a means of survival and the need to improve our locally produced machine became pronounced. Food processing industry in Nigeria is widely expanding in many areas and a wide variety of refined food items are now produced including fast food, chips, fruit juice/ beverage drinks, flour (cereal, legume, yam, cassava and starch flour) and so on (Adewumi, 2005a & b, Adewumi and Amusa, 2004; Adewumi and Adewumi, 2004).

The need for the use of precision machines and automation became essential as the food processing industry is expanding very fast. (Adewumi 2007a & 2008a). A few manufacturers such as Addis Engineering, Techno-equipment, Sahara Engineers emerged to address the problem of machinery for the food processing industry in Nigeria. The African Regional Centre for Engineering Design and Management (ARCEDEM), Ibadan and the Federal Institute for Industrial Research, Oshodi (FIIRO), Lagos were also established to address the problem. Food processing equipment such as gari fryer, baking machines, cold storage, thresher, milling machines, dryers, heat exchangers, oil extractors/ expellers, ovens, conveyors, and others were produced at commercial scale for small, medium and large scale industries (Ageh *et al*, 2005; Adewumi, 1998a; Olatunde, 2004; Sanni *et al*, 2006).

Agro-food process engineering has contributed immensely to the agricultural and food processing industries in Nigeria and the economic growth of Nigeria as a whole. Both the research institution and manufacturer of machines have contributed to the development. The research institutions have initiated researches leading to the development of machines and processes. Poor funding of the research institutions has incapacitated them from manufacturing. The best done in most research institution is to produce prototype for demonstration. A range of machines developed in some of the universities in Nigeria are reported (Ademosun *et a*l 2003, Ogunlowo *et al* 2005, Adewumi 2004a), and, a number of such machines are lying in the research institutions. However, a few manufacturers have appropriately liaised with research institutions and benefited from such relationships. This has led to improved production and quality products. Overall, the application of mechanized systems has resulted to increased production and nutritive value/ added value, and reduced unit cost of production.

Agro-food process engineering has a great potential and prospect in the Nigerian economy and can address the food security problems in Nigeria. Food process engineering had addressed a number of problems facing the food industry in Nigeria and contributed immensely to its growth. As food industries such as Mr Biggs emerged, it is becoming more evident that food industry has the capability to transform the economy of Nigeria.

3.0 MY CONTRIBUTIONS IN AGRO-FOOD PROCESS ENGINEERING

I have worked on the different aspects of agro-food process engineering, but I have mostly concentrated on the development of agro-food equipment for both plant and animal materials. In this lecture I hereby proceed to discuss my humble contributions in this area.

3.1 Development of Equipment for Processing Plant Materials

The development and use of simple machines for the processing of agricultural material is essential. This will not only enhance mechanized agriculture in the rural communities but improve income, and increase the commercial values and quality of the processed materials. I have been privileged to be involved in the development of machines for the processing of some cash and food crops, and fruits including cowpea, pigeon pea, kidney bean, locust bean, melon, cassava, cocoa, cashew, plantain, orange, pine apple and mango. These were the products of research-based designs. Those machines are peculiar for use in developing countries and shall facilitate rapid technological advancements if adapted. The machines for processing plant materials that I have developed so far are enumerated below:

3. 1.1 Equipment for the Measurement of Angle of Repose for Granular Materials

Pieces of information on the engineering properties of agricultural material are essential in the design of machines. In most parts of Africa, there is limited equipment for the measurement of the engineering properties of agricultural material. In an attempt to bridge this gap, Adewumi and Ayodele (1997) developed a device for the determination of the angle of repose for granulated agricultural materials. Fig. 1 shows the isometric view of the equipment. Angle of repose is a frictional property required for the design of hopper, storage structures, shear surfaces such as burr mill and impact members such as hammer mill (Michael and Ojha, 1987, Mittal, 1983). Angle of repose is equally related to coefficient of friction and the angle of internal friction.

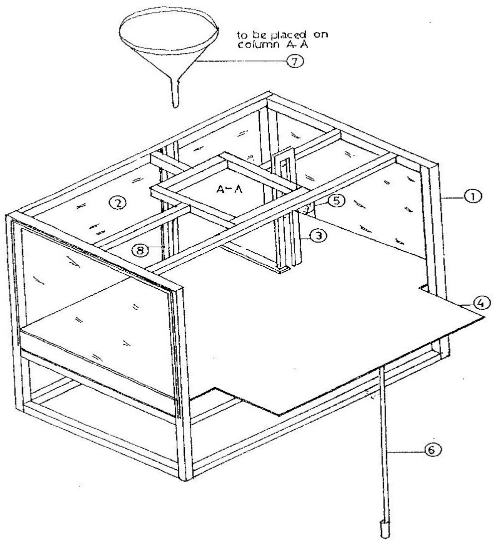


Fig. 1: Isometric View of the Angle of Repose Measuring Device

1. Frame; 2. Side glass; 3. Pointer; 4. Platform; 5. Scale; 6. Adjustable screw; 7. Funnel; 8. Metre rule

The performance of this equipment was compared with equipment used in standard laboratories and found to have a correlation range between 92 and 99.5% for static and dynamic angle of repose measurements on card board, wooden and metal surfaces at various ranges of moisture content (Adewumi and Ayodele, 1997).

The equipment was further used to determine both the static and dynamic angle of repose for wide range of granulated materials including cowpea, soybean, rice varieties, 'elubo', 'garri' and maize as data base for the design of related machines and advance studies on the physical and mechanical properties of agricultural materials (Adewumi 1996, 1997e). This equipment is also useful in the determination of other granular materials such soil and animal feeds. Empirical relationships were developed between the various parameters associated with angle or repose as reported in Adewumi (1997e)

3. 1.2 Equipment for the Measurement of Compressive Strength of Bio-materials

Mechanical or strength characteristics of agricultural materials are relevant in the design of machines, quality evaluation, packaging, transportation, handling and processing of food products. Compressive strength, impact and shear resistance are important parameters in the size reduction of cereals and legumes (Mohsenin, 1970, Mohsenin et al, 1978). The Instron universal testing machine is a standard equipment for measuring compressive strength but it is very expensive, in the range of N25 to N30 million Naira and only one or two of such machine is functional in Nigeria. Tensiometers, which are less expensive, could also be used to determine strength characteristics but the spare parts are not readily available.

Therefore, simple, cost effective equipment shown in Fig. 2 was developed for the measurement of the compressive strength of agricultural material and calibrated (Adewumi and Funmiluyi, 2001). It is made up of mechanical and electrical components including screw loading system, spring device, compression tool, plate, potentiometer, volt meter and frame. The potentiometer converts the mechanical input during compression to electrical signals obtainable on a volt meter. An empirical equation, ($F = bkV$) was developed during the study to convert the voltage readings, V, to compressive load, F, where b (mm/V) is the intrinsic characteristics of the potentiometer and k (Nmm^{-2}) is the spring stiffness. The compressive strength is obtained by dividing the compressive load by the surface area, A. The equipment was tested with rice, beans, maize and locust at a moisture content range between 10 and 13%. The equipment was calibrated with the aid of a tensiometer. A calibration curve was obtained from experimental data and calibration factor, λ, of 3.33 was obtained to standardize the equation obtained (Fig. 3).

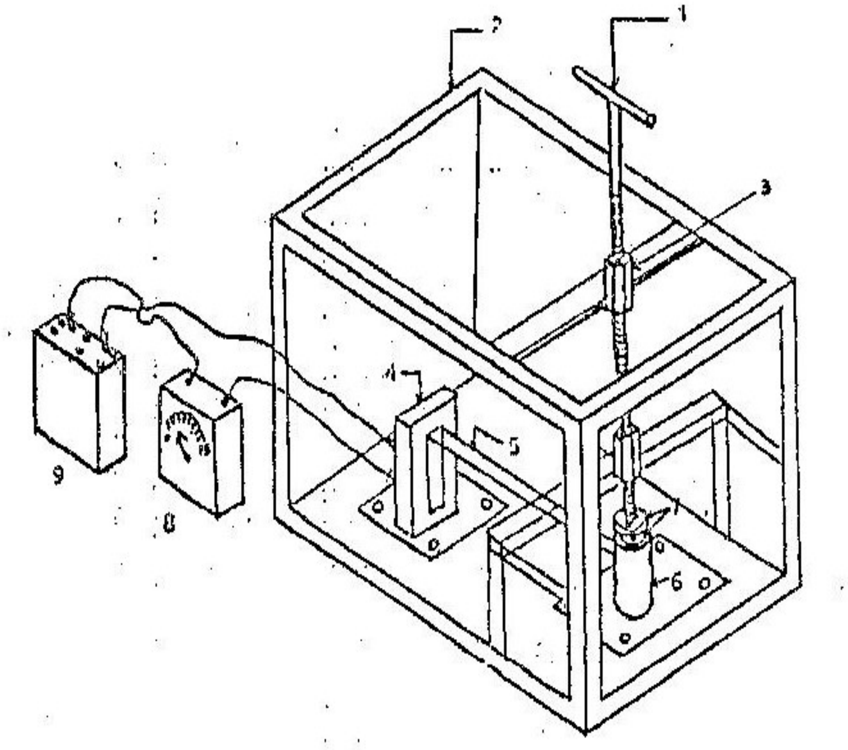


Fig. 2: Schematic Diagram of the Equipment for the Measurement of Compressive Strength

1. Screw Loading Handle; 2. Frame; 3. Nut; 4. Potentiometer; 5. Slider; 6.Spring Casing; 7. Compression Plates; 8. Voltmeter; 9. Variable Transformer

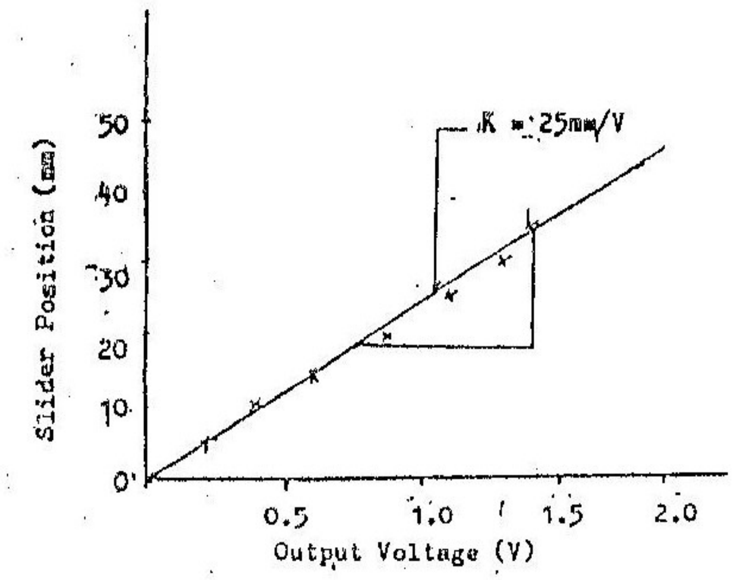


Fig. 3: Calibration Curve of the Equipment for the Measurement of Compressive Strength

3.1.3 Locust Bean Streaming Machine

Locust bean (Parkia biglobosa) is a leguminous tropical tree crop with a very high food, industrial and medicinal values. It is a raw material for the production of flavour, spices, and food condiments such as 'dawadawa' cube in Nigeria (Adewumi, 1997b). The gum extracted from the bean can be added to food cosmetics as thickners and emulsifier or made into sizes for textiles and leatherworks (Odunfa and Adewuyi, 1985; NAS, 1979). Odunfa and Adewuyi (1985) and Simonyan (2012) identified the various procedures involved in the local production of 'iru' or 'dawadawa' from locust bean seeds. Boiling of the seeds to soften the cotyledon takes a minimum of 12 hours with a resulting brownish black cotyledon.

Engineering procedures involved in the processing of locust bean include pod shelling/ threshing, seed polishing, dehull-ing, coat separation and cleanong, fermentation, drying, and so on (Adewumi, 1997a and Simonyan, 2012). Oni (1990) and Ajayi (1991), which were the earliest records found in litera-tures on the mechanization of locust, reported on the shelling related properties of locust pod and shelling machine respec-tively.

Adewumi and Igbeka (1993) in an attempt to further reduce the drudgery and time involved in iru production, and im-prove the quality of the product developed the first locust bean steaming machine (see Fig. 4). The machine is a batch type and can handle 19 kg of locust bean per operation. It is cylindrical with 3 distinct compartments namely the ash col-lection section, which is the lowest part, burner section and steaming section which has two units. The boiling of water to generate stream is done at the lower parts of the steaming sec-tion while the upper part contains the locust bean. The lower and upper parts of the steaming section are separated with a fixed screen.

The steaming machine softened the locust bean between 2 to 4 hours compared with 12 – 24 hours in local production. It eliminated traces of odour and improved the texture, flavor and color of the product. The bean maintained a more acceptable yellowish color at the end of the streaming process compared with the brownish black color in local production. Locust bean obtained from the steaming process had better dehulling characteristics with a record of 90% dehulling (Adewumi and Igbeka, 1993).

Fig. 4: Steamer Unit for Locust Bean (Charcoal fueled)

3.1.4 Burr Type Locust Bean Dehulling Machine

Dehulling or decoating is about the most tedious stage in the processing of iru. It is mostly done beside a river with cooked bean matched bare footed. The water source is to ensure the hulls are easily washed away.

A motorized burr type dehuller was developed for the dehulling of locust bean (Adewumi and Igbeka, 1996). This is also the first ever reported or documented dehuller for locust bean. The machine could operate effectively at an average feed rate of 0.69 kg/sec and powered by a 2 h.p, 1425 rpm electric motor. Efficient dehulling was recorded between the 3rd and 4th hour of steaming compared with the traditional boiling that takes about 12 hours to achieve any dehulling. When bean was steamed for 3 hours the percentage dehulling of 20%, 40%, 55%, 70%, 90% and 90% were recorded for dehulling spacing of 23mm, 18mm, 15mm, 12mm, 10mm and 8mm respectively.

3.1.5 Concave Type Locust Bean Dehulling Machines

Adwumi and Olalusi (1998) designed, fabricated and evaluated a manually operated concave type locust bean dehuller of 0.16 kW with a capacity of 20 kg/h (See Fig. 6). The machine recorded a maximum efficiency of 70.9% at a roller peripheral speed of 300 rpm, concave dehulling length of 240 cm and concave clearance of 8 mm.

Fig. 5: Motorized Burr Type Dehuller for Locust Bean

Further studies were carried out to model the performance of the machine (Adewumi, 2007b). Dimensional analysis was used to establish a model equation for predicting the relationships between the dimensionless hulling efficiency (h/M) and the dehulling stress (t), dehulling length (L), throughput (F) and dehulling speed (S). At constant concave clearance and dehulling length, the model equation developed is a linear form stated below:

$$\eta / M = k \left[\frac{\tau L^2}{FS} \right]^b \qquad \text{..} \quad \textbf{(1)}$$

Fig.6: Manually Operated Concave Type Dehuller for Locust Bean

Experiments were conducted using a manually operated concave–type dehuller to obtain the numerical value of the constants k & b for cowpea, soybean and locust bean. Using a log-log relationship, the index form of the model equation was transformed to a linear form and using regression analysis, the model constants (k and b) are 1.12 and -0.044 for cowpea, 0.15 and –0.042 for soybean and 1.21 and -0.013 for locust bean.

3.1.6 Hydro-cyclone for Separating Legume Hulls

Hull separation from cotyledons is normally down beside the river in local processing because of the volume of water required. Hydro-cyclone was developed for the separation of legume hulls (Adewumi 1997e, Adewumi *et al*, 2004a). The hydro cyclone developed for the separation of hulls from the cotyledons of locust bean was designed in accordance with Rietma's optimum design for classification. The cyclone has a diameter of 350 mm. It has a volumetric capacity of 0.034 m^3 and an inlet flow rate and power rating of 0.011 m^3/s and 0.60 kw respectively. The radical velocity of particles in the cyclone was calculated to be 0.09 rad/s. Separation efficiency of 66%, 37%, 65% and 68% was obtained for common bean, locust bean, soya bean and cowpea respectively.

Fig 7: Hydro cyclone for Separating the Hulls from Locust Beans

Adewumi *et al* (2000, 2007a) conducted further research on the testing and characterization of the hydro-cyclone for cowpea hull separation at an underflow orifice diameter of 20 mm. Parameters such as percentage mass recovery at underflow and overflow, separation efficiencies, flow rate, volumetric capacity, volume split, underflow-to-throughout ratio, pressure drop and separating force were determined for feed concentration range of 0.5 - 3.0%. The operating cut size of the hydro-cyclone was determined to be 3.50 mm. The grade efficiency curve and the full grade efficiency curve were predicted and plotted for the hydro-cyclone. The empirical constant, α, was determined and found to have a value of 1.40, indicating high overall performance efficiency.

Stepwise regression equations were developed to predict the relationship between hydro cyclone parameters. At 95% confidence level, the regression equations relating the total efficiency of separation and the separation force (F) to the operational parameters such as % mass recovery at underflow (F_{ru}) and overflow (F_{ro}), volumetric flow rate (Q_c), underflow-to-throughput ratio (R_f), volumetric split (S) and pressure drop (P_d) were generated for feed concentration range between 0.5 and 3.0, and stated in equations 2 and 3. The hydro cyclone performed best at feed concentration of 3% with a total efficiency of 82.2%.

$$E_T = -6.21\ Q_c + 7.16\ P_d + 1.65\ S + 1.93\ F_{ru} + 1.55\ F_{ro} - 109.10 \quad \ldots\ldots\ldots\ldots \quad (2)$$

$$F = 1.58\ Q_c - 1.96\ P_d + 0.46S - 2.63\ F_{ru} - 2.65\ F_{ro} + 263.79 \quad \ldots\ldots\ldots\ldots \quad (3)$$

3.1.7 Plantain Slicing/ Chipping Machine

Plantain is a major tropical crop consumed worldwide. It is essential to develop machine that can minimize the drudgery involved in plantain chapping, enhance plantain drying and storage, and improve the quality of processed plantain product for both local and international market. Adewumi (2007c) designed and fabricated a manually operated machine was for chipping plantain (see Fig. 8).

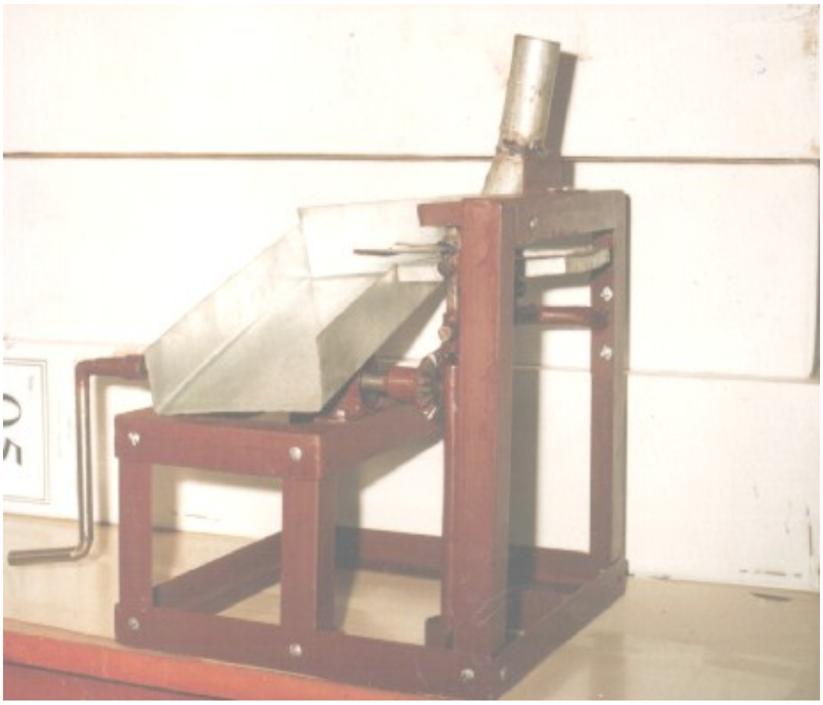


Fig. 8: Picture of the front view of the manually operated plantain chipping machine

Experiments were conducted to model the performance of the machine. The crop parameters varied during the experiments include plantain diameter or size (X_1), plantain ripeness (X_2) and chip thickness (X_3). The performance characteristics of the machine (Y) monitored includes machine capacity (Y_1), machine efficiency (Y_2) and percentage chips loss (Y_3). The machine was operated at a speed of 96 rpm and the number of cutting blade was varied, using 3, 4 and 6 blades. Stepwise multiple regression analysis was used to study the effect of the crop parameters (independent variables) on the machine performance characteristics (dependent variable). For the various cutting blades used for the study, the regression equation developed is of the form:

$$Y = k_1 X_1 + k_2 X_2 + k_3 X_3 + C \quad \ldots\ldots\ldots\ldots\ldots.. (4)$$

It was found that chip thickness had the strongest effect on machine capacity. Machine capacity increased with increasing chip thickness. Plantain ripeness had significant effect on the machine efficiency whereas plantain diameter does not have effect on machine efficiency for all blades. The percentage of chip loss was mostly influenced by the level of ripeness of plantain but not affected by plantain diameter. Percentage chip loss increased with decreasing plantain ripeness. Highest machine capacity of 382.7 kg/h was recorded for fully ripe plantain with big size (40 – 50 mm diameter) and chip thickness of 15 mm. A maximum performance efficiency of 100% was recorded for 15 mm thickness chips and fully ripe plantain. The highest value of percentage chip loss of 57.1% was recorded for unripe, medium size plantain while a least value of 0.0% was recorded for fully ripe plantain.

A motorized version of the plantain chipping machine with only one cutting blade was recently developed by Adewumi *et al* (2011a), as shown in Fig. 9.

Fig. 9: Picture of the Motorized Version of the Plantain Slicer

Highest machine capacity of 451.39 kg/hr was recorded for fully ripe plantain for 15 mm slice thickness. Maximum performance efficiency of 97.25% was recorded for fairly ripe plantain. The highest value of percentage chip loss of 15.14% was recorded for unripe, medium size plantain while a least value of 0.53% was recorded for fully ripe plantain. The performance of this machine is improved over the manually operated version event with a single blade arrangement. With more blades, the machine capacity shall definitely increase.

3.1.8 Cocoa Depoding Machine

Cocoa is a major tropical cash crop used as major raw material in beverage and cosmetic industries. Nigeria, Ghana and Cot De Voire are major producers and exporters in Africa. Depoding is a major primary processing required to obtain the bean from the pod. In order to reduce the rigor faced by local farmers in the depodding process, a manually operated impact -type machine for breaking cocoa pods was designed, fabricated and tested (Adewumi and Fatunsi, 2006). See Fig. 10. The machine was designed to be capable of breaking up to five (5) pods at once.

The pods used for evaluating the performance of the machine were classified into small (5.00 – 6.40 cm), medium (6.50 – 8.00 cm) and big (8.10 – 9.60 cm) sizes according to the dimension of their mid-diameters.

Fig. 10: Picture of the Manually Operated Cocoa Depodding Machine

The machine was tested using 1 to 4 pods per loading. The parameters measured for evaluating the performance of the machine include the average number of hammer drops/falls required to break the specified number of pods, time required to break the pods, number of broken pods per operation, machine capacity, percentage bean damage and machine functional efficiency. The machine had less than 1% seed damage with its efficiency and capacity ranging from 93 to 100% and 377 to 738 kg^{-1} respectively. The best results of 0.34% seed damage, 738 kgh^{-1} capacity and 100% efficiency were recorded for two big pods of cocoa loaded at once. The machine is easy to fabricate, assemble and maintain. It is affordable to peasant cocoa farmers with the production cost being less than twenty thousand Naira (#20,000.00), less than one hundred and fifty dollars ($150.00).

3.1.9 Cashew Decorticator

Cashew is an economic cash crop prominent in the world market. Almost all the parts of the crop are useful. The apple is edible and rich in vitamins A, B and C (Mandal, 1992). The shell, bark and leaf have medicinal values. The nut is used in confectionery and bakeries, and in the production of cashew butter.

Adewumi (2000a) designed, fabricated and evaluated a simple, low cost manually operated machine for decorticating or shelling cashew seed (See Fig. 11). The major components of the machine include a frame, cutting handle, splitting handle, springs, and cutting blades. Steamed cashew seeds were used to test the machine. The seeds were classified into five size grades with mean lateral dimension of 2.33, 2.61, 2.85, 3.23 and 3.28 cm respectively. The beans were steamed for one hour and samples were collected for test at 20 minutes interval. The performance of the machine was compared with hand shelling using parameters such as shelling capacity (C), shelling efficiency (h) percentage broken nuts (B) and percentage unshelled seeds (S).

The values of C, h, B and S for the machine ranged from 194-309 nut/hr, 70-95%, 7-32% and 0-10% respectively while the respective values for hand shelling are 25-90 nut/hr, 20-60%, 44-67% and 10-40% (Adewumi, 2004b). It was observed that the performance parameters (C, h, B and S) of the machine were influenced by the size of seed and steaming period. Stepwise multiple regression analysis was employed to establishing the relationship between the performance parameters (dependent variables), and the size of the seeds and steaming period (independent variables), and a number of empirical relationships were developed.

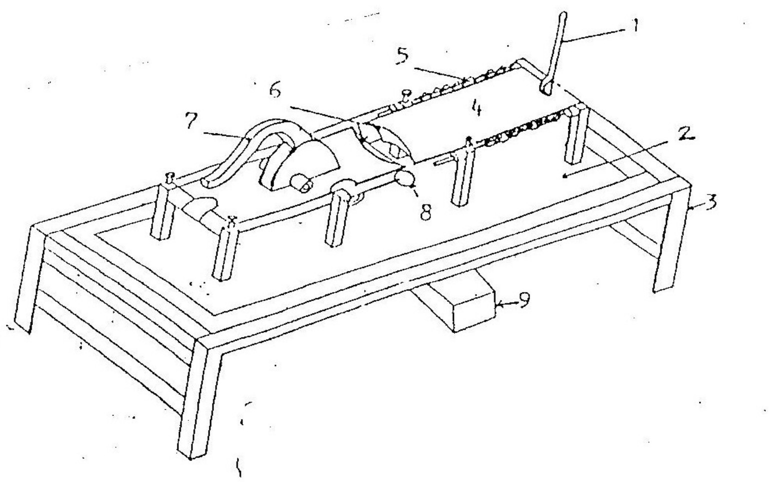


Fig 11: Isometric View of the Manually Operated Machine for Decorticating Cashew Seed

1. Pusher; 2. Machine plateform; 3. Furnace; 4. Cutting blade; 5. Helical spring; 6. Cutting edges; 7. Splitting handle; 8. Delivery outlet; 9. Delivery chute

3.1.10 Melon Sheller

Melon is a protein-rich seed of great importance in the Nigerian diet. The conversion of melon seeds to eadible forms is impossible without shelling and separating the endocarp from the cotyledon. The manual method of shelling by hand is tedious and time consuming. The production of melon products such 'robo', 'ogiri' and vegetable oil could be drastically increased by introducing mechanical system.

Adewumi *et al* (1999) reported the design of a disc type sheller incorporating a cleaner unit. The shelling unit is made up of a disc mounted on a vertical shaft (See Fig. 12). The fan unit requires a total drag force of 112.7 N to separate the endocarp from the cotyledon. The machine shells by the combine effect of centrifugal and frictional forces. The shelling and cleaning units require 1.148 kW and 0.220 kW power respectively to operate. The shelling unit was tested with a 1.1 kW, 1420rpm electric motor. The machine has a through put of 322 kgh^{-1} and 2% seed breakage at a moisture content of 8.4%, wet basis. The machine has a higher throughout compared with the melon sheller reported by Odigboh (1979) with a throughput of 145 kgh^{-1}. It also has a lower % breakage. It is recommended to small and medium scale industrialists involved in the production of vegetable oil from melon seeds.

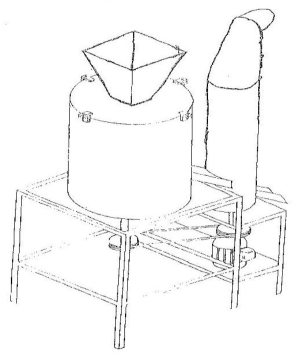


Fig 12: Isometric View of the Melon Sheller

3.1.11 Cassava Chipping Machine

Cassava is the seventh most important crop of the world and contributes a staple food for 800 million people, about one-eighth of the world's population. (FAO 1987, IFAD 1996, IITA 1996, IITA/UNICEF 1990). It is used in Africa to produce food items such as 'garri', 'fufu', 'lafu'. chips, tapioca and cassava flour for industrial uses. It is also used as raw material for animal feed production and in the production of goods such as paper, adhesives, drugs, cosmetics and explosives. Nigeria is a leading country in cassava production worldwide (Igbeka *et al*, 1992). The increased utilization of cassava and the international focus on cassava resulting in high demand for chipping machine in Nigeria indicate that there is the need for local production of cassava chipping machines (Horn and Ofon, 1991).

Therefore, a study was initiated to improve on the design of an existing cassava-chipping machine so as to produce a commercial model with an improved efficiency, at affordable cost (Adewumi *et a*l, 2005). The modified version of cassava-chipping machine (see Fig.13) requires a maximum torsional moment of 41.96 Nm, shaft diameter and length of 30 mm respectively and 620 mm, chipping disc thickness of 6 mm and 2 kW power to operate.

Fig. 13: The Modified Cassava Chipping Machine

It was tested with an electric motor at speeds of 300, 411 and 514 rpm. The three axial dimensions (length, thickness and width) of the chips produced were measured for the selected speeds. The skewness and kurtosis of the axial dimensions were determined in order to assess the normality of the distribution of the dimensions of the chips. Analysis of variance at 95% level of confidence showed a significant difference in the length of the chips with a speed 514 rpm producing the longest chips of a mean length of 33.90 mm. While there was no significant difference in the width of the chips at speed of 300 and 514 rpm, a speed of 411rpm showed a significant difference, producing wider chips with mean width of 17.44 mm. The machine had a maximum capacity of 148 kg/hr at 514 rpm and maximum chipping efficiency of 91.26% at a speed of 300 rpm. However, for optimum performance, a speed of 411 rpm with chipping efficiency of 89.88% and chipping capacity of 112.08 kgh^{-1} is recommended.

The advantages of the modified chipping machine over the existing one include the following:

1. Elimination of the accumulation of crushed cassava in the inner corners of the chipping chamber.
2. Elimination of the losses of chips as a result of back flow through the hopper.
3. Easy collection of chips.
4. Improved efficiency.
5. Reduced thickness of the chips. Hence improving the drying rate and quality of chips.
6. Reduced crushed or grated materials.

3.1.12 Citrus Juice Extractor

Adewumi (1999) designed, fabricated and tested a fruit juice extractor for citrus. The machine has a power requirement of 1.17kW and is operated by a 1420 rpm electric motor. Fig. 14 shows the picture.

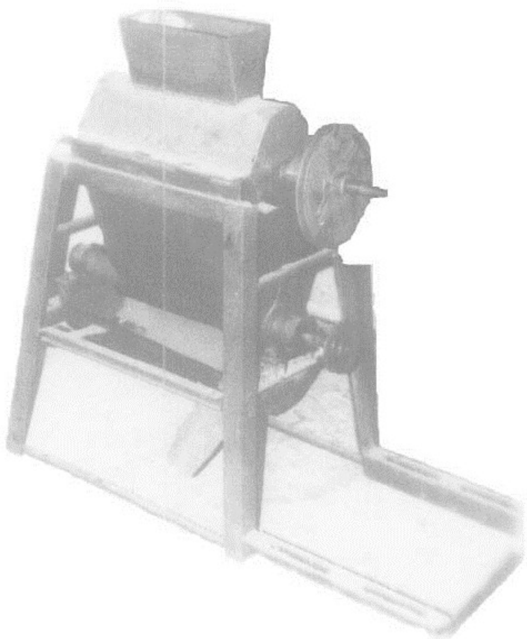


Fig 14: Fruit Juice Extraction Machine

The extraction capacity and extraction efficiency of the machine were determined to evaluate the performance of the machine. The machine has an average juice extraction capacity of 5.11 and 2.79 kg/hr for orange and grape respectively. It equally has an extraction efficiency of 78.78 and 75.66% for orange and grape respectively. For orange juice extraction, the extraction capacity of the machine was found to be 280% of the manual extraction method and 304% of the value obtained using the domestic extraction cup. For grape juice extraction, the extraction capacity of the machine was 220% of the manual extraction method and 180% of the value obtained using the extraction cup.

The machine was further modified and the tapered auger was replaced with a straight auger. The modifications resulted in an increase in the juice extraction efficiency of the machine from 78.9 to 89.2% and juice extraction capacity from 5.1 to 15.8 kg/h for sweet orange (Adewumi 2007d). The fruits were reduced to uniform sizes and the effect of fruit size (thickness) and shaft speeds were studied with respect to machine juice extraction efficiency and capacity using regression analysis. Fruit thickness of 20, 40, and 60 mm and shaft speeds of 300, 400, 500 and 600 rpm were used for the test.

Juice extraction efficiency and capacity showed very strong quadratic relationships with speed for the 3 sizes of pineapple and orange fruits studied. The exception was apple of 60 mm thickness which exhibited a very strong linear relationship between shaft speed and machine capacity. The relationships among various parameters were established and the optimum speeds for peak performance of the machine at various fruit thicknesses were also recommended.

3.1.13 Mango Juice/ Pulp Extractors

Nigeria is a leading country in Africa in fruit production, especially mango (FAOSTAT2002). But, because of the high perishable nature of mango, like other fruits, it is mostly available readily only during the harvest period. Juice and pulp could be extracted from mango. When mango is not properly soften, it is advisable to extract the pulp, either to eventually extract the juice, can or use the pulp for other end uses such as salad, puree, nectar, squash, jam, jelly, chutney, and dehydrated products.

Adewumi and Ukwenya (2012) designed and fabricated an extractor for the juice and pulp of mango fruit. The machine is made up of a main frame, the hopper, anger, extraction unit, shaft, juice outlet, belt & pulley, bearing, top cover and the machine frame. The shaft of the auger has a diameter of 18 mm. The auger has a pitch of 8.8 cm. The extractor requires a power 1.42 hp. Fig. 15 shows the isometric view of the extractor. The production cost of the extractor is less than fifty thousand Naira (N50, 000. 00).

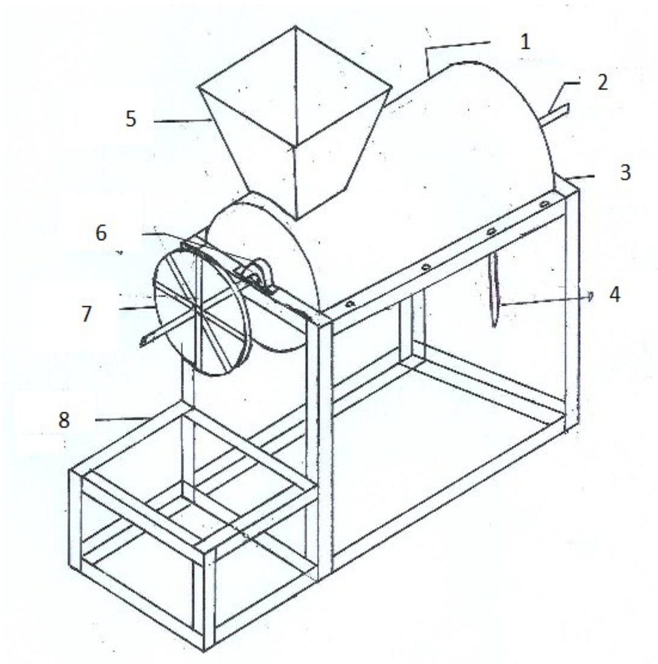


Fig. 15: The Isometric View of the Mango Extractor/ Pulping Machine

1. Extraction chamber top cover; 2. Machine shaft; 3. Machine frame; 4. Juice outlet; 5. Hopper; 6. Pillow bearing; 7. Machine pulley; 8. Electric motor seat

Juice extraction efficiency, juice extraction capacity and thorough-put of machine were determined at a speed of 300, 600 and 900 rpm. The highest juice extraction efficiency of 76 % was recorded at shaft speed of 300 rpm. The highest juice extraction capacity of 26.67 Lh^{-1} was recorded at shaft speed of 900 rpm. Also, highest thorough-put value of 14.36 g/s was recorded at shaft speed of 900 rpm. The study established linear relationships between shaft speed and juice extraction efficiency, juice extraction capacity and thorough-put of the machine.

3.1.14 Vegetable Oil Extractor

Adewumi et al (2012) reported the design, fabrication and evaluation of an oil extractor powered by an hydraulic press for decorticated groundnut seeds. It is made up of piston, cylinder, collector, hydraulic jack and frame (see Fig. 16). The extractor unit was tested using press cage with pore diameters of 3, 4 and 5 mm and cage diameters of 5.2, 7.9 and 10 cm. Whole and ground groundnut seeds (Kampala variety - *Sam nut-10*) were used for the evaluation of the machine performance. Results obtained showed that pore diamer of 3 mm gave the least oil yields of 21.2 and 23.6%, for whole and ground seed respectively at cage diameters of 7.9 cm. Pore diameter of 4 mm gave an oil yield of 23.0 and 26.9 % while that of 5 mm gave 23.0 and 26.2%; for whole and ground seed respectively with no significant difference ($p\leq 0.05$). Similar trend was observed for the extraction efficiency and machine capacity where the values increased sharply as pore diameter increased from 3 to 4 mm but decreased with a further increase from 4 to 5 mm.

Fig. 16: Picture of the Hydraulic Oil Extractor Showing the Cage Casing and Discharge Chute

The increase in cage diameter from 7.9 to 10 cm resulted in a decrease in oil yields from 23.02 and 26.87 % to 21.74 and 24.08; for whole and ground sample respectively. Maximum extraction efficiency of 79.02 and 84.22 % was recorded for diameter 5.2 cm at pore size of 4 mm for whole and ground seed respectively, while cage diameter of 10 cm gave the lowest value of 39.80 and 44.09 % for whole and ground seeds respectively. The highest machine capacity of 0.978; 1.084 kg/hr (for whole and ground seeds respectively) was obtained at cage diameter of 10 cm. Analysis of variance showed that cage diameter had a significant effect ($P>0.05$) on all the parameters evaluated. For all pore size and cage diameter except cage diameter of 7.9 cm, material type (whole and ground seed) do not have significance effect on oil yield, extraction efficiency and machine capacity.

The combined effect of pore size and cage diameter for oil yield, extraction efficiency and machine capacity showed that, pore diameter had a positive relationship with the machine performance and negative relationship cage diameter. Stepwise regression model of quadratic form stated in equation (5) below was best fitted to predict the oil yield (Y_1), extraction efficiency (Y_2) and machine capacity (Y_3) with pore size (X_1) cage diameter and (X_2) as the independent variables.

$$Y^n = a+bx_1 + cX_2 \qquad (5)$$

3.1.15 Charcoal Fueled Garri Fryer

Garri is a fried product from fermented and sieved cassava mash. It is one of the commonest stable products from cassava uses as staple food in Nigeria. In the traditional processing of cassava to garri, the frying stage is tedious, time consumingg and exposes the processors, mostly women, to excessive heat.

Adewumi and Owolaralarafe (2012) developed a manually operated, charcoal fueled garri frying machine. It is made up of the mechanical and burner units, both supported by a frame. The mechanical unit consists of the hopper, shaft, semi circular trough, paddles, turning handle, out let chute and bearing. The semi circular trough and shaft are inclined for easy discharge of the garri. The burner unit is made up of the combustion chamber, which houses the charcoal and the ash collection chamber. Fig. 17 shows the isometric view of the machine. The fryer was designed such that 2.32 kg of charcoal can burn for up to 2 h per batch. The machine was tested using 1.0, 1.5 and 2.0 kg of sieved cassava mash and it was found that an average of 15.0, 19.3 and 20.7 mins are required respectively to fry the mash from 37% moisture content to 17.5%. The machine has a capacity range between 4.66 and 5.89 kgh^{-1} and functional efficiency of 63%. Research is ongoing on the motorized version of the machine.

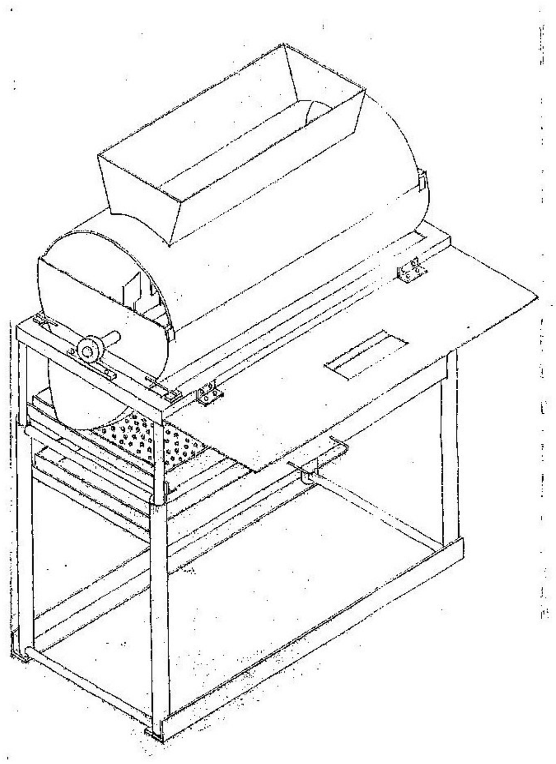


Fig. 17: The Garri Frying Machine

3.1.16 Cashew Nut Shell Liquid (CNSL) Extractor

Cashew Nut Shell Liquid (CNSL), which is one of the products from cashew seed, is phenol rich oil with a high economic value and wide industrial uses. It is used as raw material in automobile, pharmaceutical, paint, petrochemical and wood processing industries. A simple, low cost manually operated machine for the extraction of CNSL was developed (Adewumi, 2000c and 2004a). See Fig. 18. The machine has a capacity of 35.8 kgh^{-1} and could produce up to 90 kg of raw and concentrated CNSL per 8 hrs working day. The maintenance of the machine is equally easy. The machine which is affordable could be introduced to cashew farmers, the unemployed masses, and the small scale industry.

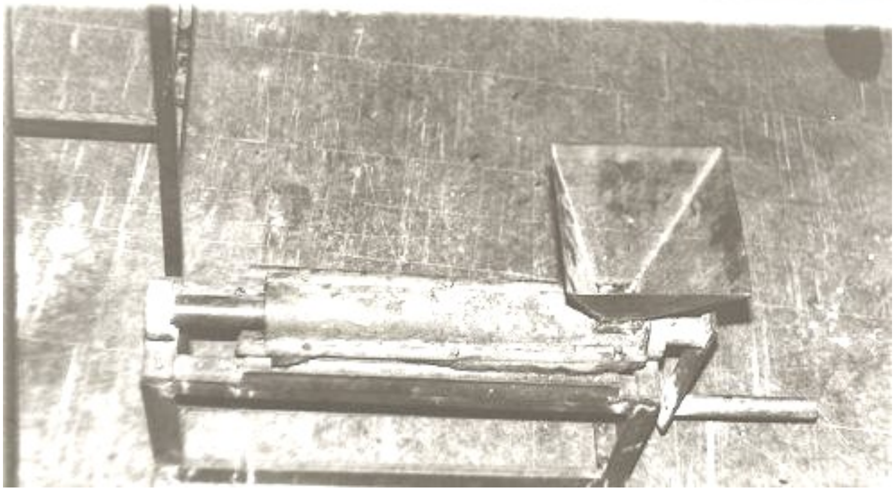


Fig 18: Manually Operated CNSL Extractor

A large model of the machine, which is motorized, was developed for medium scale industry and is being subjected to testing for industrial use (Adewumi, 2012). This could stir up interest and boost the production level of cashew seed within the nation, improve the economic value of the crop, enhance the development of related industries and alleviate poverty in the nation.

3.1.17 Medium Scale Legume Thresher/ Cleaner

Adewumi *et al* (2007a) developed a medium scale thresher-cleaner with a conveyor, thresher, fan and cleaning units (see Fig. 19).

Fig. 19: Legume Thresher/ Cleaner

The machine required 3 kW power and floor area of 1.16 m^2. The inclined flight conveyor has a maximum capacity of 350 kg/h and moves the material through a height of 2.2 m. It requires a maximum of 650 W for its operation. The threshing unit is axial flow type. It requires a power of 1.25 kW and a concave clearance of 28.2 mm, concave diameter of 46 cm and concave length of 99.8 cm. The threshing drum has a diameter of 18 cm with a thickness of 3 mm and length of 99.5 cm. The centrifugal fan requires a maximum of 787 W to clean threshed product discharged into it at 3.69 kg^{5-1} Fan pressure and air flow rate are 843.30 N/m^2 and 3.25 m^{35-1}, respectively.

The machine was subjected to preliminary test using cowpea ('Ife Bimpe' variety) at pod moisture content of 14.0 to 22.0%, conveyor speed of 400 rpm, threshing speed of 600 rpm, fan angle of inclination of 900 to 120^0, fan speeds of 900 and 1500 rpm and a concave clearance of 20 mm. The conveyor efficiency ranged from 56.9 to 74.0%, 53.2 to 73.9% and 60.1 to 79.1%, for pod moisture content of 14.0, 18.0 and 22.0%, respectively with mean values of 64.6, 67.2 and 70.3%, respectively. The threshing efficiency was 67.5 - 97.7%, 77.1 - 94.4% and 83.1 - 97.0% with mean values of 83.4, 86.7 and 84.4%, respectively for same moisture content. The cleaning unit has an effectiveness of 98 to 100%.

3.1.18 Cross Flow Grain Classifier

In order to promote research in aerodynamics and particle dynamics studies in agriculture, Adewumi *et al* (2007b, 2011b) developed a test rig shown in Fig. 20. The rig is made of the blower, separation/cleaning and collection units. The cross flow classifier is made flexible such that many parameters including grain inlet velocity, feed rate, air speed, feed height, drop height, angle of inclination of blower and angle of inclination of deflector/ guide plates can be varied. The essence and applications of particle dynamics studies are emphasized in Adewumi, 2011, Adewumi et al, 2006a, b & c. A theoretical model was developed to aid the design of the classifier (Adewumi 2008c, Adewumi et al, 2006d). Velocity profiles and distribution patterns of grains can be determined with the classifier (Adewumi, 2008d, Adewumi *et al*, 2007c). Typical experimental set up for such studies is shown in Fig. 21. The combined use of the aerodynamic model and the cross flow classifier has proved the possibilities of adapting a pneumatic system solely for performing five unit operations simultaneously namely separation, cleaning, sorting, grading and destining (Adewumi, 2006f, 2011b). This will not only reduce space but also reduce cost and improve efficiency.

Fig. 20: The assembly of the cross flow test rig with the feed hopper (without the collection trays)

3.1.19 Aerodynamic Modeling and Particle Dynamics Studies in Agriculture

Pneumatic separation is an age long means of removing light materials from grains, with winnowing as a typical example. I have been able to utilize the knowledge and applications of the science of aerodynamics and particle dynamics to improved the performance of pneumatic separators. I have utilized the understanding of the interaction/ interplay between parameters such as drag force, terminal velocity, Reynolds number, bulk ratio, and the physical properties of grains to assist in solving the complex problems associated with dynamics of grains and particles in moving air (Adewumi, 2011).

Fig. 21: A typical arrangement for an horizontal air flow experiment using high speed camera

Pneumatic separators/cleaners are basically of two types, namely, the vertical air stream and horizontal air stream types (Gorial and O'Callaghan, 1991a & b). In the vertical air stream separator, air stream is flowing vertically against the injected mixed product such that heavy particles (grains) drop through the air (counter current flow) while the light materials (chaff) move upward and are carried away by the air (concurrent flow). In the horizontal air stream separator, air is blown horizontally or at an inclined angle to the horizontal against mixed product injected along the vertical plane. The particles in the mixed product are displaced along the horizontal plane at various distances based on their aerodynamic properties (Gorial and O'Callaghan, 1991b, Adewumi *et al.*, 2006c).

A lot of literatures are available on the aerodynamic theory of separation of threshed material in vertical air stream (Uhl and Lamp, 1966; MacAuly and Lee, 1968; Rumble and Lee, 1970; Jiang *et al*, 1984; Misner and Lee, 1973; Gorial and O'Callaghan, 1991a, Ogunlowo and Coble, 2000). Only few literatures are found on the aerodynamic theory of particles in horizontal air stream (Gorial and O'Callaghan, 1991b).

Aside developing legume thresher/ cleaner and the grain classifier for aerodynamics studies, my major contribution in the theoretical and experimental studies on aerodynamics in agriculture is the development of a 2-Dimensional trajectory model for particle fall in a horizontal air stream. This model is useful for the selection of the dimensions of cross flow classifier (Adewumi *et al.,* 2006d). The 2-Dimensional model in y and x directions is stated in equations 6 and 7. These equations were solved numerically using program written in Fortran 77. The numerical solution involves iteration at 0.01

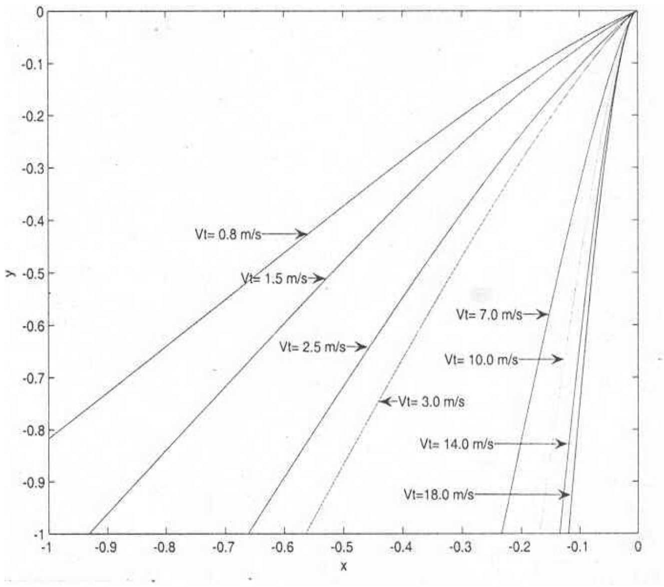
second until a steady state was achieved. The iterative schemes are accepted numerical method for trajectory studies because of the associated high accuracy (Kahl, 1996; Seibert, 1993). MATLAB software was used to solve the eqns. 6 and 7 to obtain the displacement components in the y and x directions respectively. The inter-play of the variable operating parameters was also synchronized with the MATLAB. Fig. 22 shows the trajectory plots from the model for fan angle of inclinations of 60^0, for particle inlet velocity of 0.25 m s^{-1}, air velocities of 3.6 and 7.5 m s^{-1}, and maximum x and y value of 1 m. From the trajectory plots, particles with V_t £ 3.0 ms^{-1} represent light materials while particles with V_t £ 7 ms^{-1} represent heavier materials (grains).

$$ðv/dt = C_R/M\ (v - v_a)^2 + g \quad (6)$$

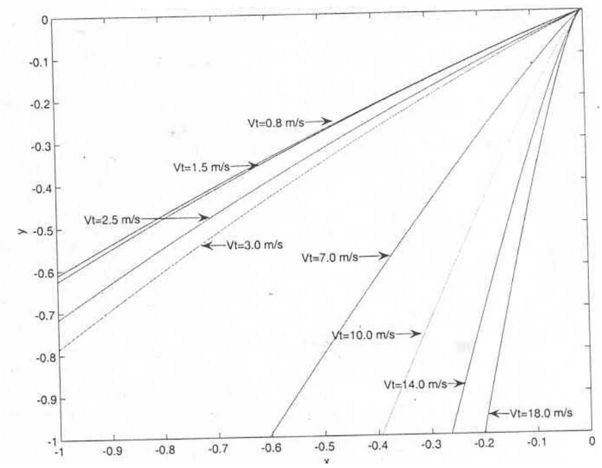
$$ðu/ðt = C_R/M\ (u - u_a)^2 \quad (7)$$

Where,
$ðv/dt$ = Rate of change of velocity in y-axis (ms^{-2})
$ðu/ðt$ = Rate of change of velocity in x-axis (ms^{-2})
C_R = Coefficient of resistance
g = acceleration (ms^{-2})
M = mass of particle (kg)
v = velocity of materials in y-direction ((ms^{-1})
v_a = velocity of air in y-axis (ms^{-1})
u = velocity of materials in x-direction ((ms^{-1})
u_a = velocity of air in x-axis (ms^{-1})

Inital attept to validate the model was done by studying the spread pattern of the various components of materials in the cleaner unit of the legume thresher/ cleaner in Fig. 19 (Adewumi, 2006c). Further validation of the model was done with a high speed camera using the classifier rig in Fig. 21 (Adewumi *et al* 2011d).



(a) Air velocity of 3.6 ms^{-1}



(b) Air velocity of 7.5 ms^{-1}

Fig. 22: Particle trajectory produced from the 2D model at fan inclination of 60^0 and inlet velocity of 0.25 ms^{-1}

The aerodynamic model and the cross flow classifier I developed established the the feasibility of using air for the classification of grains and opens opportunity for advanced particle dynamics research in cross flow systems. One of my dreams as a Professor of Food Engineering is to develop a world class particle dynamic laboratory at FUNAAB, where scholars can come for research from all the countries of the world for studies in aerodynamics in agriculture.

3.2 Development of Equipment for Processing Animal Materials

I have also developed a number of machines for handling animal products namely:

i Optical Devices for Determining Egg Fertility
ii Kerosene Fueled Incubator
iii Charcoal Fueled Incubator
iv Electrical Cum Kerosene Fueled Incubator
v Solar Incubator
vi Beak Trimming Machine
viii Milking Machine for Small Ruminants

3.2.1 Optical Devices for Determining Egg Fertility

Large scale production of chicks is essential in order to meet the protein demand and can enhance food security. The success of hatchery depends on the number of eggs hatched compared to the total number loaded. Candling of eggs during incubation is therefore central in the operation of hatcheries. Determination of egg fertility at early age is a major problem in the hatchery industry. Conventional candling commonly used has proved uneconomical for large-scale hatchery because it can not detect fertilized egg until the fifth or seventh day of incubation. There is a high probability of disappointment of the customers due to the uncertainty of the amount of fertile egg because of the inability of the candler to detect fertile egg at a tender age. This inability to determine egg fertility early enough could always jeopardize the customers' demand and it results in a shortage to the poultry farmers. It is therefore necessary to develop more sensitive and effective instruments to determine egg fertility at a tender age between 1-3 days of incubation.

To solve this problem, the photometric properties of egg were determined and three types of egg candlers were developed (Adewumi 2000b, 2005a; Adewumi et al 2001a & b). The three optical instruments developed include the vertical box optical device, bamboo case optical device and the variable lenses optical device Fig. 22 shows the candlers. The internal structure of the egg could be viewed directly with the naked eyes with the vertical box optical device but a screen in required to view the internal structure of the egg with the bamboo case optical device and the variable lenses optical device. The three optical instruments are sensitive enough to detect the embryo in the yolk of hatchable egg barely 24 hours after incubation. This implies that infertile eggs could be eliminated early enough and replaced, leading to improved performance efficiency of incubator and hatchery.

Fig. 22 : The Three Candlers for Determination of Egg Fertility

3.2.2 Kerosene Fueled Incubator

Poultry is the most efficient animal species for producing meat and egg (Singh, 1990). Compared to other important meat-producing animals, poultry population can be expanded at an extremely rapid rate, particularly through artificial means using incubator or hatchery (Anthony, 1990). It is essential to drastically multiply poultry population to be able to meet the global animal protein demand. This is possible by encouraging the mechanization of the production of eggs and chicks at small, medium and large scales through the use of hatcheries and incubators. Poultry production is particularly has the advantage for multiplication because birds attain maturity at relatively short duration. Poultry also build body weight faster and the incubation period is relatively short (Obioha, 1992).

Adewumi (1998) developed a kerosene fuelled free convection egg incubator with a capacity for 30 eggs. Fig. 23 shows the incubator during the hatching stage.

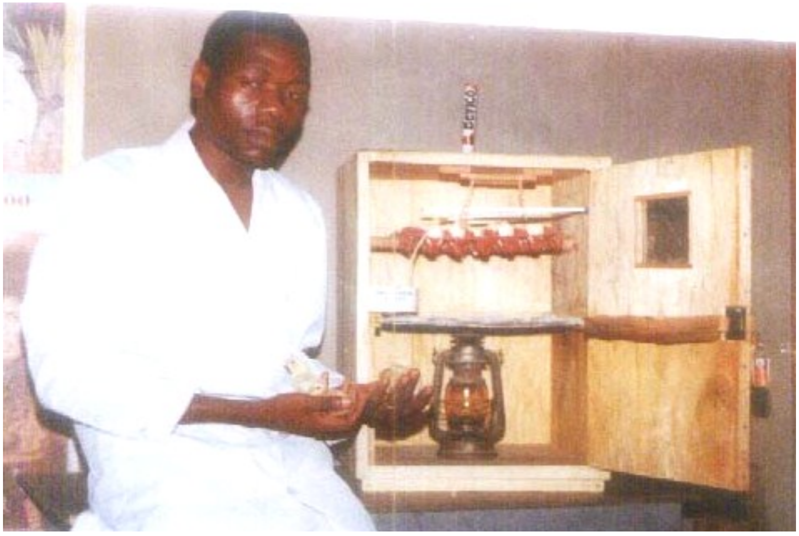


Fig 23: Kerosene Fueled Incubator

3.2.3 Charcoal Fueled Incubator

In an attempt to eliminate contact of sooth with the eggs and utilize charcoal fuel, an improve design was adapted that allows heat transfer by conduction and convection. Adewumi and Oduniyi (1999) designed a charcoal fueled incubator for 120 eggs per batched. Fig. 24 shows the photograph of the incubator during the hatching process.

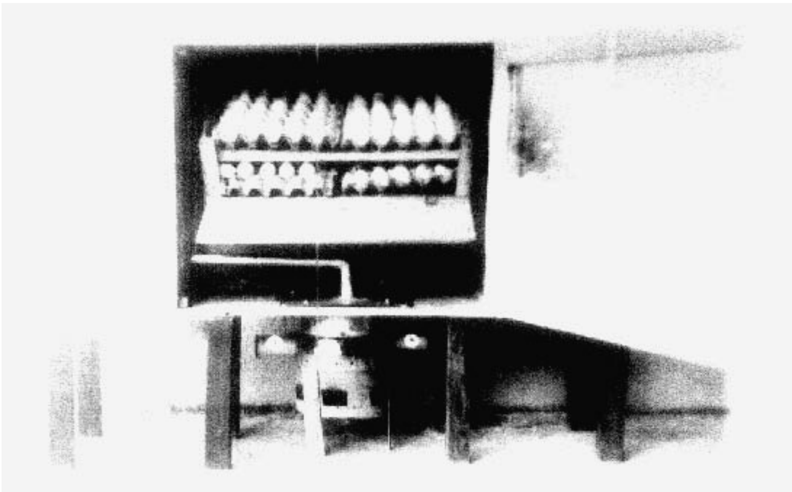


Fig 24: Charcoal Fueled Incubator

It is made of the incubation and combustion units which are coupled together. Charcoal combustion is controlled by regulating the air flow rate. Egg turning is achieved by a steel shaft turning mechanism at 30^{o}. The incubator was found to operate within a temperature and relative humidity range of 36.0 – 39.2^{o}C and 56.0 – 72.0% respectively. It has a thermal efficiency of 78.76% and average percentage hatchability of 83.84%.

3.2.4 Electrical Cum Kerosene Fueled Incubator

Attempts were made to develop electric (alternate current) incubator but the problem of erratic supply of electricity in Nigeria could not allow prolonged functioning of the incubator and the desired temperature and relative humidity could not be maintained. The use of solar panels and inverters could solve this problem but the resulting incubator shall not be affordable to peasant farmers. It was therefore opined that the electric incubator that will be appropriate for the type of erratic electricity supply could be supplemented with a kerosene fueled source that can support when electricity is off. Two types of electrical cum kerosene fueled incubators were developed. The first has a capacity for 60 eggs while the second had a capacity for 120 eggs as reported in Adewumi (2004b, 2005c). Fig. 25 shows the two versions of theof electrical cum kerosene fueled incubators.

a. 60 egg capacity b. 120 egg capacity

Fig 25: Electrical Incubator

Temperature and relative humidity range within the incubators were within the acceptable limits. However, hatchability records were very low, probably because of poor ventilation. It was found at the end of the tests that the chicks developed to maturity in the shell but got suffocated towards the hatching period (Adewumi, 2004b) Further research to study and improve air circulation in the incubator could drastically improve the performance of these incubators, and those shall be embarked on as soon as facilities are available.

3.2.5 Solar Incubator

The large scale poultry industries in Nigeria utilize hatcheries but the profit margin is relatively low because of relatively high cost of acquiring imported hatcheries and heavy investment to secure regular supply of electricity. Also, the conventional electrical energy is erratic in Nigeria. Solar energy is proposed as an alternative cheaper source of energy for incubation.

Adewumi *et al* (2006e) designed and constructed a solar incubator for rural and small scale farmers (Fig. 26). The incubator is made up the incubating chamber, solar collector and heat storage units. It has a total capacity for 120 eggs. 517.89 KJ of heat is required for 21 days of incubation of hen eggs. A preliminary test was conducted to evaluate the temperatures and relative humidity in the incubator to aid effective modification before the final evaluation of the incubator. Dry bulb temperature ranged between 25 – 39^{0}C while relative humidity ranged

Fig 26: Solar Incubator

ranged between 69 – 80%. This is an indication a modification is required to evolve a stable environment before the final tests are conducted. This shall be achieved by selecting better insulation material for the walls and adequate storage of heat during the day.

3.2.6 Beak Trimming Machine

Beak trimming, otherwise called debeaking, is a process consisting of the partial removal of the beak of bird to prevent vice habits including pecking, feather pulling, cannibalism and egg eating depending on the age at which they occur. For most of poultry farmer, the risk of not trimming beaks is too

Fig. 27: Beak Trimming Machine

The machine has a beak trimming efficiency of 100%. It has a capacity of 2472, 3556 and 2160 birds per 8 hour working day for the 8 weeks old cockerels, 8 weeks old broiler and 16 weeks old cockerel respectively, given 40% delay time. The machine could operate between 0^0C and 420^0C. It cuts the beak and cauterises under 10 seconds. It costs less than twenty thousand naira (N20,000.00) which is less than 20% of the market cost of imported machine of the same capacity. The birds were observed to feed adequately immediately after the beak trimming and showed no social effect in their behaviors or feeding.

3.2.7 Machine for Milking Small Ruminants

A hand operated milking machine for a small ruminant was designed, fabricated and tested (Adewumi et al, 2006f). The machine is the piston-cylinder type (Fig. 28). It is made from locally available materials. The machine has a hose diameter of 8.6 mm, cylinder length of 365 mm, cylinder diameter of 47.6 mm and power requirement of 25.65W. The total cost of production of the machine was five thousand Naira (N 5,000.00), less than 35USdollars. The machine was evaluated using African breed of lactating ewes and does between the first three weeks of lactation (see Fig. 29).

Fig. 28: The Milking Machine

Plate 2: The Milking Machine in Operation

Fig.29 : Milking Machine during Operation

It was operated at an average speed of 0.56 m/min and a milking time of five minutes per test A maximum of 0.005 litre/min was recorded during the test. The animals were exposed to mechanical milking for the first time in this study and were uncooperative with the artificial milking. It is therefore essential to train the African breeds of ruminants to respond appropriately to mechanical milking. It is recommended that a milking table should be utilized to restrain the animals during the milking operation to ensure better milky process and improved performance of the machine.

4.0 EXTENSION, PATENTING AND COMMERCIALIZATION OF RESEARCH PRODUCTS

Mr. Vice Chancellor, Sir, my contributions as highlighted, are just a little out of many. There are several prototypes of machines in the laboratories and workshops of many Universities in Nigeria (Ogunlowo *et al*, 2005, Ademosun, 1997, Ogunlowo, 2003). When research products from the University systems are readily available to common men, at home and on the streets, the University system shall gain the desired reputation from the public. Laboratory prototypes must therefore be up graded to commercial prototypes and Nigerian manufacturers must be ready to commercialize them. While I have worked with some individuals and organizations, on demand, to get some of the machines I have developed to end users, I still strongly feel that efforts should still be made to get the machines to farmers and food industries that can benefit optimally from the use of the machines.

Adeoti *et al* (2010) observed a very big gap between the research institutions and the end users (consumers, industries and farmers) in Nigeria. The reasons for this are numerous, including:

i. Inadequate relationship between research institutions and the end users
ii. Inadequate extension services within and outside the University system in Nigeria

iii. Inadequate funding of the University in Nigeria and lack of adequate facilities for in-depth research.
iv. Lack of patriotism and inferiority complex of Nigerians
v. Energy problem
vi. Lack of facilities for large scale production of engineering components
vii. Lack of patent initiatives by the Nigerian academic & research institutions

4.1 Inadequate Relationship between Research Institutions and the End Users

Most researches in Nigeria are not end user driven and not oriented to solve particular problem faced by end users. The products of most of the researches eventual end up in the laboratories and workshops. If researches are only inclined towards paper writing/ publications, the interest to patent, commercialize or introduce them to the end users may not be there. Industries, farmers, manufacturers or other end users of research products must necessarily be involved in the conception of research. This will provide a platform for ready market. Market survey and analysis must be integral component in the effective completion of any profitable research. Organizations such as the Nigerian Institute of Social and Economic Research (NISER) should step up efforts to facilitate working relationships between research institutions and industries to fast track economic development.

4.2 Inadequate Extension Services Within and Outside the University System in Nigeria

Extension services, especially engineering extension services are very essential in promoting the commercialization of research products (Adewumi, 2000d). The translation of technical terminologies to layman language for daily implementations and applications are adequately handled by engineering extension officers. They are also relevant in the marketing of engineering products to end users. ARMTI, Ilorin and NAERLS, Zaria are highly relevant in this respect.

4.3 Inadequate Funding of the Nigerian Universities and Lack of Adequate Facilities for In-depth Research

It is glaringly clear that University system in Nigeria is not adequately funded, particularly engineering training that is capital intensive. Adequate facilities are not available for research in Nigeria. For example, in the whole of Nigeria, we cannot boast of two functional Instron Universal testing machines, common equipment used for testing the physical properties of bio material, whereas a single institute in India has three of such machines. In Nigeria, no single university has a high speed or motion camera for aerodynamic studies in agriculture; no single instrumented extruder for food product research, whereas a single Institute in Brazil has up to three of such equipment. My researches on electrical cum kerosene lantern incubator was truncated because of lack of facilities. I have to necessarily go to India to conclude my studies on particle dynamics studies because of lack of facilities in the Nigerian Universities. Advanced engineering studies are limited because of lack of adequate facilities as a result of poor funding. The unfortunate part is that maintenance culture is terribly poor in Nigeria. These are lamentable.

4.4 Lack of Patriotism and Inferiority Complex of Nigerians

.It is unfortunate that Nigerians do not value the gifts of nature but give greater values to imported materials and expatriates. Therefore, the average Nigerian citizen is not fully committed to the development of the nation (Adewumi, 2006b). Everybody looks for what the nation can offer and not what he/ she can offer to the nation!! This is tantamount to lack of patriotism and it is a great sickness. Nigerians also suffer from inferiority complex by being too crazy and giving more value to inferior items from outside the country, while we under value our good qualities. We prefer that dollar and pounds sterling should appreciate while our Naira should depreciate. We have killed our industries involved in the production of goods by selfishly opening our borders and making it porous such that all forms of unnecessary items are imported into the country. This has invariably affected research and the commercialization of research products.

4.5 Energy Problem

No University in Nigeria can boast of consistent 8 hours regular electricity supply per day, except in few dedicated areas. How then can our workshop and laboratories give the best. In countries where research is given the right priority, we have almost 24 hours regular daily supply of electricity. Most of the sensitive laboratory equipment in such countries were provided with inverters and stabilizers but this is not so in Nigeria. The Nigerian Universities should be supported with adequate power supply to ensure that the best of products are developed by our universities.

4.6 Lack of Facilities for Large Scale Production of Engineering Components

Commercialization requires standardization and facilities for mass or large scale production Such facilities for mass manufacturing ensure precision, best finishing qualities, reduction of wastages and cost of production. Cost effective mass production thrives well when we have engineering standards. The Nigerian Government needs to further support the Standards Organization of Nigeria (SON), the Nigerian Society of Engineers (NSE), Nigerian Institution of Agricultural Engineers (NIAE) National Centre for Agricultural Mechanization

(NCAM) and Nigerian Institution of Food Science and Technology (NIFST) to develop more Engineering Standards for agro-food machineries and food products in Nigeria.

4.7 Lack of Patent Initiatives by the Nigerian Academic & Research Institutions

Patent right protects innovations and facilitates commercialization. Unlike some third world countries and developed nations, where institutional patenting is done and encouraged, and researcher involved in the innovations are integrated into the patent, Nigerian Universities are only minimally involved in institutional patenting of research outputs and products. Whereas it is mostly rigorous and stressful for individual researcher to patent his products, it is relatively easier for institutions to embark on patenting innovations. Universities are advised to have industrial parks where laboratory prototypes can be further developed into commercial prototypes and patented for local or international market. The industrial park which should be responsible for packaging research outcomes into acceptable, consumable and commercial forms can be a source of huge internally generated fund for the universities in Nigeria.

5.0 CONCLUSION AND RECOMMENDATIONS

Mr. Vice Chancellor, Sir, food security is essential for national development and livelihood. It is clear from my presentations that agro-food process engineering is a major contributor to food security. Nigeria is an agrarian nation blessed richly with land, water, crop, animal, climate and human resources. Why should we suffer in the midst of vase agricultural resources, with our farmers wearing elusive crown, as highlighted by Omotayo (2010)? Suffering of the masses and elusive crowning of the Nigerian farmer must come to an end. Nigeria must recognize herself as an agrarian nation and tap expediently and efficiently from the vase agricultural resources. Therefore, I have the following recommendations toward ensuring food security in Nigeria and direct impact of agro-food process engineering research on the masses:

i. Nigeria must recognize she is not only blessed with agricultural and natural resource but much more human resources and the expertise to provide the required techno-economic development. Nigeria as a nation needs to minimize the importation of expatriates and equipment to the barest minimum. Most of the expatriates and equipment we bring into the nation are not necessary but prodigal, selfish and wasteful exercises. We only need to value ourselves, identify our potentials and utilize them without unnecessary political biases.

ii. All the facets in the food chain including the agricultural production system, post harvest activities, added value component, and the distribution and marketing of food materials must we well coordinated and harnessed to gain food security for Nigeria.

iii. Research should be seriously geared toward developing indigenous machines and plant for secondary processing of our crop and animal materials to finished products.

iv. Researches must be end user driven and applied, such that they shall no more end in the laboratories. Relevant organizations such as the academic and research institutions, Nigerian Institute of Social and Economic Research (NISER), Nigerian Society of Engineers (NSE), National Agency for Science and Engineering Infrastructure (NASENI), Raw Material Research and Development Council (RMRDC). Agricultural Research Council of Nigeria (ARCN) should inter relate to provide a platform or forum to harmonize researches and facilitate the processes to enhance the emergence of commercial prototypes of functional equipment for the Nigerian, African and overseas market at competitive cost. Nigeria should play a major role in this respect in Africa.

v. Institutional patenting and commercialization of research products should be encouraged in the Nigerian academic and research institutions. The roles that the Raw Material Development and Research Council and the National Agencies for Science and Engineering Infrastructure is playing in this respect is commendable but should be strengthened by the government.

vi. The Federal Government of Nigeria should recognize the importance of the entirety of mechanization in Agriculture and ensure the full incorporation of mechanization component on the Agricultural Transformation agenda of the Government.

vii. The Government should fast track the emergence of agricultural mechanization policy for Nigeria, with appropriate inputs from seasoned professionals. It is alarming to note that the nation is yet to have a definite agricultural mechanization policy. Though, I am aware of the recent efforts of the Federal Government via the Federal Ministry of agriculture to get a draft of the agricultural mechanization policy, I strongly suggest that the policy should be wholesome and the technical base should be globally compliant. The policy should encourage the manufacturing of agricultural tools, including indigenous types, at competitive cost and liberate the nation from unnecessary importations. Nigeria should desist from being a dumping ground for all carcasses of imported machines and machineries

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- Central Food Technological Research Institute, India

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