Journal of the Ghana Institution of Engineering (2023) 23:4
https//doi.org/10.56049/jghie.v23i4.117

REVIEW

Contributing towards meeting Africa Agenda 2063: progress made by Nigerian Agricultural Engineers in the development of small-scale agricultural machinery

Folasayo T. Fayose[1,]*, Matthew O. Arowolo

Received: 16th March, 2023 / **Accepted:** 26th June, 2023
Published online: 20th December, 2023

Abstract

One of the major aspirations of the African Union's Africa Agenda 2063 is to eradicate poverty and achieve a high standard of living, quality of life and wellbeing for all. It is key to develop relevant machinery to meet this target. Hence in this study, the importance of agricultural machinery and its development as a way to achieve the Agenda 2023 vision is highlighted. The research efforts of Agricultural Engineers towards helping to feed the populace effectively by way of developing small-scale machines and systems have been reviewed. The machines and systems include those for planting and weeding, bird scarring on rice fields, fruit harvesting, food and feed extrusion, wet sieving, drying and food cutting. The challenges faced during these activities are also highlighted. Finally, the recommendations towards improving the development of agricultural machinery in Nigeria were elucidated. It is hoped that this study goes a long way to encourage researchers who are in this discipline to do more while also ensuring wider patronage so we can realise the 'The Africa We Want'.

Keywords: Agricultural Machinery, Agenda 2063, Small-scale, Planting, Food, Nigeria

Introduction

"The Agenda 2063 - The Africa We Want" is an initiative of Africa to build a continent per excellence. Among the aspirations of the AU agenda is to eradicate poverty and achieve a high standard of living, quality of life and well-being for all (African Union, 2021). To achieve these aspirations, engineering Africa's agriculture as a business for sustainable development is paramount. This is because engineering and technology have a role for Africa's agricultural transformation and industrialization. Also, the need for promotion of agricultural mechanization for agricultural productivity cannot be over emphasized. This is despite the trending emerging techniques, technologies and different types of farming that now exist. Modern agriculture must be imbibed for increased proactivity and production, and this will lead to job creation and transformed economies. Also, there is a need for a radical transformation in Africa's agriculture, from production to consumption, to sustainably contribute to feeding the global population that is estimated to reach 10 billion by 2050.

In Nigeria, agriculture provides employment to over 70 % of the population and 88 % of Nigerian farmers are considered small-scale family farmers. Nigeria has great potential for cultivation of a wide variety of crops as its soil and climatic conditions are very suitable for crop cultivation (TETFund, 2014). However, growing crops with human labour has been the common practice. Therefore, more than 72 % of Nigeria small-scale farmers live below the poverty line of USD 1.9 a day (FAO, 2018), making agricultural productivity largely stagnant. Also, the mechanization rate in Nigeria is 0.27 hp/hectare. This is far below the FAO recommended rate of 1.5 hp/hectare. About 16 % of small-scale farmers have access to equipment for enhancing their production and most of the farmers in Nigeria still make use of crude farming tools such as hoes, matchets, diggers and so on with only about 2 % reported to engage in mechanized agricultural system (Faleye *et al*., 2012; FAO, 2018). Moreover, most machines being used presently in Nigeria are imported machines whereas, efficient and increased production could be achieved by developing and using indigenous machines (Ademosun, 1997).

*Corresponding author: folasayo.fayose@fuoye.edu.ng

Federal University, Oye Ekiti, Nigeria

Engineering and technology have a role for Africa's agricultural transformation and industrialization. The position of Nigeria in driving the food security and technological development in Africa cannot be overemphasized. Also, Agricultural Engineering in Africa is expected to be a key driver for transforming agriculture to deliver food security and to support economic prosperity thereby leading to the AU 2063 Agenda – The Africa We Want (African Union, 2021). There is the need to foster small scale farm machinery for improving sustainable agricultural production, particularly in Nigeria, at a time when the country is considering renaissance of agriculture as the economic mainstay in place of oil. Hence, this study focussed reviewing the research effort and contribution some Nigerian innovators in the development and utilization of small-scale cottage machines and technologies for improved agricultural production in Nigeria.

The use of simple agricultural machines and labour-saving devices like weeders, planters, cutters have the potential to improve agricultural productivity of smallholder farmers. Also, they expand and promote increased land under cultivation and ecological system stability (Bai, 2004). However, this role lacks a clear emphasis but has been lumped together with other agricultural production units in Nigeria (Ndukwu *et al*., 2018). Technically, although crop production aspect involving the application of biological sciences and technology to increase yield and quality of produce play a major role, the agricultural mechanization component of agriculture sector development has been less emphasized or suffered a neglect. Moreover, the common practice of small farm holders in Nigeria is intercropping (Nweke, 2018; Ajayi, 2014) and this is being done using cutlasses and hoes. Efforts must be geared to get over these challenges to achieve the AU agenda 2063.

Machinery is an integral part of modern agriculture and farming systems. It has the potential to render activities and functions more efficient, effective, and environmentally friendly. Production rates and bottom lines can be exponentially increased and boosted with machine applications. Agricultural machines have been designed for practically every stage of the agricultural process, notwithstanding the scale and the techniques involved. Successful implementation of mechanized agriculture depends on the availability of machinery and efficient and increased production could be achieved by developing and using indigenous machines. Moreover, the future of

ISSN: 0855-0743/

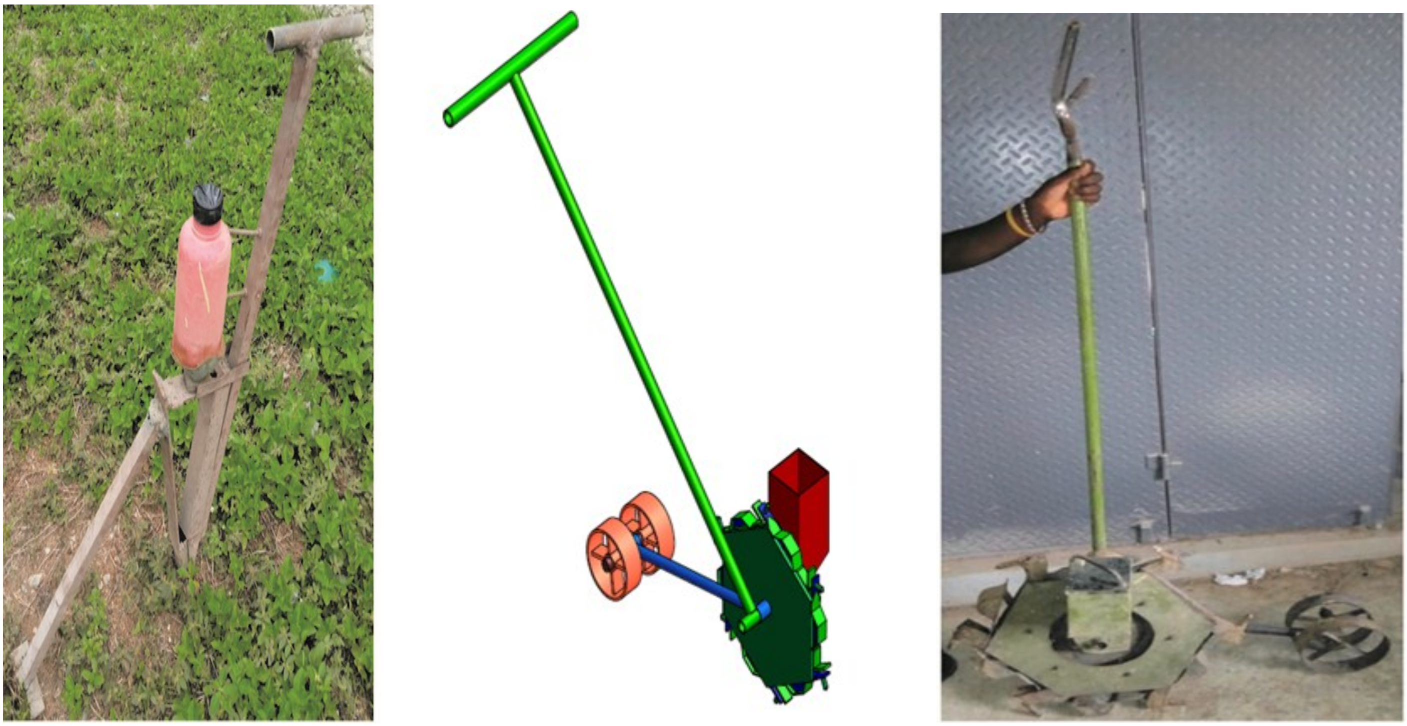
agricultural mechanization and machinery development are interrelated, and the successful implementation of mechanized agriculture depends on the availability of machinery (Omofunmi and Olaniyan, 2018). Appreciation, development, and application of machines to agriculture will boost food production and help Nigeria to be food sufficient. Therefore, this study is aimed at reviewing reported studies by researchers towards development and utilization of small-scale machines and appropriate technologies for agricultural production in order reduce drudgery and to make agriculture a viable venture.

Main Areas of Focus and Discussion

Planting devices

Planting is a major operation in crop production. For some years now, research efforts have investigated developing two types of planters; namely, jab and rotary jab planters. Jab planter is a manually powered machine about 85 cm long, designed by IITA (Leonard, 1984) and has been in use in the country till date. At the bottom of the seed hopper is the seed plate, which is controlled by a reciprocating bar actuated by the compactor. The furrow opener is spring loaded to control its opening to drop the seed. Figure1 shows the jab planter (Fayose *et al.*, 2021). The production cost of the machine as of 2023 was Twelve Thousand and Eight Hundred Naira (N12, 800).

Rotary jab planter connects six jab planters' mechanisms to a single seed hopper. Instead of having to carry the planter, the farmer pushes it along. However, for this design, the hexagonal main frame was replaced with 10 mm plate to enhance the depth penetration of seeds (Fayose *et al.*, 2021). The production cost of the machine as at 2023 is Seventy Six Thousand and Six Hundred Naira (N 76, 600). These machines were fabricated in the Department of Agricultural and Bio-resources Engineering, Federal University Oye Ekiti, Nigeria. Results from the use of the jab planter showed that it has a field capacity of 0.44 ha/h as against 0.24 ha / h for manual weeding while for the rotary jab planter, it was 1.53 ha/h (Fayose *et al.*, 2021). However, the exertion experience with the use of the rotary jab planter was higher than the others. Further study is looking at how to improve the machines by incorporating sensors are actuators to make the operation of the machines easy.



(a) (b) (c)

Figure 1 The (a) jab planter, (b) 3D view of rotary jab planter, and (c) rotary jab planter (Source: Fayose *et al.*, 2021)

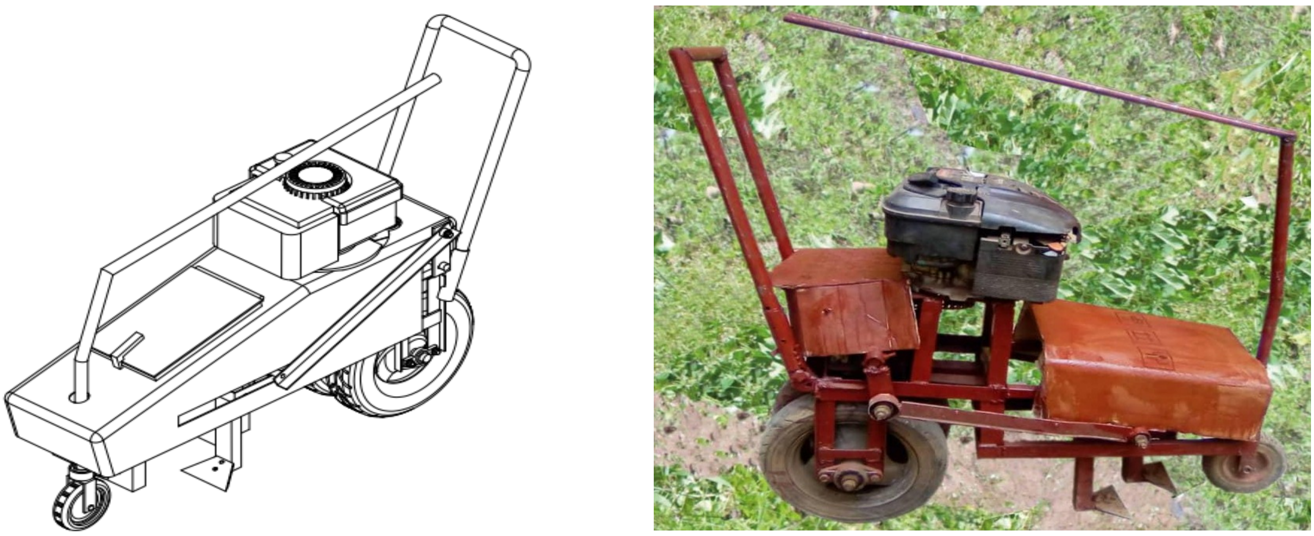


Figure 2 Weeding machine for cottage use (Fayose *et al.*, 2020)

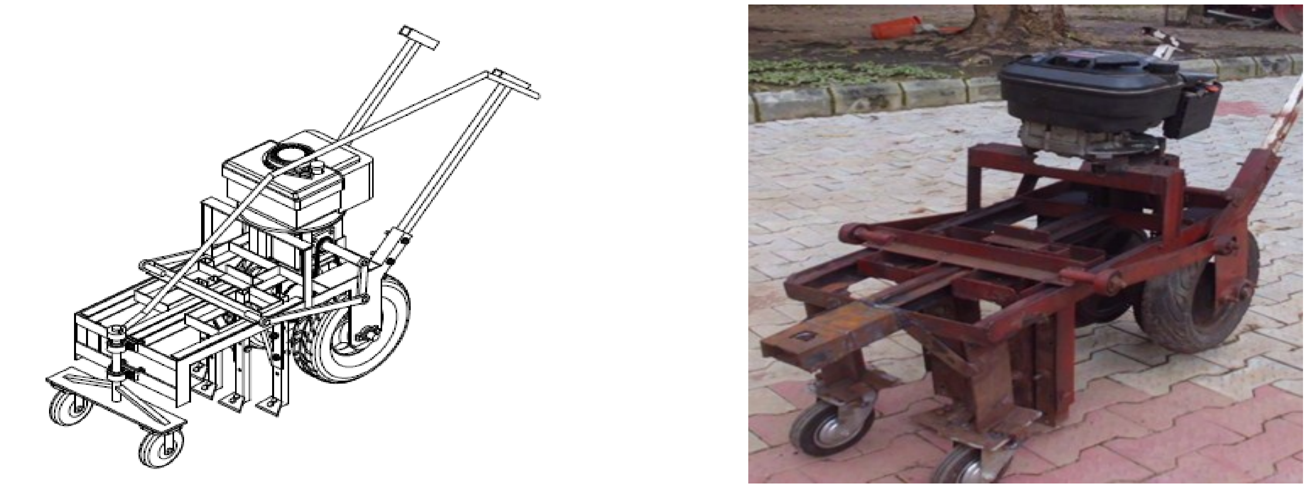


Figure 3 Two-row weeding machine for rice fields (Fayose *et al*., 2018b)

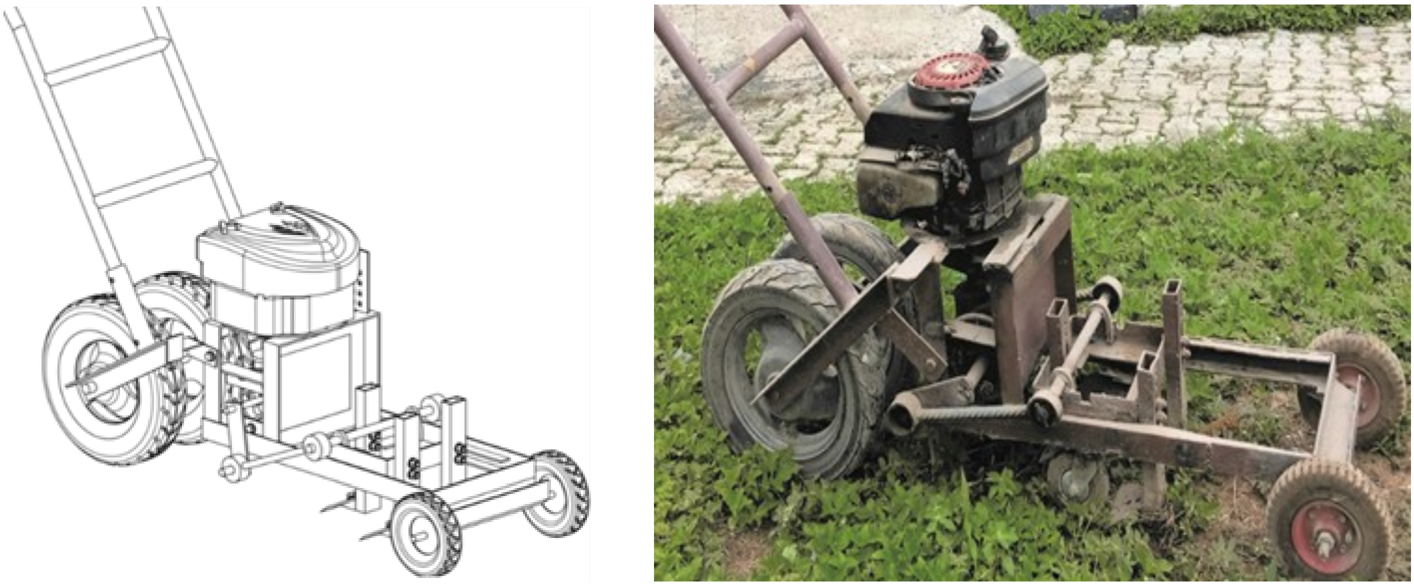


Figure 4 Weeding machine for food and tree crops (Fayose *et al*., 2022a)

Weeding machines

Manual weeding is still the common practice in most African countries. Although the use of chemicals for weeding has been adopted in several places, its side effects have been a major concern. In the reviewed studies on weeding machines, three prototypes (Figures 2, 3 and 4) actuated by reciprocating mechanisms were reported to have been developed for use on most crops' fields (Fayose *et al*., 2021; Fayose *et al*., 2020; Fayose *et al*., 2018). The reciprocation prevents the need to move the blades back and front during operation, as this action is automatically achieved in one process.

Basically, the machines comprise a main frame, speed decreasing gear, wheels, reciprocating arms, blades, shafts, coupler, and IC Engine. The field capacities of the machines varied from 0.012 ha/h and 0.0108 ha/h as against 0.003 ha/h and 0.0036 ha/h for manual weeding. The cost of production of the machines as of 2023 varies between N226, 000 for the two-row weeding machine to N160, 000 for the single-row.

Machines for bird scarring on rice plantations

Mechanical bird scarer

Rice (*Oryza sativa*), is one of the most consumed staple foods for most people in the developing countries especially in Asia and West African Sub-region. However, its cultivation is being faced with the menace of bird infestation, which has led to its reduced production in Nigeria. Consequently, a large proportion of foreign exchange is being spent on massive importation of the commodity into Nigeria. Thus, a mechanical bird scaring device (Figure 5) was developed based on standard engineering principles by throwing stones on the rice field. The machine consists of a hopper, a rotating arm with batons fixed on the opposite two dynamically balanced edges, a chute to convey the stone (made of extruded saw dust) to the throwing arm, rotating frame, damper, and power transmission systems. Each touch of the stone on the rice stalk is aimed at scaring the birds. Also, the materials for construction were made of light materials to enhance the propelling ability of the throwing arms and to give room for vibration, which assists the dropping of the stones from the hopper. The designed capacity of the bird scarer is 960 throws/hour, and the area of coverage is a perimeter of 30m. The cost of production of the machine as of 2023 is Three Hundred and Twenty-two Thousand, Two Hundred and Fifty Naira (N322, 250). The modified version of the machine comprising a stone metering device fixed directly under the hopper is shown in Figure 6.

Energy-efficient audio-based repellent system for rice fields

Conventional audio-based systems used in repelling birds deteriorate in effectiveness, cause noise pollution, and consume excess power (Arowolo *et al*., 2022). In view of this, an energy-efficient audio-based repellent system for rice fields incorporated with a convolutional neural network (CNN) model for

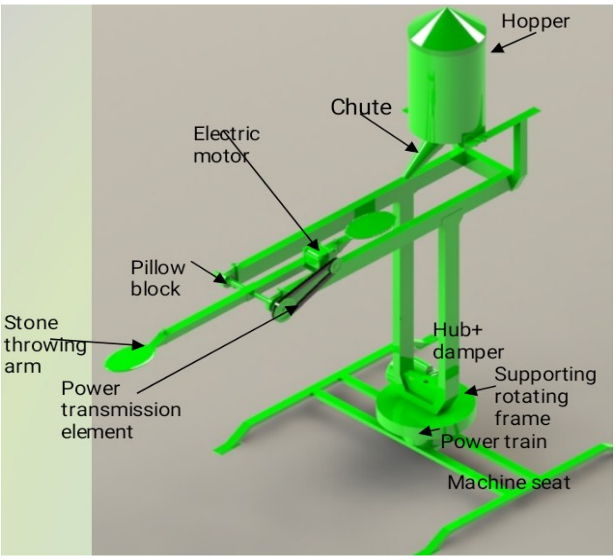


Figure 5 Bird scarer (Fayose *et al*., 2016)

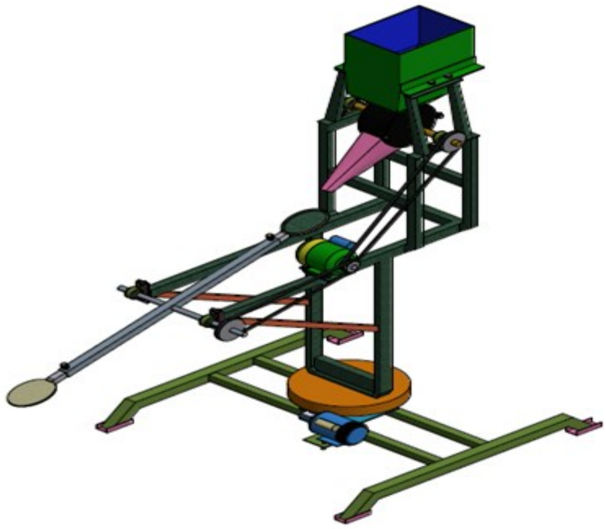


Figure 6 Modified stoner thrower

bird detection was developed. The block diagram of the audio bird scarer is shown in Figure 7 while the isomeric view is on Figure 8. A CNN algorithm was developed using inception V3, built on transfer learning technique in Google Colab. The CNN model was trained with bird dataset of 275 bird species obtained from Kaggle database. The core of the system was the Raspberry pi 4, a low-powered micro-computer adopted to run the CNN model with information from a camera. The mechanical framework for the system was designed to support its sustainability in rice fields. The estimated area of coverage was 42 m^2. The system used a maximum power of 4.10 W. The system supported multiple production of various sounds to prevent bird -adaptability to fixed sounds, which could sustain its effectiveness.

The incorporated camera aided in the detection of birds with a consequent reduction in noise pollution inherent in conventional audio devices. The developed system used 53.52% of the average power reported for conventional audio systems. The developed audio-based repellent system is better in terms of bird detection, lower consumption and less noise pollution than the normal practice of humans doing so. A unit of the machine costs two hundred thousand Naira as at 2023.

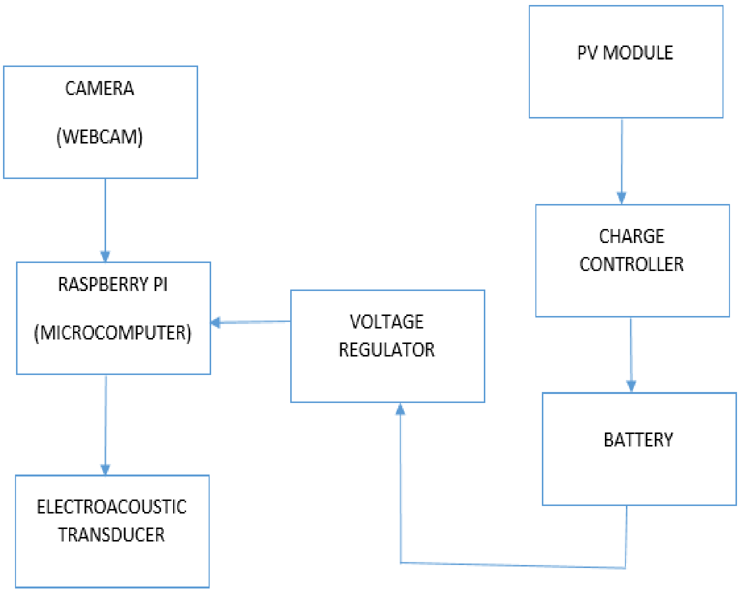


Figure 7 Block diagram of the audio bird scarer

Machine for fruit harvesting

Cashew is one of the domestically focused crops upon which the Nigerian government is currently seeking to engender food security and build a healthy base for agricultural export, thereby leading to economic development. Despite this and its being rich in vitamins and minerals, which are good for health, cashew apple is still not exploited to its full potential by developing new products in Nigeria, unlike other countries fruit (Olalusi and Erinle, 2019). Also, it is inaccessible to poor local consumers which may be due to poor harvest practices, among others.

In view of the above, a small-scale cashew harvester was developed (Figure 9). The harvester has the following compo-

Figure 8 Solar powered audio based bird repellent system for rice fields (LEGEND: 1- Frame, 2- Solar panel, 3- Stand, 4- Charge controller, 5- Nut, 6- Speaker, 7- Camera, 8- Cable, 9- Adaptable box) (Arowolo *et al*., 2022)

Figure 9 Cashew Harvester (Fayose *et al*., 2022b)

nents: an extend-able telescopic pole of 9 m range, cutting blade, electric motor (DC), housing, delivery siphon, a blade holder, 12 V 18 Ah battery and a manual switch. The designed thickness of the blade was 3 mm to withstand shearing and bending stresses, and with a bending moment of 0.645 Nm. The capacity of the D.C. electric motor is 165 Watt.

The result showed that functional and quality performance efficiencies of the machine are 98.2 % and 90 % respectively while those for manual harvesting are 66 % and 60 %. The field capacity for the machine is 0.4 ha/h as against 0.18ha/h for manual plucking while the material capacity for the machine is 0.0565 ton/h as against 0.0192 ton/h for manual harvesting. The level of exertion with the use of the harvester is 20.1/mm for the machine when compared with manual plucking which is 25.3/mm. This machine when adopted will contribute to safe and efficient handling of cashew enterprise in Nigeria and it will be easier to diversify its products. Moreover, the liveli-hood/survival of local producers would be enhanced. Finally, better performance can be attained if the machine is automated. The cost of production of the machine as of 2023 is Fifty-Two Thousand, Eight Hundred and Fifty Naira (N52, 850).

Machines for food and feed extrusion

A single screw starch extruder (Figure 10) was designed, fabri-cated and evaluated using locally available materials. The study facilitated the development of an indigenous starch extruder adaptable to local conditions. Database on food extrusion of

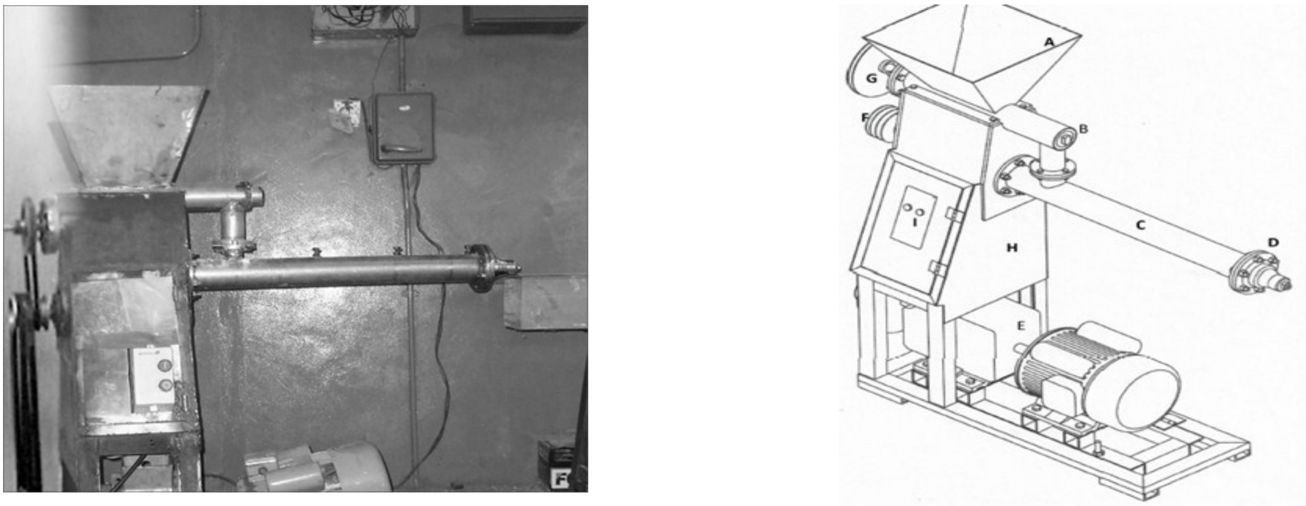


Figure 10 Food extruder 1. (LEGEND: A- Hopper, B- Feeding Conveyor, C- Extruder worm, D- Die Unit, E- Pow-er train, F- Conveyor pulley, G- Extruder pulley, H- Extruder Housing, I- Control switch) (Fayose *et al*., 2017)

Figure 11 Fish feed extruder with extruded fish feed

benefit to food processing was provided. The machine served as a test rig which will be useful in further research and training on extrusion. Figure 11 showed a fish feed extruder with extruded fish feed. A unit of the machine costs one million, four hundred and forty thousand Naira.

Cooling system for a food extruder

Burning and undesirable puffing of extruded products has proven to be a major challenge causing serious economic loss during extrusion. This experience affects adversely the quality of the food being processed. Also, it may be necessary to introduce heat through the barrel walls to reduce the viscosity of extruded products during extrusion to improve the performance of the extruder. In view of the above, this project was borne out of need to control the heat generated by frictional dissipation of a cooking extruder (Fayose *et al*., 2018). The components of the heat control system include a radiator with fan, water jacket, reservoir, water pump, hose and distribution pipes and thermostat. The study employed the principle of counter flow heat exchanger for the water jacket. The highest temperature attained by the extruder through vicious dissipation at 150 rpm was 150 °C and the desired temperature to cool the products to was 52 °C. The total cost of production for the cooling system is estimated to be One Hundred, Fifty Two Thousand, Three Hundred and Fifty Naira only. The 3D drawing of the machine is shown in Figure 12.

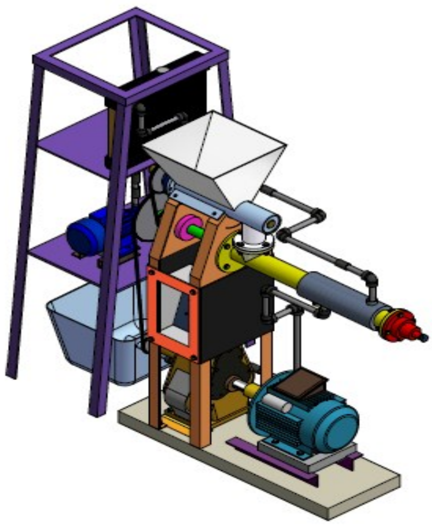


Figure 13 Food extruder with heat control system (Fayose *et al*., 2018a)

Wet sieving machines

Wet sieving is still a manual operation in tropical crop processing. It is a time-consuming operation. Most of the existing wet sieving machines are available in large scale industries and they are too sophisticated to operate and maintain by local processors (Aspiring Youths, 2023). Therefore, wet sieving machines, based on shaking mechanism were designed, fabricated and evaluated to solve the problem associated with wet sieving of starch and other agricultural products in Nigeria. The machines are shown in Figures 14 and 15. The machine consists of a sieving compartment operated by a crank through vibratory and reciprocating mechanism obtained with the use of an eccentric cam and springs arrangement, collecting trays and outlets. The study showed that the machine performance coefficients and sieving capacity decreased with increasing concentration and feed rate of the starch slurry. The highest performance and sieving capacity are 76.42 % and 7.5 x 10^{-3} kg/s respectively. A unit of the machine costs N20, 721.00 as at April 2023 and it requires little maintenance.

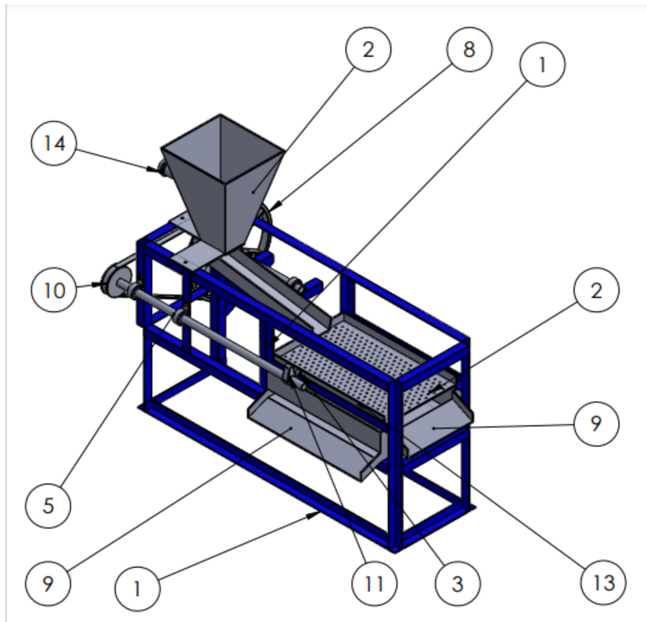


Figure 14 Manual Wet sieving machine (LEGEND: 1- Hopper, 2- Camshaft, 3- sliding cover, 4- Compression spring (4Nos), 5 - Cam and follower, 6- Angle adjuster, 7- Frame, 8- Sieving compartment, 9- Trash Discharge chute, 10- Starch discharge chute, 11- Hand crank lever, 12- Driver pulley, 13- Driven pulley) (Source: Fayose 2009)

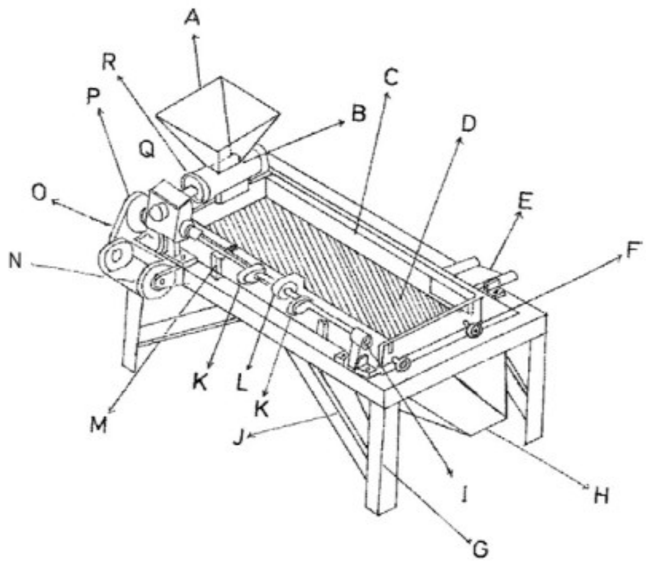


Figure 15 A. Motorised wet sieving machine (LEGEND: A- Hopper, B- Mixing compartment, C- Sieving compartment, D- Mesh, E- trash outlet, F- Roller (4nos), G- Frame, H- Milk outlet, I- Bearing, J- Brace, K- Cam balance, L- Cam, M- Spring holder, N- Electric motor, O- V-belt, P- Pulley, Q- Speed reducing gear, R- Teflon) Source: (Fayose 2008)

The volumetric flow rate and the capacity of the motorized version of the machine are 0.0206 m^3/h and 22.45 kg/h respectively. The machine performance coefficients and sieving capacity of the motorized version increased with decreasing concentration of the starch slurry being processed. Also, highest performance coefficients of 98 % was obtained for sieving of maize slurry while sieving capacity of 16.90 g/s/m^2 was obtained when the machine was used to sieve cassava slurry. A unit of the machine costs N70, 044.00 as at April 2023. The maintenance of the machine is simple and recommended for small holders, local processors, and domestic use.

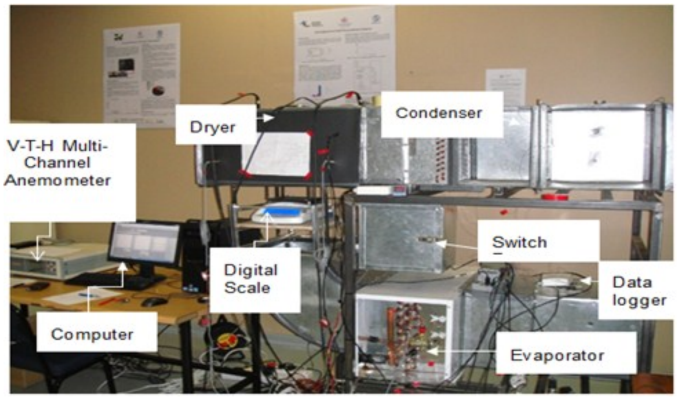
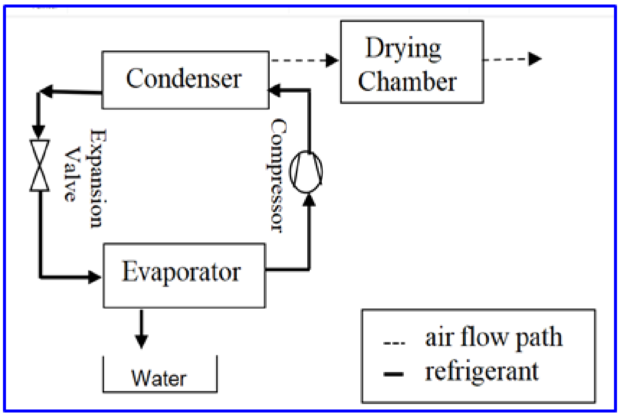


Figure 16 Heat pump dryer rig ((Fayose and Huan, 2019a)



Drying machines

Drying is one of mankind's oldest preservation techniques of different products such as furs, wools, textiles, clay, timber, grains, fruits and vegetables. Up to date, drying is still a common process in several industries. Traditionally, drying is a very energy consuming procedure. Statistics show that developed as well as industrialized countries use over one third of their primal energy for drying operations (Butz and Schwarz, 2004). Drying to produce high quality agricultural produce is yet a bottleneck in most Sub Sahara countries. Figure 16 shows an open loop laboratory air source heat pump dryer (HPD) set up for biomaterial drying (Fayose and Huan, 2019). The HPD systems improve energy efficiency and cause less fossil fuel consumption. HPD is a low temperature drying process, it gives a double advantage over the conventional, common, and unreliable sun drying in the region. The set-up was efficient for the drying of banana and Fish feed. Another attempt by the author is a rotary dryer (Figure 18). Rotary dryers are notable for greatest capacity than any other type of conventional dryer. It was used for the drying of plantain slices for plantain flour and for cassava mash for production of fish feed. A Unit of the machine costs Eight hundred and eighty thousand Naira as of 2023.

Figure 17 Rotary Dryer

Food cutting machine

Cutting is a major operation in food processing. It is time consuming and labour intensive. In Nigeria and most developing countries, it is normally done manually with the exception of a few processing factories where some imported equipment are used. In view of the above, a low cost motorized, table, rotary cutting machine was designed and fabricated using locally available materials to solve the problems associated with cutting of agricultural and food products in Nigeria. The machine (Figure 18) consists of a feeding compartment, cutting compartment, power transmission and outlets. It was designed for cutting vegetables, fruits and confectionaries like chin-chin and salad ingredients. The machine has a throughput of 37.8 g/s. A unit of the machine costs Sixty Thousand, Three Hundred and Forty-One Naira (N60, 341.00). The maintenance of the machine is simple and recommended for small holders, local processors, and domestic use. The mode of operation of the machine is described in Fayose (2007).

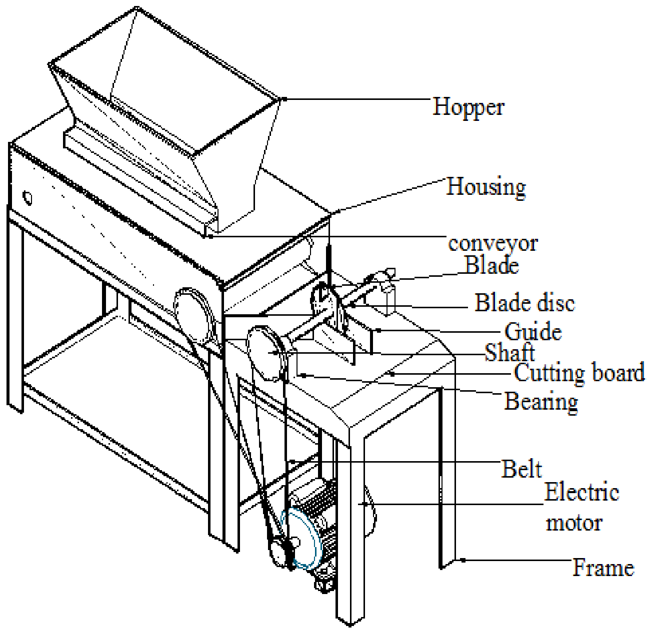


Figure 18 Food Cutting Machine (Fayose 2007)

The Challenge

From the above descriptions of devices and machines designed and manufactured locally, it could be seen that the agricultural machinery industry hold promises for relieving smallholder farmers of the drudgery involved in agriculture. These efforts give indication that researchers are ready to do even more if given the needed support and their products are patronized. Mostly the limited patronage of agricultural machines is due to farmers' low private investments. It is quite unfortunate that there is inadequate attention being given to the development of technical education in Nigeria. Hence, there is shortage of competent technicians and artisans for machine fabrication with a consequent hike in cost of machine fabrication. This is an area that demands attention if the country would like to lead in the Agenda 2063 in order to create opportunities and wealth for the present and future generations.

Another issue has to do with the lack of raw materials for fabrication. Additionally, there seem to be no coordination between the public, private sectors, and farmers when it comes to research efforts and implementation leading to low adoption by the end-users (farmers). More so, in some cases, modern technologies are transferred to small-scale farmers are not done by engineers or researchers/experts in Agricultural Engineering due to apparent political reasons. Government policies are not definite and clear. For example, no clear policies enacted to support the importation of components for local fabrication and discouragement of importation of finished products. This gave room for competitive market, thereby killing local productions. Looking at it from another side, seasonal demand of agricultural machines is a challenge to producers due to non-practice all year round because of dependence on rain-fed agriculture. Also, agricultural operations are time specific, so a machine cannot be used through-out the year.

Conclusion

Agricultural transformation is enhanced by engineering and technology. The research efforts of innovators in geared towards developing machines and systems for boasting agricultural production in Nigeria has been presented. The machines and systems include those for planting and weeding, bird scarring on rice fields, fruit harvesting, food and feed extrusion, wet sieving, drying and food cutting. These machines have proved to reduce drudgery and increased productivity of users. However, going forward, it is imperative steps are taken for policy reforms in the promotion of agricultural mechanization and machine development with efficient implementation strategies. Industrial clusters where these machines can be improved and assembled for pay as they use, or user hire service can be pursued by the private sector.

Government should strengthen local agricultural machinery development with financial incentives like power purchase agreements and feed-in tariff among others. Efforts must be geared toward direct agricultural production to be exposed to the imminent dangers involved in new agricultural innovations and be able to tackle it headlong. It is not just enough for people to carry out research in the laboratory or on a small field plot and make deductions. The result must be practised on a direct commercial farm to be able to drive home the outcomes of such innovations. There should be synergy and strategic collaboration between universities, research institutes, industries, and other stakeholders to enhance the dissemination of research-breakthroughs and information for a successful machinery development. Technology incubators to fast-track innovation and commercialization of research and development outputs should be established in/or near the nation's academic institutions.

Development of technical education must be given priority to stop the prevailing shortage of competent technicians and artisans. There is the need for application of physical systems engineering approach to machinery development and utilisation. Mechatronics devices, robots, drones, 3D printing, sensors and other trending emerging technologies should be explored. For example, while mechanical linkages were able to control three-point hitches successfully, the complex linkages were expensive to manufacture and were subject to wear. Thus, such linkages are being replaced by the more efficient mechatronic devices.

Acknowledgement

The assistance of TETFUND in supporting the development of some of the machines reported in this write-up is highly acknowledged.

Conflict of Interest Declaration

The authors declare no conflict of interest.

References

Ademosun, O. C. (1997). Indigenous technology for local agro-based industries. Inaugural Lecture Series 1 l. Federal University of Technology Akure, Nigeria.

African Union (2021). Our aspiration for the Africa we want, Available from https://au.int/agenda2063/aspirations. [Accessed 2 Sept. 2022].

Ajayi J.O. (2014). Comparative economic study of mixed and sole cassava cropping systems in Nigeria. Agris On-line Papers in Economics and Informatics, 6 (4), pp. 15-20.

Arowolo, M.O., Ade-Omowaye, J.A., Akinsanmi, O.A., Fayose, F.T. and Akindele, S.O. (2022). Design and development of an energy-efficient audio-based repellent system for rice fields. International Journal of Emerging Technology and Advanced Technology, 12 (10), pp. 82-94. doi.org/10.46338/ijetae1022_10.

Aspiring youths (2023). Advantages and disadvantages of large scale industries. https://aspiringyouths.com/advantages-disadvantages/large-scale-industries. [Accessed 25 March. 2019].

Bai. R. (2004). Agricultural mechanization and increase in farmers' income. Transactions of the Chinese Society of Agricultural Machinery, 4, pp. 179–182.

Butz D. and Schwarz, M. (2004). Heat pump drying (HPD) - How refrigeration technology provides an alternative for common drying challenges. KI-Kalte.Luft.Klimatechnik pp. 140-144. Available at https://www.ki-portal.de/wp-content/uploads/featured_image/09b4cd1f4fd.pdf [Accessed 12 Jan. 2017].

Faleye, T., J. A. Adebija and A. J. Farounbi. (2012). Improving small-farm productivity through appropriate machinery in Nigeria. International Research Journal of Agricultural Science and Soil Science. 2 (9), pp. 386–389.

FAO (Food and Agriculture Organization of the United Nations). 2018. Family farming knowledge platform: smallholders data portrait. Italy: FAO. Available at http://www.fao.org/family-farming/data-sources/ dataportrait/farm-size/en [Accessed 12 Jan. 2017].

Fayose, F. T., Olaniyan, A. M., Ogunleye, K., Ilesanmi, O. (2022). Development of a reciprocating weeding machine for cottage crop, FUOYE Journal of Engineering and Technology, 7 (2), pp. 1-6. https://doi.org/10.46792/fuoyejet.v7i2.817.

Fayose F., Afolabi O. and Adewale D. (2022) Development of a small-scale cashew harvester for enhancing economic productivity in Nigeria. Book of Readings of Humboldt Kolleg International Conference, Federal University Of Technology Akure, March 2022. pp. 83

Fayose, F. T., Olaniyan, A., Alabadan, A., Fajimi, A., Ogunleye, K., Omoju, O., Aladejebi, O. and Ilesanmi, O. (2021). Effect of different modes of planting and weeding on machine field capacity and yield of a mixed cropping small-holder farm. Engineering in Agriculture, Environment and Food, 14 (1), pp. 13-20.

Fayose, F., Olaniyan, A., Osetoba, A., Ogunleye K. and Ilesanmi , O. (2020). Development of a reciprocating weeding machine for commodity crop production. LASU-JEST 2, pp. 5-17

Fayose, F. T. and Huan Z. (2019). Cassava flour substitution and moisture content variation on some quality characteristics of heat pump dried extruded fish feed. Journal of Natural Sciences, Engineering and Technology, 18(1&2), pp. 11-21. https://doi.org/10.51406/jnset.v18i1.2028.

Fayose, F., Adejuyigbe, S., Alabadan,B., A. Olaniyan, T. Babalola, S. Ogunjimi, O. Aladejebi and B. Olorunfemi (2018). Design of a cooling system for a food extruder. Journal of Emerging Trends in Engineering and Applied Sciences, 9(4), pp. 211- 217.

Fayose, F.T., Olaniyan, A. M., Alabadan, B. A. A. A. Fajimi, Ogunleye, K., Omoju, O., Aladejebi, O., O. Ilesanmi (2018). The design of a two-row reciprocating weeder for upland rice field. In: Akinoso, R., Alonge, A. F. and Omobowale, M. (eds), Proceedings of the XII CIGR Section VI Technical Symposium, Ibadan, Nigeria, pp. 736-747.

Fayose, F. T., Ogunlowo, A. S. and Agbetoye, L. A. (2017). The design, fabrication and preliminary testing of an indigenous single screw extruder. Journal of Engineering Science and Technology, 12 (10), pp. 2585 – 2598.

Fayose, F. T., Alabadan, B. A., Olaniyan, A. M., Fakayode, S. B., Okonji, C. J., Ajiboye, A. T., Ajayi, E.S., Oloye, A. O., Ibrahim, A. G. (2016). Development of a mechanical bird scaring device. In: Adewumi, J. K., Adekunle, A. A., Olayanju, T. M. A., Ismaila, S. O. and Dairo, O. U. (eds.), Proceedings of the College of Engineering International Conference, Abeokuta, Nigeria, pp. 399-403.

Fayose, F.T. and Bolu, C.A. (2015). Computational Fluid Dynamics: an effective tool for agricultural engineering analysis. Technical Library of the American Society of Agric. and Biological Engineering (ASABE), Paper No: 2190496.

Fayose, F.T. (2009). Development of a wet yellow maize mash sieving machine. NSE Technical Transactions, 44 (4), pp. 40-48.

Fayose, F.T. (2008). Development of multipurpose sieving machine for wet agricultural products. Agricultural Engineering International, 10, pp.1-9.

Fayose, F.T. (2007). Development of a cutting machine for food materials. Journal of Agricultural Engineering and Technology (JAET) 15, pp. 58-65.

Leonard, D. 1984. Traditional field crops. Peace Corps Information Collection and Exchange M0013. 283 p. books.google.com.ng/books retrieved on 13/8/2018.

Ndukwu, M.C., Asoegwu, S.N. and Ahaneku, I.E. 2018. Status of research on agricultural machinery development in Nigeria: a case study of cassava tuber processing machineries. Agricultural Mechanization in Asia, Africa and Latin Am. (AMA), 49 (2) pp. 150-155.

Nweke, I. A. (2018). In support of a well-planned intercropping systems in south eastern soils of Nigeria: A review. African Journal of Agricultural Research. 13 (26), pp. 1320–1330. https://doi.org/10.5897/AJAR

Olalusi, A. P. and Erinle, O (2019). Influence of drying temperature and pretreatment on the drying characteristics and quality of dried cashew (Anacardium occidentale L.) apple slices. Croat. J. Food Sci. Technology, 11(1), pp. 97-103. https://doi.org/10.17508/CJFST.2019.11.1.14

Omofunmi, O. E. and Olaniyan, A. M. (2018). Present status and future prospects of farm mechanization and agricultural machinery industry in Nigeria. Agric. Mechanization in Asia, Africa and Latin Am. (AMA), 49, pp. 13-19.

TETFund (Tertiary Education Trust Fund) (2014). Guidelines for assessing TETFund National Research Fund. Abuja: TETFund.