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TRENDS AND CHALLENGES TO GOVERNMENT TRACTOR HIRING UNITS IN ONDO STATE, NIGERIA

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ABSTRACT

The paper reviews the benefits and problems associated with several methods of multi farm use of farm machinery including problems hampering the growth and profitability of Government Tractor Hiring Units (THU) in Nigeria. It discusses previous efforts at the development of tractor hiring models for Ondo State from commercialization to leasing as a case study and a proposal for improving the efficiency and service delivery of the existing government THU by the creation of a semi autonomous unit domiciled in the Ministry of Agriculture was also offered.

KEYWORDS: Tractors, THU, subsidy, machinery, commercialization.

1. INTRODUCTION

Agricultural mechanization has been described as the application of tools, implements and powered machinery as inputs into agriculture (Clarke, 2000). These include use of simple tools, oxenisation and tractorisation. Tractorisation has been embraced by farmers in Nigeria like all other developing countries because of the daunting level of physically demanding nature of farm work. According to Manuwa (1992), the first tractor unit farm was started in Agege in the colonial province of Nigeria in 1952. Reports of the World Development Indicator of the Food and Agricultural Organization (FAO) (2010) showed that as at 2007, Nigeria had 0.247 hectares of arable land per person and 6.79 tractors per 100 sq km of arable land.

The objective of this paper is to review the previous methods of machinery used in Ondo state, examine the reasons for the inefficiency in delivery of service and propose a workable system that will offer sustainability in machinery management toward the effort to improve food security in the state.

2. MULTI FARM USE OF FARM MACHINERY

The use of agricultural machines in more than one farm is to reduce running cost, initial capital outlay and prevent under utilization. The farmer pays a definite rate or charge for the work performed based on the number of hours or days the machine has worked or the number of work units completed (hectares, bags etc). Three methods of this type of machinery use are currently available in Nigeria.

i. A commercial enterprise which is expected to give out machines and make profit: This option has not been attractive for farmers and businessmen in developing countries because of high initial cost of machinery and high maintenance cost. Low returns on farm produce, inadequate technical knowledge of imported machinery, difficulty in sourcing for foreign exchange and spare parts are some other factors that may affect the operations of a commercial Tractor enterprise.
ii. Government enterprise: There is no profit motive but costs may be recovered, including salaries of managers and operators. There is no direct income benefit in the running of this type of enterprise. There is however a sustained multiplier effect of increased food production and reduction in unemployment. This in the long-term combine to fetch cash benefit to government through increased exports and reduced food imports due to increase in productivity that is the main ingredient of the wealth of a nation. This type of enterprise is frequently run at a loss, the cost of operation been heavily subsidized by government as a social and extension service.

iii. Mixed enterprise: This involves the cooperation of a government organization and registered farm machinery cooperative organization for the supply of machinery services.

According to Adama *et al*. (2009), other machinery management systems that are adaptation of these methods include, the nucleus centre model proposed by Anazodo (1986) that proposes the joint ownership and management of large farms, the National Agricultural Land Development Authority (NALDA) model that recommended specific crops for states and ecological zones and the proposed community-driven Centre for Community Farm (CCF) where government is expected to provide technical and economic support to farmers having small sized and fragmented land holding with common boundaries. This will enable the group to utilize common mechanization services through a representative while still retaining their individual ownership

3. THE TRACTOR HIRING SERVICE

The Tractor Hiring Service (THS) or Tractor Hiring Units (THU) which is a form of multi farm use of tractor services has been the main programme used by governments for supply of farm power in Nigeria. The THU started in Nigeria in the former Western Region in 1954 before it grew and spread to other Regions and States Ministries of Agriculture with the creation of more States (Manuwa, 1995). Initially, they were essentially an extension programme to show farmers the effect of increased farm power on productivity. However, with increase in population and awareness, the orientation and size of the THU has been considerably changed.

The Government THUs has been heavily subsidized to the tune of not less than 45% at any time (Manuwa, 1995). This is apart from government's purchase of tractors, paying of wages and salaries. Although, they are not profit oriented, yet they are supposed to be able to break-even and replace itself to ensure constant availability of this service after the initial Government capital outlay.

Regrettably, this has not been the case due to a number of reasons identified by several researchers, some of which are characteristics of multi-farm use of farm machinery while some are peculiar to most government run organs. They include:

i. Administrative bottlenecks and Government Bureaucracy
ii. Prolonged down time and idle time arising from (a) above.
iii. Fragmentation of farm holdings
iv. Poor condition of roads and excessive unproductive traveling
v. Poor development of essential support services
vi. Shortage of spare parts
vii. Inadequate land clearing equipment
viii. Insufficient professional handling resulting to Sidelining of purchase specifications and wrong staffing.
ix. The Timeliness problem.

Every farm operation is time bound. There is an optimum period when an operation should be completed to give maximum profit to the farmers. Besides, in THUs due to the seasonality of operations, many farmers often want to use the tractor services at the same time. Thus a machine that is not maintained because fund is not released or some government officials want to use machinery for a private purpose will ultimately have adverse consequences on the effectiveness of the THU.

This frustration generated by the aforementioned reasons, culminated in the Aribisala report of 1984, which recommend that all government THUs should be phased out within 2 years to be replaced by privately owned THU (Aribisala, 1984). This represents a shift in the national policy on agricultural mechanization and it has remained the extant national policy on agricultural mechanization and farm machinery management.

One of the attempts made by the Federal Government of Nigeria to develop privately owned tractor services led to direct purchase and subsequent selling of over 6000 units of tractors directly to cooperative societies, group farmers and retired tractor operators to run THU (Aribisala,1984). Some of the tractors got into wrong hands; they were not used for farming. Most farmers who got them regretted, because it tied down their capital and it is of very little use, due to lack of spare parts, service workshop and the high cost of spare parts when available. An example is Mobarikisu Farms at Oke-Igbo – Ondo State that became defunct in 1983 after only a few years of operation.

3.1 Ondo State Case Study

In Ondo State, the attempt at commercialization tractor hiring services, include the transfer of 102 tractors and assorted equipment to the Ondo State Investment Holdings (1989-1992) and later the Agricultural Inputs Supply Company (AISC) (1992-1999). This is after an Agricultural Mechanization Company founded in 1985 became defunct in 1986 (Ministry of Agriculture, 2010).

These attempts failed woefully, necessitating a review of this tractor commercialization policy. Not only have the tractors not been making profit as envisaged, they have in fact constituted a drain on the resources of their parent organizations. Table 1 shows the trading account of the Tractor Hiring Unit of the Agricultural Inputs Supply Company between the periods of 1992-1995.

Table 1: Trading Account of the Ondo State Agricultural Inputs Supply Company

Description	1992	1993	1994	1995
Income	₦9, 63,501.00	₦8,938,478.00	₦3,067,016.00	₦5,874,427.00
Cost of Operation				
Spare Parts Consumed	1,754,565.00	43,677.00	184, 078.00	3,795,010.00
Depreciation	9,128,319.00	9,128,319.00	10,682,946.00	8,510,583.00
Rent/Building Construction	1,200.00	1,200.00	1,538,801.00	34,872.00
Staff Salary, Allowances and Welfare	479,730.00	583,054.00	184.078.00	1,427056.00
Local Transport Expenses.	123,890.00	140,357.00	-	94,777.00
Vehicles / Equipment Operation Maintenance	180,474.00	168,105.00	1,100,529.00	714,890.00
Land Clearing Expenses.	180,944.00	110,000.00	-	
Staff Training/Periodicals	-	-	-	38,150.00
Printing and Stationary	-	-	-	37,409.00
Total	11,849,122.00	10,174,712.00	13,521,354.00	14,656,687.00
Gross Loss	2,085,621.00	1,236,234.00	10,454,338.00	8,782,259.00

Source: Ministry of Agriculture (2010)

Also the desire to recover the costs of these machines for easy replacements has not been achievable, because apart from the Companies having most of the constraints of the government THU they also have other problems which include:

1. Lack of requisite infrastructural facilities including repair and maintenance tools and fuel storage facilities, which account for about 1.2% of cost items for tractors (Manuwa, 1995).
2. High cost of operations per area basis.
3. Inadequacy of trained personnel – Most commercial THU require the Engineers and associated technical officers, craftsmen etc. who are professionals on the job. They are also deficient of the time and resources to embark upon long-term staff training and development.
4. Non release of subsidy fund by Government to support equipment maintenance. Governments erroneously believe that as with most other industries that once the hardware has been purchased, it should just sit back and enjoy return on its investment.
5. Lack of loyalty of company staff when handling government investments. This may lead to all manners of indiscipline. In fact, it is very unwise of Government to purchase units of farm

machinery at a great cost and hand it over to a commercial organization it has no direct control over.

6. Lack of loyalty to other government agricultural programmes e.g. Back to Land, Farm Settlement etc., Tractorisation is a vital part of the food production package which is always a priority of governments for poverty reduction and mass employment.

In the absence of government subsidy, by straight line depreciation, the cost of unsubsidized tractor use, for a N6.5 million tractor having a life span of 7 years, 10% salvage value and works for 800 hours per annum comes to about N1, 100 per hour. This is without regard to the cost of the implement it carries. Comparatively, Roy (1972) gave an elementary estimate of the cost of machinery use in the US National Farm Equipment Association. This formula includes charging: 1% of the newly delivered equipment retail price for a 10 hour day; 5% of one newly delivered equipment retail price for a week; 15% for a month, 25% for 2 months; 331/3% for 3 months. Farmers are responsible for picking up and returning the equipment and funding the operator and providing fuel and supplies. Using this custom-based leasing method on a N6.5 million tractor and a N500, 000.00 implement the cost of use comes to about N70, 000 per 10 hour day. This has made tractorisation unattractive to local farmers and leading to a general lack of interest in farming and increase in the cost of food. Manuwa (1995) further reported that due to this high cost of use, many small-scale peasant farmers could not hire tractors even at government rate. This could lead to a further reduction in the annual use of available tractors.

Another attempt by the Ondo State Government to provide tractor services through leasehold to known tractor operators and farmers in line with the Aribisala report of 1984 also failed in a similar fashion. Under this scheme 30 tractors and complimentary implements consisting of one unit each of a disc plough, 2 gang tandem disc ridger, rotary slasher, tine cultivator and 4 ton tipping trailer were offered for lease in 2008 to farmers, few agricultural cooperatives and a local Government authority upon payment of a deposit and signing of an MOU covering the repayment, use and maintenance of the machinery (Table 2). Tractors are due for confiscation after 3 consecutive months of default in repayment.

To encourage compliance, the government set up a loan recovery team with a mandate to carry out on-farm-visit to beneficiaries and issuing regular demand notices. Notwithstanding, what could be taken as a well packaged deal, only 28 tractors were taken up in the program, most of the leasers defaulted woefully in the contractual agreement to the extent that the state government constituted a 10 man task force to forcefully recover the machinery after only the third year of the program. The record of repayment on tractors and implements provided on leasehold is presented on table 3.

Table 2. Description of Leased Tractors and Implements

S/N	Brand Name/Make	Horse Power	Number
1	Swaraj 987 FE	74	18
2	Eicher 5660	50	4
3	Eicher 450	45	2
4	Mahindra 5312	39	2
5	Taishen Vitec 120	12	1
6	Massey Ferguson 4135	72	1
	Total		30

Source: Ministry of Agriculture (2010)

Available record at the Ministry shows that only 4 farmers were able to achieve above 40% of the payment required in three years of a possible 5 year repayment period, within this period many of the tractors have been badly damaged due to poor maintenance and over use. Total repayment on all 28 tractors was 27.8 million out of a possible 86.84 million naira. To make matters worse, efforts by Government to recover the tractors even with the force of the law were continually frustrated with political connections.

It is noteworthy that the State Ministry of Agriculture has most of the required infrastructural facilities in place. There are standard workshops at Akure, Ondo and Ikare with underground fuel storage tanks and adequate shelter. Lack of these have been known to account for decrease in the useful life of machinery due to the elements of rain, sunshine, wrong fault diagnosis, poor maintenance and repair operation (Manuwa,1995).

There is also a pool of Agricultural Engineers and other cadres of allied staff that only require periodic retraining to enhance their capability to cope with even the newest innovations in the field. The exploitation of farm machinery for efficient production is definitely not a job for the unskilled.

To further show the decay within the company set-up. From 1990 – 1992, Ondo State Government tractors were regularly taken to other States to work to the detriment of local farmers.

3.2 Proposal for an Efficient Government THU in Ondo State

The following proposal is therefore made from the analysis of the present unsatisfactory situation of machinery management in Ondo state.

i. An enumeration and conditional survey of tractors and implements owned by Ondo State Government should be conducted.
ii. The unserviceable tractors and implements should be sold off at subsidized rates to genuine private farmers for continued usage in the private sector.
iii. The serviceable ones should be returned to the Ministry of Agriculture. The management of Government Tractors and implements should continue to be under the Engineering Division, Tractor Hiring Service as a semi autonomous unit. This is an agreement with the recommendations of Manuwa (1992).
iv. The Government THU should be run on a cost accountability center basis. The head of this unit should be empowered to approve the release of fund for urgent minor repairs to reduce down time. Major repairs will be referred to a higher authority thereby maintaining necessary control and a system of graded responsibility/authority. This system should empower officers along the unit's organogram to exercise certain powers with regard to utilization of revenue for urgent repairs within the limit of his responsibility subject to an upper limit. For example; a tractor operator may be allowed to spend the sum of N100.00 for vulcanizing his tyre without reference to any higher authority, with a limit of N500.00 of such expenditure in a month. Ditto the supervising engineer may be authorized to spend some amount for the repair of bounced ball bearings or any of such urgent jobs subject to a predetermined threshold per month. This spending limit should be tied to the workers output. All claims for major repairs or involving large sums must be referred to the Permanent Secretary and Commissioner for approval. This will reduce the bureaucracy associated with Government set up which has been injurious to the THU; allow repairs and service to be rendered in a timely manner and ensure that practitioners are not handicapped because the control of the machines and the people are not with them (Ige, 1984).
v. Administration should be limited to not more than 1 accountant, 1 administrative officer, typist, office assistant and clerical officer to reduce monthly recurrent expenditure.
vi. Cost of Tractors services should continue to be government subsidized. To do otherwise is to increase the cost of hiring to an unsatisfactory level for farmers. Shagavan (1990) found out that the 3rd World peasant farmer will need up to 28 years to produce enough crops to pay for one average tractor while the developed country farmer needs only 0.9 years. Subsidy of agriculture will also create some balance in international trading. According to Lipton (2005) subsidy by western economies often leads to a depression of world food prices such that peasant farmers of the developing countries cannot compete.

Table 3. Record of Payment on Leased Tractors and Implements

S/N	*Vendor	No of Tractors Allocated	Description	Total Amount (N'000)	1st Payment (N'000)	2008 (N'000)	2009 (N'000)	2010 (N'000)	Total Repayment Due (N'000)	Total Repayment Made (N'000)	% Repayment	Tractor Recovered Yes/No
1	A	1	Swaraj,74hp	5,630.00	387	387	100	-	3,869.68	874	22.5	No
2	B	1	Swaraj,74hp	5,630.00	387	387	258	-	3,869.68	1,032.00	26.6	No
3	C	2	Swaraj,74hp	11,260.00	774	774	516	1,560.00	7,739.37	3,624.00	46.8	No
4	D	1	Swaraj,74hp	5,630.00	387	386.97	260	155	3,869.68	1,189.00	30.7	No
5	E	1	Swaraj,74hp	5,630.00	387	387	260	55	3,869.68	1,089.00	28.1	No
6	F	1	Swaraj,74hp	5,630.00	387	587	400	-	3,869.68	1,374.00	35.5	No
7	G	1	Swaraj,74hp	5,630.00	387	515.96	128.	516	3,869.68	1,547.95	40.0	No
8	H	1	Swaraj,74hp	5,630.00	387	515,96	258	774	3,869.68	1419	36.6	No
9	I	1	Swaraj,74hp	5,630.00	387	645	1,290.	1,267.81	3,869.68	3589.81	92.7	No
10	J	1	Swaraj,74hp	5,630.00	387	258	-	-	3,869.68	645	16.6	No
11	K	1	Swaraj,74hp	5,630.00	387	-	-	-	3,869.68	387	10.0	Yes
12	L	1	Swaraj,74hp	5,630.00	387	-	-	-	3,869.68	387	10.0	Yes
13	M	1	Swaraj,74hp	5,630.00	387	-	200	190	3,869.68	777	20.0	No
14	N	4	Swaraj,74hp	22,520.00	1,547.87	-	-	-	15,478.72	1,547.87	9.0	Yes
15	O	1	Eicher,50	4,434.21	230	354	70	90	1,995.39	744	37.2	Yes
16	P	1	Eicher,50	4,434.21	222	222	80	-	1,995.39	524	26.2	No
17	Q	1	Eicher,50	4,434.21	221.71	221.71	-	-	1,995.39	443.42	22.2	No
18	R	1	Eicher,50	4,434.21	221.71	221.71	291.71	-	1,995.39	735.13	36.8	No
19	S	1	Eicher,45	4,181.56	209.1	209.1	-	-	1,812.01	418.2	23.0	No
20	T	2	Eicher,45 Mahindra,39	7,744.37	2,827.50	-	-	-	3,474.65	2,827.50	8.1	No
21	U	1	Mahindra,39 Taishen	3,562.81	178.14	358.14	240	-	1,662.64	776.28	46.1	No
22	V	1	Vitec,12 Massey	1,346.59	67.35	-	15	34.5	605.96	116.85	19.2	No
23	W	1	Ferguson,	5,823.94	291.19	-	291.19	-	1,650.11	582.38	35.2	No
**Total		28							86,841.18	27609.77	31.79	

Source: Ondo State Ministry of Agriculture,(2010)
*Name of client protected
**Leasors were not interested in 2 Taishen Vitec tractors

The low capability for investment in the ownership or hiring of farm machineries are the consequences of low farm gate prices of most agricultural crops due to the loose, inefficient and mostly unprofitable distribution systems of food crops produced by the mainly subsistence farmers in Nigeria. Extracts of a survey report by Babatunde (2008) on agricultural production in Kwara state in 1986 (table 4) illustrates the state of unprofitability of farming activities in Nigeria. This can be taken to be a fair representation of the national figures due to the central geographical and location of the state. The result shows that the mean total farm income is 45% of the income per capita per year over all income sources while the income from crop production is merely $115. Access to formal or informal credit was put at 0.204 on a scale of 0 to 1. Another report by Babatunde and Oyaloye (1998) reported that the farm gate price for maize in the same community is as low as #15,000.00 per ton.

Table 4. Survey Report on Agricultural Production in Kwara State in 1986

S/N	Description	Value
1	Average farm size	1.9 ha
2	Mean total household income	#30,245.70 ($250)
3	Mean total farm income	#15,226.50 ($127)
4	Mean crop income	#13,797.80 ($115)

The resulting low production level completes the vicious circle. These are the factors necessitating the intervention of government through the subsidization of improved technology to boost provision.

Subsidy recovery should be in form of grants payable to the THU at the close of each season based on the percentage of subsidy per area basis and achievement annually. The non-recovery of subsidy from government is accountable for the failure of most THU. In the private sector, failure can be accounted for by the non-charging of economic rates by vendors of farm machinery either due to ignorance or lack of patronage.

As an illustration, in a THU that ploughs 2000 hectares per annum that is subsidized up to 55% of the economic rate of N6000, the cost of subsidy recoverable from government on ploughing alone is N6, 600,000 per annum. Ditto for other operations performed. Where government does not pay the total cost of subsidy at the end of every year, the THU runs into problems. This is in line with what obtains in most advanced countries and this is done both at the production level and even in some cases when marketing. According to Ige (1984), in Japan mechanization was stipulated as a government policy such that purchasing power of its producers was increased through subsidization of farmer price for rice at an artificial high level of three to four times world market price. Ige (1984) further noted that the buoyancy of the U. S. agriculture is hinged on policies of: price supports, acreage limitations, federal land and bank loan, rural electrification, research, extension and educational programs. No country that is not self sufficient in food production is ever truly great (see what politics the USA/USSR is playing with wheat import).

vii. Since currently available tractors in the Ministry of Agriculture are nearing the end of their useful life (10 years), Government should consider the purchase of new tractors for this unit as a priority project and to take off.

viii. Land clearing equipment such as Bulldozers, rakes etc should be deployed to meet the requirement of expanded land development through land clearing which is a precondition for participation in the T. H. U operations for increased food production and rural development. However clearing of large hectarages (above 5%ha) at a location should be avoided to prevent avoidable and unintended environmental hazards.

4. CONCLUSION

In consideration of the aforementioned as a result of the cumulative experience at the Agricultural Mechanization Company, the Ondo State Investment Holdings, Agricultural Inputs Supply Company, this paper submits that Governments in the less developed countries must continue to be involved in sustainable agriculture through subsidized tractorisation as done with fertilizer use for our current level of agricultural development. The challenge is daunting, far above the level of the ordinary farmer and since it is not attractive to businessmen, the government will have to pick up the gauntlet if we are not to remain at the primitive mechanization stage of hoes and cutlasses forever.

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ANALYSIS OF THE MOTION OF WEEDING TOOLS AND DEVELOPMENT OF A ROTARY POWER WEEDER

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ABSTRACT

The motion of the weeding disc at any point on the surface of a rotary tiller travels was studied. Parametric equations were used to describe the motion of path followed by the weeding tines. The effective performance of soil working tool was related to the kinematic parameter of the soil working tools, the forward travel distance and speed of the rotary tines and working action of components of weeding tool. The design parameters for appropriate soil working tools and implements were established. The weeder consists of a 5 hp-petrol engine, three ground wheels (pneumatic), tool assembly, frame and handle. The construction of the powered rotary weeder was done in the workshop of the Department of Agricultural and Biosystems Engineering, University of Ilorin, Ilorin, Nigeria. The performance of the weeder was investigated by considering the effects of four (4) weeding tools (Iron rod tine, Cable tine, Line yard tine and Plastic strand tine) and three (3) levels of weeding speeds (1804 rpm, 2435 rpm, 3506 rpm) on the weeding index, weeding efficiency and field capacity. The data were subjected to analysis of variance (ANOVA) using a 4×3 factorial experiment in a randomized complete block design. The analysis of results indicated that the forward speeds of 0.4 m/s to 0.5 m/s and engine speeds of 1804 rpm to 2261 rpm resulted in weeding efficiency of 54.98% to 59.05% respectively. Weeding tool type had significant effect on the weeding efficiency and on field capacity. The performance of the iron rod tine was better than line yard tine, cable tine and plastic tine in terms of weed removal efficiency, field capacity and ease of operation.

KEYWORDS: Weeding, tool, rotary tiller.

1. INTRODUCTION

Weeds generally devalue the potential of land for agricultural application. Perennial weeds which tend to accumulate on long fallows increase cost of clearing, cleaning and reduce effective application of energy expected to be utilized on productive value added activities on agricultural production. Weeds waste excessive proportions of farmers' time, thereby acting as a major barrier on agricultural development. The use of mechanical weeder will reduce drudgery and ensure a comfortable posture for the farmer or operator during weeding operation. Hand hoes are common futures in farms in Nigeria for the purpose on weeding. Manual weeding is labour-intensive, accounting for about 80% of the total labour required for producing food in Nigeria (Odigboh and Ahmed, 1979). The weeds may be poisonous to man or livestock. The weeds act as a vector for crop pests and diseases, which may spread to the crop. Weeds delay maturity, slow down the process of harvesting and depress crop quality by contamination of the harvested product. Oni (1990) noted that without adequate weed control, it is impossible to obtain good yields from cultivated crops and also that weeds accounts for about 50-70% reduction in yield; particularly in the humid tropics where torrential rainfall significantly interrupt work on the farms in the season.

According to Nganilwa *et al.*, (2003), a farmer using only hand hoe for weeding would find it difficult to escape poverty, since this level of technology tends to perpetuate human drudgery, risk and misery. The productivity of using traditional hoe is low with very high energy demand in the range of 7.0 to 9.5

KJ/min compared with 4.5 KJ/min optimal limit of continuous energy output of man (Nwuba, 1982). Weeds interfere with crop production in several ways and they reduce yields by competing directly for the resources of the environment and inputs in terms of water, nutrients and light (Lavabre, 1991). Weed must be properly controlled and in timely fashion. Other methods of weed control were reported to have negative influence on the land, environment, crop and operators. The use of herbicides has adverse effects on desert encroachment and intensive application of pesticides contributes significantly to environmental pollution Busari, 1996, Gobor and Lambers, 2007.

The problems with existing power weeder are diverse. The problems of improper design of farm machinery for specific ecological zone, excessive manual labour required to move the machine and high energy requirements to propel the operational components of the tillage machines is higher for soil engaging equipment also the implications of the unfair competition of imported alternatives, and design and development of some prototypes that are not yet perfected among other factors constitute the major problems in farm tillage machinery development in Nigeria (Hoki et al., 1992, Odigboh 2000, Olaoye 2007). A critical review and analysis of the motion and working action of components of weeding tools is important to arrive at suitable design parameters for appropriate soil working tools and implements.

The main objectives of this study are to carry out an analysis of the motion of soil working components and to develop a rotary powered weeder.

2. MATERIALS AND METHODS

2.1 Description of the Motion of Weeding Components of a Rotary Powered Weeder

A vivid arrangement of a rotary powered tiller is shown in Fig. 1. The weeder consists of the following components; a 5 hp-petrol engine, three ground wheels (pneumatic), tool assembly, frame and handle. The weeder is pushed manually and the power to the rotary hoe is supplied from the engine through belt and pulley arrangement. A theoretical analysis of the motion of a rotary tiller blade was undertaken after Hendricks and Gill (1978). The motion of the weeding disc at any point on the surface of a rotary tiller travels through a trochoidal or cycloidal path depending on the distance of the point from the rotor axis (radius). During operation, the motion of the rotor of a rotary tiller is generated by a combination of the machine's forward motion, the rotors rotational motion of the tines on the disc and the distance of rotational axis to the point of interest (rotor radius). The parametric equation which describes the path of a point $p_{x,y}$ on the rotor is as shown in Fig 2.

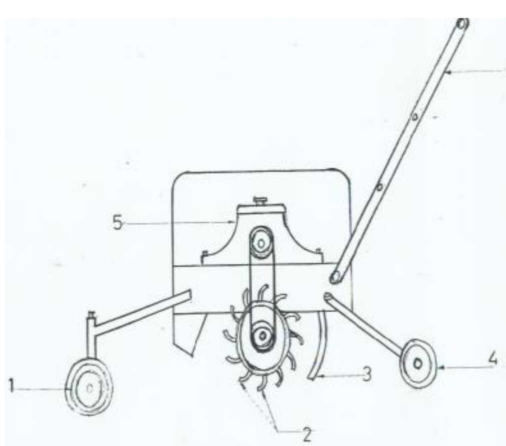


Fig. 1. Schematic Illustration of Power Rotary Tiller: 1. Front Wheel, 2. Tine, 3. Guard, 4. Rear Wheel, 5. Prime Mover, 6. Handle

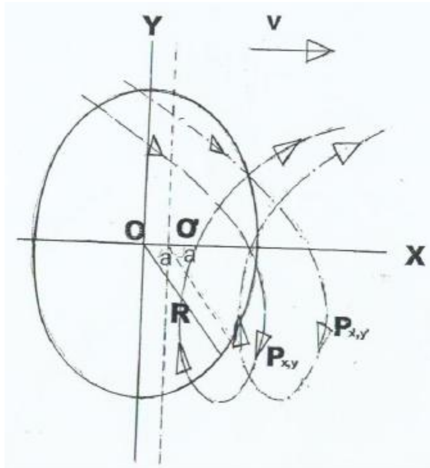


Fig. 2. Graph of the Path of a Pair of a Forward Travel of a Rotary Tiller

The displacement *x* and *y* axis are as shown in equations 1 and 2.

$$x = Vt + R\cos wt \quad 1$$
$$y = R\cos wt \quad 2$$

Where:
R = rotor radius or distance from the rotational axis to the point of interest, *V* = machine forward velocity and its value is between $0 < V < Rw$, *t* = time taken the machine to operate, *w* = angular velocity of the rotor. Note: w is negative for forward rotation, *wt* = angular rotation of the times.

The corresponding *x* and *y* components velocities, accelerations and directions of the point $p_{x,y}$ are presented by equations 3 to 6.

Velocities; $\dot{x} = V + Rw\sin wt$ 3

$\dot{y} = Rw\cos wt$ 4

Acceleration; $\ddot{x} = -Rw^2 \cos wt$ 5

$\ddot{y} = -Rw^2 \sin wt$ 6

Hence, velocity of point of interest $p_{x,y}$ on the rotor is given by equation 7 and the direction is determined by equation 8.

$$\dot{V} = \left(x^2 + y^2\right)^{1/2} \quad 7$$

$$\tan \cdot = \frac{\dot{y}}{\dot{x}} \quad 8$$

Where:

· = angle between the *x*-axis and velocity vector *V*.

Similarly, acceleration of $p_{x,y}$ in the direction of point of interest is determined by equation 9 and the direction is indicated by equation 10.

$$a = \left(\ddot{x}^2 + \ddot{y}^2\right)^{1/2} = Rw^2 \quad 9$$

$$\tan \cdot = \frac{\ddot{y}}{\ddot{x}} \quad 10$$

According to Odigboh and Ahmed (1979), there exists a point of inflection in the locus as the tines penetrate the soil. At this point; the absolute velocity of the tine in the *x*-direction is zero as shown in equation 11. According to Sineokov (1965) for any weed to be dislodged, the kinematic parameter, a must be greater than one for all soil working rotary tools. The kinematic parameter is defined by equations 13 to 15.

$$\dot{x} = \frac{dx}{dt} = V_m - Rw\sin\text{¤} = 0 \qquad 11$$

$$\therefore \sin\text{¤} = \frac{Vm}{Rw} = \frac{1}{\text{a}} \qquad 12$$

$$\text{a} = \frac{Rw}{Vm} = \frac{1}{1-m} \qquad 13$$

Also, $\text{a} = \frac{V_p}{V_f}$ 14

$$m = \frac{a}{R} V_f \qquad 15$$

Where,

$\cdot = wt$ = angular rotation, V_p = the peripheral velocity of tine tip. (m/s), V_f = the forward velocity of machine (m/s), a = depth of cut by slice, a = velocity ratio (or kinematic parameter of a rotary tine) r = the rake angle, w = the angular rotation of the rotary tines.

The forward travel distance (X^2) is related to the distance between two consecutive points on two adjacent tines (Kepner *et al.,* (1978)). The time required for one revolution of rotary hoe is presented by equation 16. The forward travel distance per slice is given by equation 21 and the number of tines on hoe is "Z" with each tine cutting off a soil slice per revolution.

$$t = \frac{2\text{®}}{w} \qquad 16$$

$$\therefore X_{rev} = V_m t$$

$$\Rightarrow V_m = \frac{2\text{®}}{w} \qquad 17$$

But, $\frac{1}{\text{a}} = \frac{Vm}{Rw}$ 18

$$\therefore V_m = \frac{Rw}{\text{a}} \qquad 19$$

Substitute equation (19) in (17)

$$X_{rev} = \frac{Rw}{\text{a}} \cdot \frac{2\text{®}}{w}$$

$$= \frac{2\text{®}R}{\text{a}} \qquad 20$$

$$X^2 = \frac{2\text{®}R}{\text{a}Z} \qquad 21$$

Equation 21 reveals that for a given values of R and a , the greater the number of tines the smaller the soil slices (Odigboh and Ahmed, 1979). The thickness of the soil slice is presented by equation 22.

$$\partial_{\max} = X_2\left(2m - M^2\right)^{1/2} \qquad 22$$

Where,

$m = a/R$

a = depth of cut by slice.

Equation 22 shows that the thickness of the soil slice decreases as the radius, R of the tine increases, thereby reducing the depth of cut, "a" and leads to pulverization of the soil.

2.2 Design Assumptions and Design Calculations

The assumptions made in the design of the rotary weeder were considered with reference to the field conditions, machine capacity and energy requirement required to power it. The machine is to be powered by a 5-hp internal combustion engine. Belt and Pulley arrangement shall be employed for transmission of power. Engine speed, N_1 is 3600 rpm, diameter of pulley, D_1 = 50 mm, diameter of pulley, D_2 on shaft = 50×6 = 300 mm, pulley ratio = 1:6, shaft speed, N_2 = 600 rpm, maximum soil resistance value = 1.5 kgf/cm^2, coefficient of friction = 0.1, depth of cut, d cm (15 cm) and w = effective width of cut, cm (50 cm).

2.3 Belt and Belt Drive

The factors considered for belt selection are: power rating of the prime mover, length of belt, the centre distance, and correction factor for belt and angle of wrap. The centre distance denotes the centre between the two pulleys (engine pulley and machine pulley). It is determined by equation 23, the pitch length is given by equation 24 and the velocity of belt, V is given by equation 25.

$$C \geq \frac{D_1 + D_2}{2} + 50\ mm \qquad 23$$

$$L = 2C + \frac{\text{®}}{2}\left(D_1 + D_2\right) + \frac{\left(D_2 - D_1\right)^2}{4C} \qquad 24$$

Velocity of belt, $V = \dfrac{\text{®} \times \text{Minimum pitch diameter} \times \text{Speed}}{60}$ 25

The centre distance, $C \geq$ 225 mm and C = 250 mm. The pitch length, L is estimated as 1112.4 mm and a *V*-belt of B-type 1210mm is preferred. The calculated velocity of belt, V evaluated as 9.43 m/s.

2.4 The Main Rotary Weeder Shaft

Shaft design consists primarily of the correct shaft diameter to ensure satisfactory strength and rigidity when the shaft is transmitting power under various operating and loading conditions. During weeding process the shaft is subjected to torsion, bending and axial loads. These are estimated by using Equations 26 to 28.

$$\text{¥}_{XY} = M_t / J = 16M_t / \text{®}d^3 \qquad 26$$

$$S_b = M_b \text{¥}_{XY} = 32M_b / \text{®}d^3 \qquad 27$$

$$d^3 = \frac{16}{\text{®}} S_a \left(K_b M_b\right)^2 + \left(K_t M_t\right)^2 \qquad 28$$

Where; $¥_{XY}$ = torsional shear stress, N/m^2, M_b = bending moment; Nm, M_t = torsional moment, Nm, d = diameter of shaft, m, S_a = axial stress, N/m^2, S_b = bending stress, N/m^2, K_b = combined shock and fatigue factor applied to bending moment, K_t = combined shock and fatigue factor applied to torsional moment.

2.5 Assessment of Power Required

Power required to dig the soil, Pd is obtained from equation 29 and Total power required is calculated from equation 30.

$P_d = S_R * d_1 * w * v$ 29

Total power, $P_t = P_d/ή$ 30

Where; d_1 = depth of cut, cm, (5 cm), w = effective width of cut, cm, (50 cm), S_R = soil resistance, kgf/cm^2, (1.5 kgf/cm^2), P_d = power required to dig the soil, ή = efficiency of transmission, % (75 %).

The estimated power required to dig the soil, Pd is 3.5 hp and the total power required as 4.23 hp, thus, a prime mover of 5*hp* was required for this weeder.

2.6 Determination of Length of Tines

Each hoe consists of twelve tines of equal length. Length of each tine (L_t) is determined by considering sector ABC in Fig. 3.2, length of arc AB, which form the curved tine may be calculated by equation 3.15.

Length of arc AB = $\left(\bar{}_1 - \bar{}_2\right) + \frac{2®r\bar{}}{360^o}$ 31

Where,

$$r = \frac{3}{5}R$$

r = radius of curvature, mm, R = Outer wheel radius, mm, $\bar{} = 90^o$, $\bar{}_1$ = outer wheel diameter, mm, $\bar{}_2$ = disk hole diameter, mm.

Length of time for ¤ 160mm hoe

$$R = \frac{128}{2} = 64\text{mm},$$

$$r = \frac{3}{5}R$$

$$= 38.4\text{mm}$$

$$\bar{} = 90^o$$

$$\therefore AB = \frac{2® \times 38.4 \times 90^o}{360^o} = 60.3$$

$$\therefore \text{Length} = \left(\bar{}_1 - \bar{}_2\right) + \frac{2®r\bar{}}{360^o}$$

$$= 138^o$$

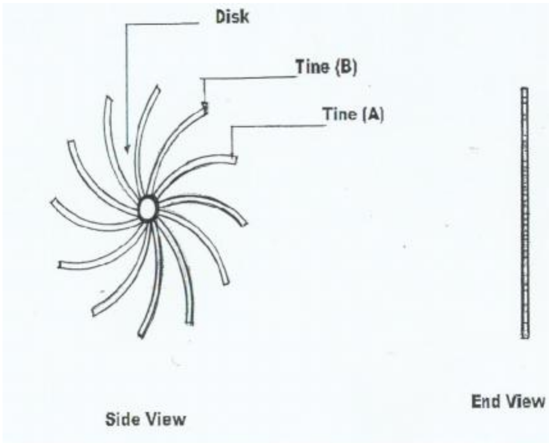


Fig. 3. Sketch of a Disk with Tines

2.7 Handle Design and Ergonomics

Handle is a sensitive part of this machine. It is the point of application of propelling force. Engineering designs and ergonomics considerations of a handle becomes imperative for better performance. Ojo, (1994), ascertained the average hip height to be 940 mm. The information was used to determine the length of the handle where the farmer/ operator can position his hands without bending down. The handle was positioned above the hip height so as to avoid the bending posture; this was reported by Nwuba, (1982) to have contributed mostly to the high energy demand of most manually operated hoes. Hence, this weeder handle was considered good at 1000 mm height above the ground.

2.8 Cutting Geometry

Tines are the working part of the rotary hoe. They break and loosen the soil, uproot the plant and displace the soil particles. Fig. 4 illustrates the geometry associated with a weeder in which the tines move with rotary motion. The plant material is uprooted as the disk which carries the tines rotates. The tine has a velocity component V_{km}, relative to the weeder and a component, V_f due to the forward speed of the weeder. The vector sum of these two components gives the tine velocity, V_{kg}, relative to the ground. In general, the relationship between the rake, bevel and clearance angles is presented by equation 32.

$$¤_{rk} + ¤_{bk} + ¤_{ck} = 90^o \qquad 32$$

Where,
$¤_{rk}$ = rake angle, $¤_{bk}$ = bevel angle, $¤_{ck}$ = clearance angle.

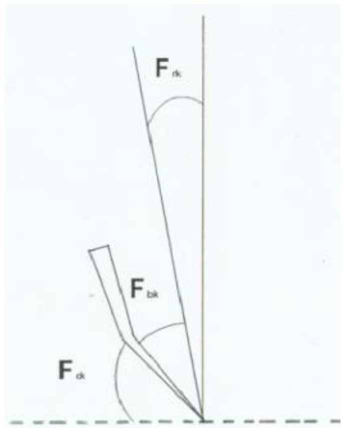


Fig. 4. Illustration of geometry of tine

2.9 Deflection of Plant Stem

The bending strength of a plant may be important during cutting (Ajit et al., 2006). The radial load that would cause failure in bending can be calculated using equation 33 and the deflection of the stem is given by equation 34.

$$F_{bu} = \frac{IS_u}{Lc} \qquad 33$$

Where,
F_{bu} = ultimate load at bending failure, N, I = moment of Inertia of the cross section, mm^4, c = radius from neutral axis of stem to most distant load carrying fiber, mm, S_u = ultimate stress of plant fibers, N/mm^2, L = distance from concentrated load to point of support, mm.

$$\text{¢}_r = \frac{F_r L^3}{C_b EI} \qquad 34$$

Where,
¢_r = radial deflection, mm, F_r = radial concentrated load, N, E = modulus of elasticity of stem fibers, N/mm^2, C_b = constant, I = moment of inertia for a circular section, which is given by equation 35.

$$I = \frac{\text{®} d_2{}^4}{64} \qquad 35$$

Where,
d_2 = diameter of the section, mm

2.10 Weeding Force

Draft data for tillage implements are reported as the force required in the horizontal direction of travel (ASAE D230, 1990). Only functional draft (soil and crop resistance) is reported. Total implement draft is obtained by adding the rolling resistance (*RR*) of the transport wheels. Draft per unit effective width at typical field speeds for row cultivator is given by ASAE standards as:

115-230d_3 N/m Where, d_3 = tool depth, cm 36

The average of the two extreme values, draught per meter at 2cm depth (by design) is

$$\left[\frac{115+230}{2}\right]\times 2 = 345N/m$$

Width of weeding tool is 40 cm (by design).
Hence, draft of implement = 345×0.4
= 138 N

The rolling resistance (RR) is given by ASAE (1990) as

$$RR = \frac{CIbd_4}{C_n}\left[\frac{1.2}{C_n}+0.04\right] \quad 37$$

Where,
C_n = dimensionless ratio which is a function of the cone index (CI) for the soil
b = unloaded tyre section width
d_4 = unloaded overall tyre diameter
For tilled agricultural drive wheel tyres, bd/w = 0.25 on typical soil surface, CI = 80, C_n = 20

Where,
W = dynamic load in Newton normal to the soil surface and is given as

$$W = \frac{CIbd}{cn} \quad 38$$

For wheels on the weeder, b = 0.0738, d = 0.0355m
Substitute these values into equation (19),

$$RR = \frac{80\times 0.0738\times 0.0355}{20}\left[\frac{1.2}{20}+0.4\right] = 1.048\times 10^{-3}N$$

RR for the 3 wheels = $4.19\times 10^{-3}N$
$\therefore$ Total draft = $138+4.19\times 10^{-3}N$
= 138.004 N

The force acting during cutting is illustrated in Fig. 5. The force, F applied at an operating angle ~ can be resolve into two components namely, the vertical components, Fsin~ that causes the penetration of the cutting knife edge and the horizontal component, Fcos~ that causes the shearing of a thin sheet of soil along with roots of weeds.
For the weeder, ~ = 2.3^0, therefore,
$F\cos 2.3^0$ = 138 N and F = 138.11 N

The perspective and other views the rotary weeder are presented as Figures 5 to 8.

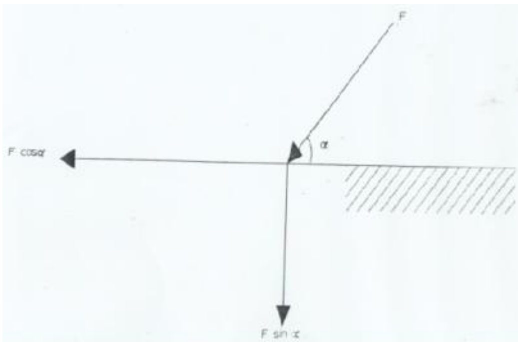
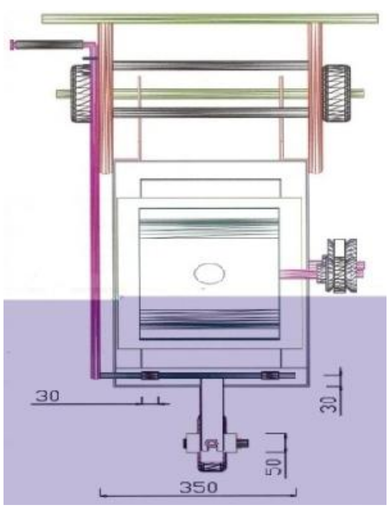


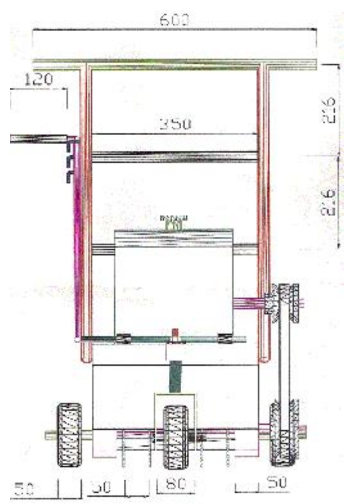
Fig. 5: Forces acting during weeding

2.11 Fabrication Processes

The construction of the powered rotary weeder was done in the workshop of the department of Agricultural and Biosystems Engineering, University of Ilorin, Ilorin. The fabrication processes involved cutting, folding and welding of different parts together. The weeder was constructed in such a way that the prime mover and the weeding gang can be detached from the machine without damage.

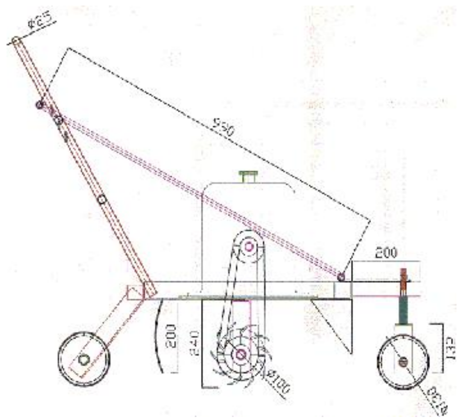


All Dimensions in mm
Fig. 6: Plan View of the Rotary weeder



All Dimensions in mm
Fig. 7: Front View of the Rotary Weeder

Figures 6, 7, 8 and 9 show different perspectives of the powered rotary weeder.



All Dimensions in mm
Fig. 8: Left Side View of the Rotary Weeder

Fig. 9: Isometric View of Rotary Power Weeder

2.1 Experimental Methods for Machine Testing and Performance Indices

The performance evaluation of the constructed rotary power weeder was conducted at the experimental field behind the department of Agricultural and Biosystems Engineering, University of Ilorin, Ilorin, Nigeria. The textural soil classification in this field was ascertained to be sandy loam. About 54 m$\times$4 m plot of land was mapped out and sub-divided into 2 plots of 27 m$\times$2 m to allow for two replicates of field experiment. The weeding tools were tested on the mapped out plots to determine the weeding index, weeding efficiency and field capacity. The experimental area was infested mostly with weeds like *Trifolium repens* (clover), *cryperus eragrotis* (umbrella sledge), *cyperus rotumdus* (Nut grass), *cynodon dactrylon* (couch grass), *cynosures echinatus* (Dog's Tail), *phyllanthus amarus* (Petty spurge), *Lactuca taracifolia* (Wild lettuce), *Sida acuta* (broom weed), *Imperata cylindrical* (logongrass), *Amarantus spinosus* (thorny pig weed) and *Eleusine indicae* (goose grass).

The performance of the weeder was investigated by considering the effects of four (4) weeding tools (Iron rod tine, Cable tine, Line yard tine and Plastic strand tine) and three (3) levels of weeding speeds (1804 rpm, 2435 rpm, 3506 rpm) on the weeding index, weeding efficiency and field capacity. The data were subjected to the analysis of variance (ANOVA) using a 4$\times$3 factorial experiment in a randomized complete block design.

Weeding index is a ratio between the number of weeds removed by a weeder and the number present in a unit area and is expressed as a percentage (Rangasamy, *et al.*, 1993). A plot of 27 m$\times$ 2 m meter is selected out of the main plot for sampling. Weeds in the plots are counted before and after weeding using the constructed rotary weeder. The time taken to perform this operation was noted. Equation 39 was used to calculate weeding index.

$$\text{Weeding index, } I_W = \frac{W_1 - W_2}{W_1} \qquad 39$$

Where,
W_1 = weeds before weeding, W_2 = weeds after weeding,

The weeding efficiency was determined by using equation 40.

$$\text{Weeding efficiency, } \Sigma = \frac{W_1 - W_2}{W_1} \times 100\% \qquad 40$$

Where; W_1 = number of weeds before weeding, W_2 = number of weeds after weeding, Σ = weeding efficiency

The weeding tools were tested on the same plots to determine the field capacity of each of them. Field capacity is the amount of area that a weeding tool can cover per unit time as shown in equation 41.

$$\text{Field capacity (ha/h)} = \frac{60}{t} \times \frac{A}{10{,}000} \qquad 41$$

Where; A = Area covered (m^2), t = Time taken in minutes

3. RESULTS AND DISCUSSION

3.1 Weeding Efficiency

Tables 1 and 2 show the mean densities after weeding operations were conducted on the experimental blocks. In Table 3, Rod tine has the highest weeding efficiency while the plastic tine has the least weeding efficiency. This is because the teeth of the iron rod had more interaction with the soil. This indicates that the Plastic Strand is not effective as a weeding tool. Figures 9 and 10 show the effects of the four tested weeding tools on weeds. Table 2 shows that higher engine speed leads to higher efficiency of iron rod tine. The relationship between mean values of forward speed and weeding efficiency was highlighted in Table 2. The values show that if the weeder is operated at higher speeds above 0.8 m/s a characteristic rough weeding will be observed. A comparison of weeds removed by the different weeders are shown in Fig. 10.

Table 1. Mean Weed Densities Before and After Weeding

Weeding tools	Blocks	Number of weed		
		Before weeding	After Weeding	Number of weed removed
Rod tine	1	588.78	244.33	344.45
	2	722.22	292.33	429.89
Cable tine	1	644.44	566.56	77.88
	2	729.78	648.00	81.88
Line yard tine	1	716.78	603.56	113.22
	2	742.78	625.67	117.11
Plastic Strand Tine	1	787.11	757.44	29.67
	2	762.89	739.11	23.78

Table 2: Time taken, speed and efficiencies for various engine speeds (Rod tine weeder)

Engine speed (rpm)	Distance moved (m)	Time taken (Seconds)				Forward Speed (m/s)				Efficiency (%)			
		Block 1	Block 2	Block 3	Mean	Block 1	Block 2	Block 3	Means	Block 1	Block 2	Block 3	Mean
1804	27	55.09	52.33	52.88	53.35	0.49	0.46	0.51	0.49	53.67	56.37	54.89	54.98
2004	27	51.00	51.44	52.44	51.63	0.53	0.53	0.52	0.52	58.48	57.81	57.52	57.94
2261	27	47.35	46.23	46.75	46.78	0.57	0.58	0.58	0.58	58.87	59.11	59.18	59.05
2435	27	45.48	45.41	45.49	45.46	0.59	0.59	0.59	0.59	63.73	63.79	63.71	63.74
3506	27	31.74	32.00	31.85	31.86	0.85	0.84	0.85	0.85	75.62	72.10	72.41	73.37

Table 3: Weeding efficiencies for block 1 and 2

Weeding tools	Weeding Efficiencies (%) (block 1)	Weeding Efficiencies (%) (block 2)
Rod Tine	58.50	59.52
Cable Tine	15.79	15.77
Line yard Tine	12.08	11.21
Plastic Strand Tine	3.77	3.12

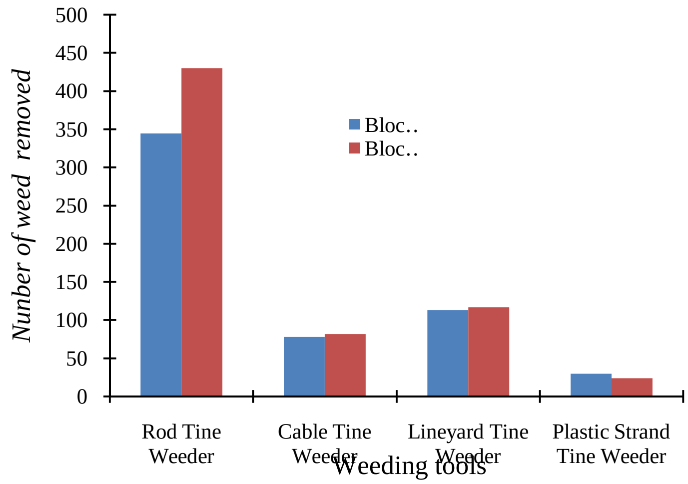


Fig. 10: Weed removed for various weeding tools

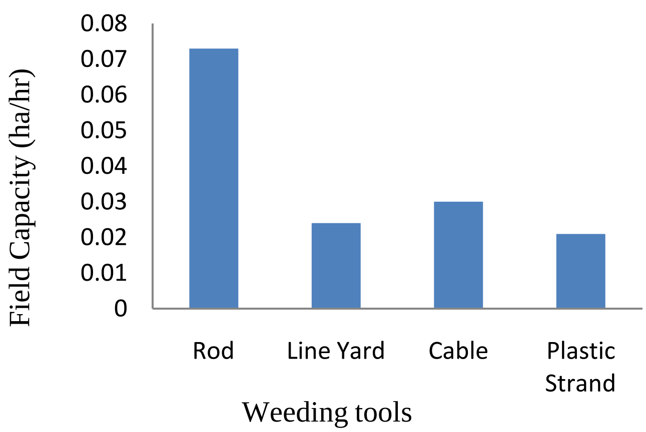


Fig. 11. Field Capacities for 4 Different Weeding Tools

3.2 Effect of Engine Speed on Weed Density

Table 2 shows the number of unremoved weeds after weeding trials at different levels of engine speed. It shows that engine speed has a proportional effect on iron rod tine, i.e. engine speed influenced the efficiency of the weeder. The analysis of variance of the effect of weeding tools and speeds on weed density indicated that engine speed is one of the critical factors during weeding operation (Table 4).

Table 4: Analysis of variance for the effect of weeding tools and speeds on weed density

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F-value	P-value
Blocks	1	8214.00	8214.00	7.722	0.018^{s}
Weeding tools	3	750029.571	250009.857	235.026	0.0001^{s}
Speed	2	111693.639	55846.820	52.5	0.0001^{s}
Weeding tools × Speed	6	15124.194	2520.699	2.370	0.102^{ns}
Error	11	11701.290	1063.754		
Total	23	8363540.442			

[s] = significant at 5% level of significance
[ns] = not-significant at 5% level of significance

- ✓ There is significant difference between the blocks (1&2)
- ✓ There is significant difference in the main effects-Weeding tools and Speed (after weeding)
- ✓ The interaction between Weeding tools and Speed is not significant.

A multiple comparison of the influence of the effect of weeding tools and speeds of operation of the weeding tool using the Duncan's New Multiple Range Test (DNMRT) showed clearly that the mean weeding density obtained are significantly different compared to other mean values (Tables 5 and 6).

Table 5: Duncan Multiple Range Test for the effect of weeding tools on weed densities

Weeding tools	Mean densities*
Rod Tine	268.33^{a}
Cable Time r	602.67^{b}
Line yard Tine	611.83^{b}
Plastic Strand Tine	748.28^{c}

*Means with different letters are significantly different from each other.

Table 6: Duncan Multiple Range Test for the effect of Speeds on weed densities

Speed	Mean densities*
1804	559.33^{b}
2435	640.54^{c}
3506	473.46^{a}

* Means with different letters are significantly different from each other.

3.3 Field Capacity and Weeding Efficiency

The results in Fig 11 show the computed field capacities for the four weeding tools. It was observed that the iron rod tine had a higher field capacity (ha/hr) than other weeding tools. The field capacity of the power weeder was observed to range from 0.068 ha/hr and 0.079 ha/hr as shown in Figure 12. Figure 13 shows the weeding efficiency of the power weeder at various levels of speed.

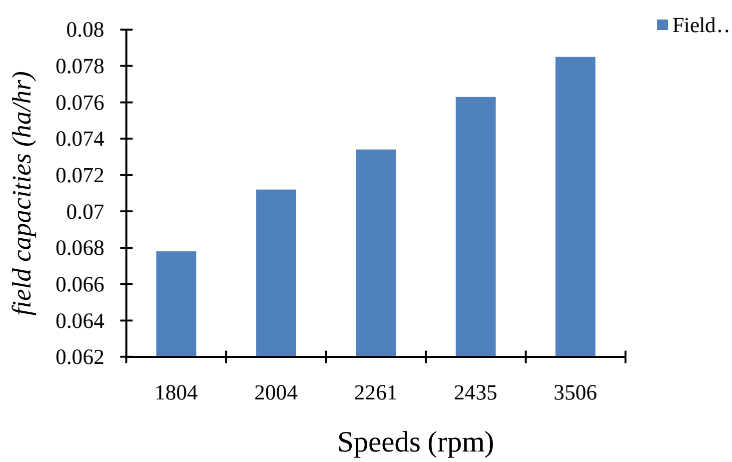


Fig. 12: Field capacities at various engine speed

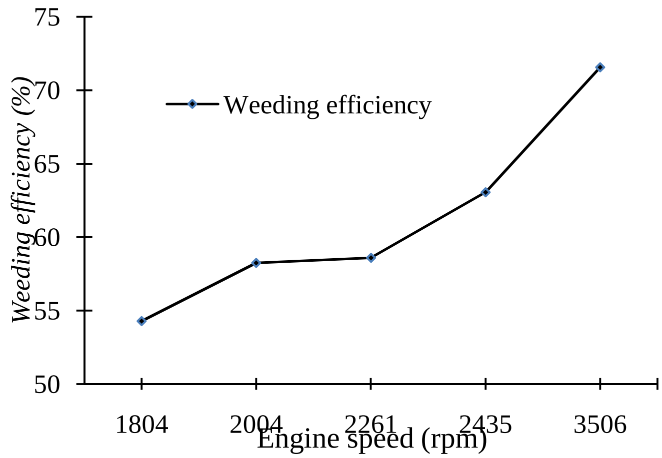


Fig. 13: Weeding efficiencies for engine speeds

Table 7: Number of weeds removed and efficiencies at various engine speeds (Rod tine weeder)

Engine speed (rpm)	Blocks	Weed Density		Number of weeds removed	Efficiency (%)
		Before weeding	After weeding		
1804	1	520.22	241.49	278.73	53.67
	2	554.33	241.85	312.48	56.37
	3	602.89	277.75	325.14	54.89
2004	1	577.85	245.70	332.15	58.48
	2	615.78	265.96	349.82	57.81
	3	668.15	290.51	377.64	57.52
2261	1	652.00	274.69	377.31	58.87
	2	694.75	291.03	403.72	59.11
	3	753.87	315.27	438.60	59.18
2435	1	703.19	262.07	441.12	63.73
	2	746.30	277.69	468.61	63.79
	3	811.84	302.74	509.10	63.71
3506	1	1012.45	257.05	755.40	75.62
	2	1074.53	310.53	764.00	72.10
	3	1168.77	334.15	834.62	72.41

At the forward speeds of 0.4 m/s to 0.5 m/s and engine speeds of 1804 rpm to 2261 rpm resulted in weeding efficiency of 54.98% to 59.05% respectively.

4. CONCLUSION

The motion of the weeding disc at any point on the surface of a rotary tiller travels through a trochoidal or cycloidal path depending on the distance of the point from the rotor axis of rotary weeder and parametric equations were used to describe the motion of path followed by the weeding tines. The effective performance of soil working tool was related to the kinematic parameter of the soil working tools, the forward travel distance and speed of the rotary tines. The design parameters for rotary power weeder indicated that the choice of transmission elements affects the performance of the weeder. The type of weeding tines, tine velocity components and the weeder forward speed affect significantly the corresponding values of weeding density and weeding index.

Weeding efficiency of the rotary weeder is influenced by the type of weeding tines adopted and the weeding tine with high value of soil – material interaction significantly increase the weeding efficiency. The analysis of variance of the effects of the weeding tools and speeds on the weed density indicated that engine speed is one of the critical factors that influence the operation of the rotary weeder. The highest field capacity was observed when the iron rod tine was used as weeding tools.

NOTATIONS

a = depth of cut by slice
A = Area covered (m^2)
b = unloaded tyre section width
d = diameter of shaft, *m,*
d_1 = depth of cut, cm, (5 cm)
d_2 = diameter of the section, *mm*
d_3 = tool depth, *cm*
d_4 = unloaded overall tyre diameter
c = radius from neutral axis of stem to most distant load carrying fiber, *mm*
C_b = constant
C_n = dimensionless ratio which is a function of the cone index (*CI*) for the soil
E = modulus of elasticity of stem fibers, N/mm^2
F_{bu} = ultimate load at bending failure, *N*
F_r = radial concentrated load, *N*
I = moment of Inertia of the cross section, mm^4
K_b = combined shock and fatigue factor applied to bending moment
K_t = combined shock and fatigue factor applied to torsional moment.
L = distance from concentrated load to point of support, *mm*
$m = a/R$
M_b = bending moment; *Nm*
M_t = torsional moment, *Nm*
^{ns} = not-significant at 5% level of significance
P_d = power required to dig the soil
r = the rake angle
R = rotor radius or distance from the rotational axis to the point of interest.
R_1 = Outer wheel radius, mm
^{s} = significant at 5% level of significance
S_a = axial stress, N/m^2
S_b = bending stress, N/m^2
S_R = soil resistance, kgf/cm^2, (1.5 kgf/cm^2)
S_u = ultimate stress of plant fibers, N/mm^2
t = time taken the machine to operate
V = machine forward velocity and its value is between, $0 < V < Rw$
V_p = the peripheral velocity of tine tip. (m/s)
V_f = the forward velocity of machine (m/s)
w = effective width of cut, cm, (50 cm)
W = dynamic load in Newton normal to the soil surface
W_1 = weeds before weeding
W_2 = weeds after weeding
¢$_r$ = radial deflection, *mm*
ή = efficiency of transmission, % (75 %)
¯$_1$ = outer wheel diameter, mm
¯$_2$ = disk hole diameter, mm
¤$_{rk}$ = rake angle
¤$_{bk}$ = bevel angle
¤$_{ck}$ = clearance angle
Σ = weeding efficiency
w = angular velocity of the rotor. Note: w is negative for forward rotation.

wt = angular rotation of the times.

▪ = angle between the *x*-axis and velocity vector *V*.

ª = velocity ratio (or kinematic parameter of a rotary tine)

$¥_{XY}$ = torsional shear stress, N/m^2

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DEVELOPMENT OF A GREENHOUSE ROOF CLEANER

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ABSTRACT

The efficiency of a greenhouse is influenced by the cleanliness of the glazing material through which heat and light penetrate into the enclosure. The common cleaning method for most greenhouses in developing countries is the use of a ladder to climb onto the roof to clean which is labour intensive, time-consuming, imposes severe loads on the roof that could cause failure and is dangerous to the cleaner. Consequently, many greenhouse roofs are rarely cleaned and the accumulated dirt reduce the amount of light and heat penetrating into the house. Experimental studies in such greenhouses may fail to produce valid findings while crop production may not yield the desired produce. There is therefore the need for appropriate equipment for effective cleaning of greenhouse roofs in order to eliminate the disadvantages of the existing common method. The focus of this study was to develop simple equipment that could be used for the cleaning of a greenhouse roof.

A manually operated brush type greenhouse roof cleaner was designed, fabricated and tested. The equipment consisted of a roughly cylindrical brush mounted on a frame attached to a handle made of three concentric and adjustable cylindrical pipes. The equipment was fitted with a wash mix dispenser operated by a 1 hp sump pump. The equipment testing involved recording the illumination within and outside three greenhouses before and after washing with the equipment.

Increases of 6.03, 13.19 and 16.36 % in transmittances of the roofs following washing with the equipment were recorded. A simple, easy to set-up, operate and maintain equipment for the cleaning of greenhouse roof has been designed and demonstrated great potentials in cleaning. Further studies aimed at reducing the weight, prolonging service life and improving efficiency are required.

KEYWORDS: Greenhouse, roof cleaner, transmitted light intensity, transmittance, light transmission efficiency.

1. INTRODUCTION

Greenhouses are buildings used to create enabling environments for the production of crops either for commercial purposes or for research. The objective is to achieve temperature ranges, relative humidity, light and Carbon dioxide (CO_2) levels that are optimal for crop cultivation (Redmond, 2009). Greenhouses were initially designed for commercial crop cultivation during winter in temperate regions where the natural climate could not support the cultivation of crops while in the tropics the few that existed were exclusively used for research (Mijinyawa and Gbadebo, 2011). There was no need for greenhouses for commercial crop production in the tropics as the natural climate was adequate to support crop production until very recently when the negative effects of climate change on agriculture began to manifest and the hitherto stable climate became unpredictable. The desire to mitigate some of the negative effects of climate change has resulted in an increase in the use of greenhouses in the tropics in recent times. The inherent benefits include extension of cropping period, repeated cropping, efficient water and fertilizer utilization through drip irrigation, qualitative and quantitative food production, reduction of the risks of crop failure, safety of foodstuffs, specialization in crop production and controlled environment for research (Lindley & Whitaker, 1996; Mijinyawa, 2011).

The glazing or roof covering material of a greenhouse is a critical component of the greenhouse, because it is the material that permits the penetration of light and heat into the structure (Gedalyahu, *et a*l, 2004).

The covering material used on a greenhouse influences the productivity and performance of the structure, greatly impacting on the level and quality of light available to the crop (Giacomelli and Roberts, 2005). Therefore, the greenhouse coverings irrespective of the type must be clean and clear enough to provide optimum light transmission.

Light transmitted to crops within the greenhouse is affected by the build-up of internal condensation that forms on the greenhouses' cladding due to temperature gradients, accumulation of birds' droppings which frequently perch and defecate on the roof, carbon deposits, oil droplets from tractor, algae growth, dust and particles from various agricultural operations in the greenhouse neighbourhood. The accumulation of these dirts on the roof sheets diffuses light rays and prevents about 30% of light energy or photosynthetic radiation from penetrating into the cropping space of the greenhouse (Manor, *et al*. 2004). As a result, the growing rates of the produce and ripening processes of the seeds or fruits are delayed and retarded. In addition, a decrease in amount of light results to about 30% loss of plants' weight and the quality of yield is lower than that of the yields from greenhouses with clean roofs. There are also high risks of plant disease and pest attack, high risk of dormancy, reduction in flowering and tuberization as well as poor stalk development. Keeping the roof of greenhouses in perfectly clean condition is therefore very important if the maximum benefits of using a greenhouse are to be derived. Regular and thorough cleaning of both the exterior and interior of the greenhouse roof is absolutely essential to maintaining the transmittance of the roof material (Gedalyahu *et al*, 2004; Mohammad, 2004).

The cleaning of greenhouse roofs could be done manually using ladders or automated using the roofmaster (Fig 1 and 2). As a result of cost and high technology involved, the roofmaster is more restricted to advanced countries while the manual method is the one commonly used in many developing countries, especially Nigeria. The manual method does not only endanger the labourers, it is both time consuming and labour intensive, and exposes both the greenhouse glazing and framing to damage arising from imposed live load from the ladders and workmen. For these reasons, many greenhouse roofs are hardly cleaned.

Fig 1. Manual Cleaning Procedure at the International Institute of Tropical Agriculture (IITA), Ibadan, Nigeria.

Fig 2. The Roofmaster

Despite the importance of maintaining the cleanliness of the glazing material, many greenhouse roofs especially those in Nigeria are rarely washed and this has been partly due to the bottlenecks associated with the manual cleaning method which is the only one available. If accurate research results must be obtained and maximum produce yield, it is necessary that cleaning methods which are easy to use should be developed. This is the origin of this study the primary objective of which is to develop a simple and effective cleaning method for greenhouse roofs.

2. MATERIALS AND METHODS

2.1 Design Considerations

In the design of the greenhouse roof cleaning equipment, the following factors were considered.

2.1.1 Adjustability

The equipment to be designed should be usable in cleaning roofs of different slant heights and in order to achieve this, an adjustable handle was considered. A handle of three concentric pipes of the same thicknesses and weights was chosen.

2.1.2 Materials of Construction

The choice of materials of construction was based on suitability, availability and cost.This was to ensure that the equipment performs and that if the design is found useful, then it should be easy to replicate it. It will also be cheap while local artisans would be familiar with its fabrication. The primary materials of construction are stainless and galvanized mild steel, aluminium, wood and fibrous material. These are all materials that are readily available in many Nigerian markets and those used in this work were sourced locally at Mokola and Agodi Gate Construction materials markets in Ibadan, Nigeria.

2.1.3 Weight of Components

The washing tool is to be moved by the washerman and hence it must be as light as possible so that it can easily be lifted during operation.This is why aluminium was recommended for the brush attachment so that the weight could be reduced to the bare minimum.

2.2 Materials Selection

2.2.1 The Cleaning Brush

The cleaning brush was selected in consultation with painters who use similar tools and the length was chosen to be equal to the length of a glass pane to achieve maximum coverage during cleaning. A length of 610mm was considered adequate. The brush is an assembly of eight 305mm long brushes mounted on a rectangular frame of 305mm and 610mm made of aluminum using 10cm bolts and nuts. The shaft is 6.35mm diameter solid steel rod. Attached to the brush frame is a mix dispenser, which distributes the cleaning mix along the length of the brush during cleaning.

2.2.2 The Brush Handle

The handle which the brush is attached was made from a 2.5mm thick cylindrical hollow pipe and it was considered necessary to make it three concentric pipes for ease of use in cleaning different heights of the roof. Pipes of internal diameters 55mm, 50mm and 45mm and of lengths 500mm, 1000mm and 1,300mm respectively were used for the lower, middle and upper sections of the handle and this was based on the dimensions of the greenhouses expected to be used in testing the equipment while the thickness was to minimize weight. These were tested for bending stress and deflection using the maximum length and least area of cross section in order to confirm their adequacy most especially when the brush is lifted off the roof. Shown in Figure 3 is a schematic representation of the handle as a cantilever. The base of the handle where the operator holds while cleaning is taken to be fixed while the other end where the brush is attached is taken to be the free end with the weight of the brush as the point load.

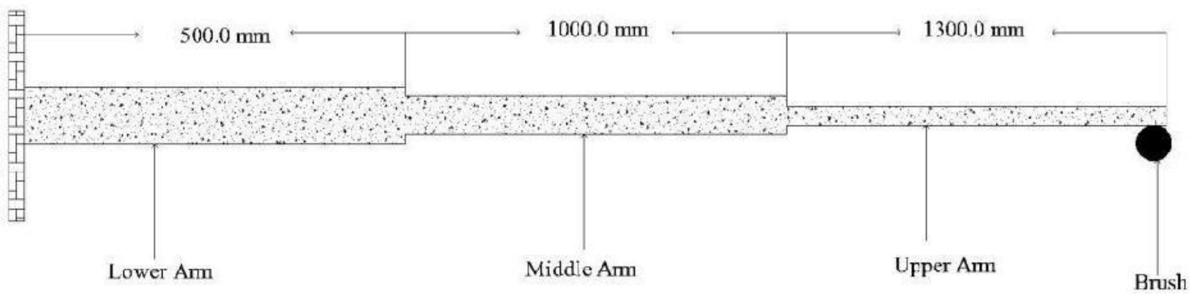

Figure 3. Schematic Representation of the Brush Handle

2.3 Design Calculations

2.3.1 Bending Moment Criterion

By the locking system, when assembled, the three concentric pipes behave as a unit and when in operation, it acts as a cantilever with the weight of the brush supported at the free end. The smallest of the three cross sectional areas can be used to evaluate the bending stress as follows:

Bending moment = $M_b = \dfrac{W_b \times l}{2} = \dfrac{50N \times 2{,}800mm}{2} = 70{,}000Nmm$ …………………(1)

Section modulus = $Z = \dfrac{\circledR\left(D^3 - d^3\right)}{32} = \dfrac{\circledR\left(45^3 - 40^3\right)}{32} = \ 2{,}663.3\ mm^3$ ……………..(2)

$Bending\ stress = \dfrac{\max imum\ \ bending\ \ moment}{\sec tion\ \mathrm{mod}\, ulus} = \dfrac{70 \times 1000}{2{,}663.3} = \ 26.28N/mm^2$ ..(3)

Where: M_b, = moment due to brush, W_b = weight of the brush, l = length of the handle, D = outer pipe diameter, d = inner pipe diameter, Z = section modulus.

This value is far less than the permissible bending stress of 500N/mm^2 for mild steel (Singh, 2005) and from the point of view of bending stresses, the selected dimensions are adequate.

2.3.2 Deflection

Treating the arm as a single beam of length 2,800mm and using the least cross sectional area, the maximum deflection can be calculated as follows:

$$\Delta = \frac{W_b \times l^3}{3EI} \quad \text{……………………………………………………..(4)}$$

$E = 200 \times 10^6 N/mm^2$

$$I = \frac{\circledR(45^4 - 40^4)}{64} = 75{,}635.06\ mm^4 \quad \text{………………………………..(5)}$$

$$\Delta = \frac{(W_b\ )}{3EI} \times l^3 = \frac{500 \times 2{,}800^3}{3 \times 200 \times 10^6 \times 75{,}635{,}06} = \ 0.024mm \quad \text{…………..(6)}$$

Where; Δ is the maximum deflection; E = Young's modulus; I is the moment of inertia and l is the length of handle.

The permissible deflection is given as 0.003 l = 0.003 x 2800 = 8.4mm. This is greater than the calculated maximum deflection and hence the handle is safe.

2.4 Sump Pump Capacity

The capacity of the sump pump to be used to pump the washing mix was based on experience with the pumps used to pump water in domestic houses and offices within the premises of the greenhouses. Taking into account that the height of most greenhouse roofs is less than the height of storey buildings in which 1 hp sump pump is used to pump water, a 1 hp sump pump was recommended for use.

2.5 Fabrication

2.5.1 The Brush

Aluminum hollow pipe of square dimension was cut to 610mm and 305mm lengths for the fabrication of the brush frame using an arch saw. The brushes were attached to the aluminum frame using 10cm bolts and nuts. The shaft was fabricated from 6.23mm diameter solid steel rod and was welded to the frame to provide the revolutional motion of the brush. Because of the initial cutting forces of the arch saw, welding operation and bolting of the brush to the aluminum frame, the brush assembly was balanced on a balancing machine in order to detect the amount of unbalance in the brush. The amount of unbalance detected was corrected by grinding and filing edges and joints. The mix dispenser is a 610mm long and 19.05mm diameter pipe with 2.54mm diameter holes perforated along its length for proper dispensing of the cleaning mix to the brush. The brush is shown in Fig 4.

Fig 4. The Brush

2.5.2 The Handle

The outer diameters of the pipe are 55mm, 50mm and 45mm. The pipes were cut to 500mm, 1000mm and 1300mm using an arch saw. The 55mm and 50mm pipes were welded, while bolt holes were drilled through both the 50mm and 45mm pipes making their connection a bolted one. The bolted connection between the 50mm and 45mm pipes makes it possible for the 45mm pipe to be extruded and retracted into the 50mm during the cleaning process. The connection between the arm and the brush is also bolted. To ensure durability, the equipment was painted with an oil paint to repel moisture. The components of the cleaner are shown in Fig 5 while the coupled equipment is shown in Fig 6. The materials and cost of construction are presented in Table 1.

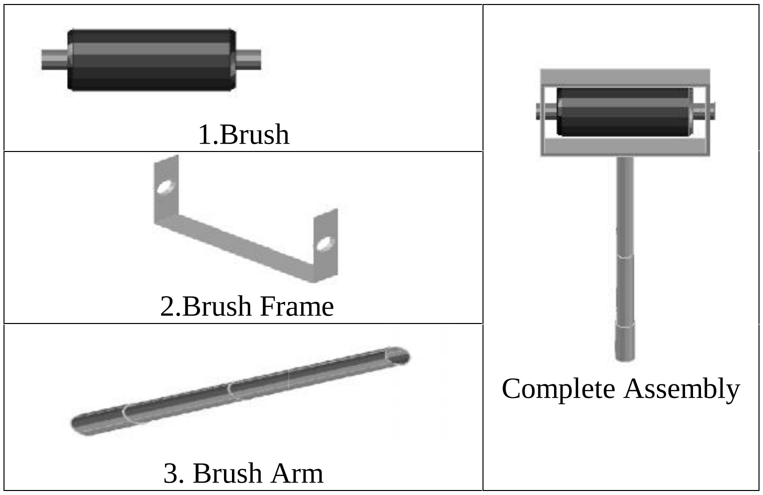

Fig 5. The Cleaner Components

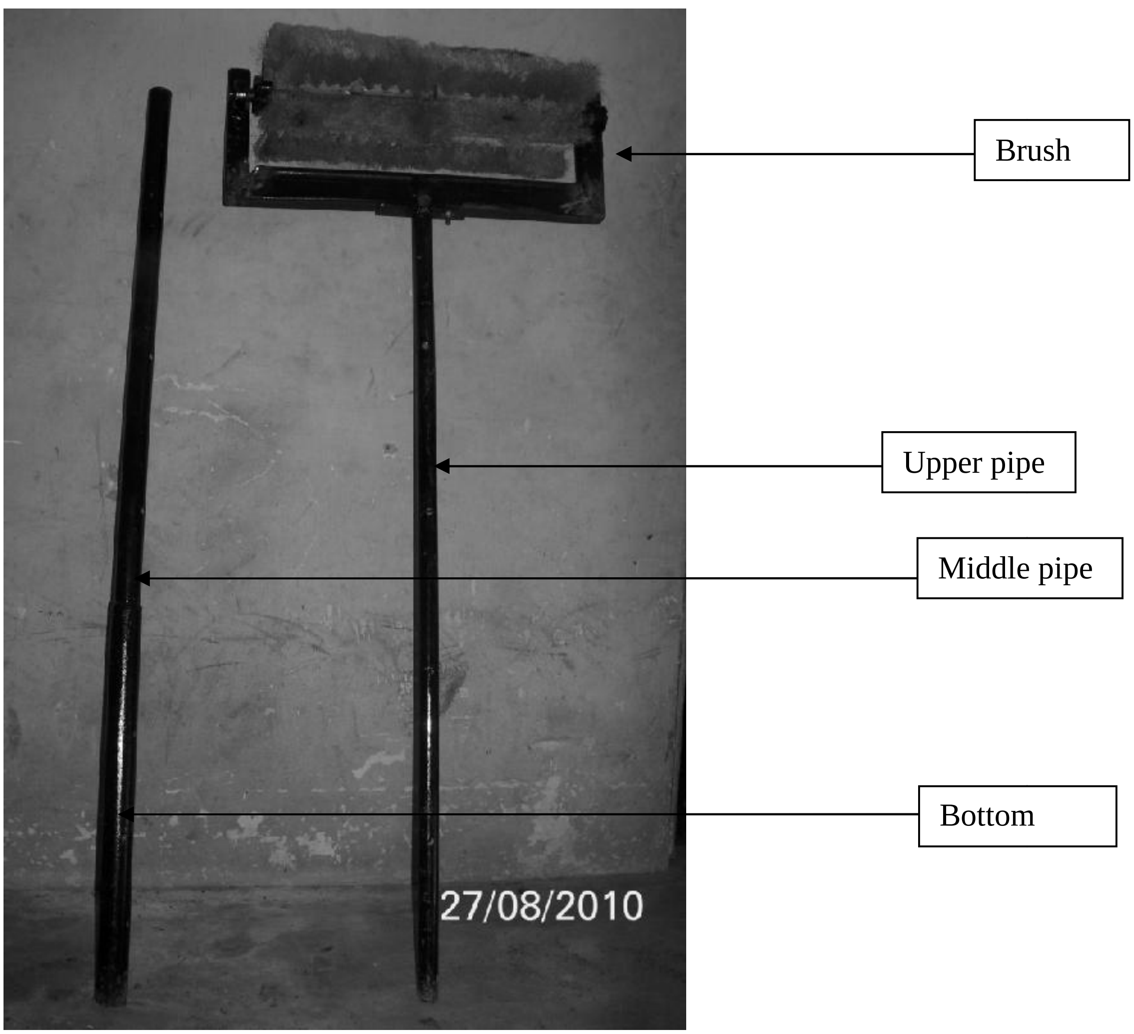

Fig 6. The Coupled Equipment

Table 1. Estimated materials of Construction and Specifications

S/N	Description	Dimensions	Quantity	Cost, N
1	Upper arm pipe	1300L and 55OD (mm)	1	800.00
2	Middle arm pipe	1000L and 50OD (mm)	1	600.00
3	Bottom arm pipe	500L and 45OD (mm)	1	500.00
4	Brush	550H and 40OD (mm)	1	2,000.00
5	Brush Frame	600L and 30W (mm)	1	1,500.00
5	Sump Pump	1hp	1	8,000.00
6	$\frac{3}{4}$ inches hose	10m	2	1,500.00
	Total			**14,900.00**

2.6 Testing

The performance of the cleaner was evaluated based on the comparison between light transmission efficiency of the roof before and after cleaning. The test involved the following four steps:

2.6.1 Experimental Set-up

The water tank within the greenhouse was filled with water, the water pump was connected, the solution dispenser was plugged to the water source while a stand by generator was available in the event of failure of public power supply. This set-up is shown in Fig 7.

2.6.2 Pre-Cleaning Illumination

The incident light illumination was taken at various locations around the green house which were then averaged to know the incident light in the environment. The light intensity within the greenhouse was measured at six locations. Repeated readings were taken and later averaged as shown in Fig 8.

2.6.3 Washing

Cleaning was done from the ridge down to the eave while the workman stands on a scaffold. The washing mix was pumped to the mix dispenser with a dispensing hole of diameter 6.05mm. Three bays could be washed from one standing position of the scaffold. The set-up was moved to adjacent bays until the entire roof was washed. The washing process is shown in Fig 9.

2.6.4 Post – Cleaning Illumination

After the cleaning, the roof was allowed to drain and dry after which the illumination was measured again both around and within the greenhouse.

The testing procedure reported above was carried out in three greenhouses.


Fig 7. The Cleaning Set-up


Fig 8. Recording Light Transmission inside the Greenhouse


Fig 9. Greenhouse Roof Cleaning using the Designed Cleaner

2.7 Assessment of Cleaning Efficiency

The primary objective of the claeaning was to improve the transmittance of the glazing mateerial. A reasonable method of assessing the efficiency of the designed equipment is to compare the pre- and post-cleaning transmittances of the glazing material. This was done using equations 7 (Anonymous, 2011)

$$T_a = \frac{I_1}{I_o} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (7)$$

Where: = Transmittance before cleaning,%, I_o = Average Incident Light outside the Greenhouse (I_o). Lux, I_1 = Average Transmitted Light within the Greenhouse (I_1), Lux

3. RESULTS AND DISCUSSION

The results of the equipment tests are presented in Table 2. The average pre- and post- cleaning transmittances for the three greenhouses were 36.62 and 42.65; 43.0 and 56.19; and 38.79 and 55.15 % respectively. These data indicate an improvement of 6.03, 13.19 and 16.36 % in transmittances of the roofs as a result of the washing. This trend in improvement in transmittance among the greenhouses was not unexpected from the physical observation of the roofs. While the first greenhouse was an abandoned one, the other two that were occasionally used have not been washed since erection close to two decades ago. The best maintenance practice that is done on the roofs of those occasionally used is to remove creeping plants and fallen leaves when the density becomes severe.

Because these roofs have not been cleaned for a long time, the accumulated dirts have stuck into the roof such that a single washing may not completely remove the dirts. This is possibly why the improvement in transmittance is not very high. A repeated washing after the dirts must have been softened will remove further dirt and improve the transmittance.

This equipment has a number of advantages over the traditional ladder cleaning method. Only one person can operate the equipment as against the ladder method in which at least two people are required with one to secure the ladder. The load imposed on the roof is also reduced as only the weight of the brush as against that due to the ladder and washmen are imposed on the roof. The time for equipment movement is also reduced. Another advantage of this equipment is that it could be used in small roofs where the ladder may not be appropriate even if desired.

Table 2. Transmitted Light Intensity (T_a) Before and After Cleaning for Greenhouses

Point of Measurement within the Greenhouse	Greenhouse I		Greenhouse II		Greenhouse III	
	Before Cleaning	After Cleaning	Before Cleaning	After Cleaning	Before Cleaning	After Cleaning
A	23,500.1	30,132.84	28,734.76	45,890.78	30,456.30	46,325.67
B	22,200.0	29,591.40	31,655.52	41,654.89	30,762.88	42,765.34
C	48,200.00	54,411.00	28,454.87	42,564.23	28,786.65	44,123.56
D	22,082.75	23,686.10	29,500.00	43,259.78	29,125.65	45,321.76
E	24,114.24	25,825.51	29,275.89	43,523.67	28,534.70	43,231,60
F	24,912.6	27,058.82	30,194.005	43,623.56	28,125.30	44,324.60
	165,009.69	190,705.67	177,815.05	260,516.91	175,791.48	266,151.93
Average Transmitted Light within the Greenhouse (I_1)	27,501.62	31,784.28	29,635.84	43,419.49	29,298.58	44,357.66
Average Incident Light outside the Greenhouse (I_o)	75,100.0	74,520.70	68,920.56	77,275.75	75,524.56	80,432.12
Transmittance $T_a = \frac{I_1}{I_o}$	36.62%	42.65%	43.00%	56.19	38.79	55.15

4. CONCLUSIONS AND RECOMMENDATIONS

To facilitate cleaning of greenhouse roofs especially in Nigeria, a simple roof cleaning device was conceptualized, designed, fabricated and tested. When tested on three greenhouses, an improvement of between 6.03 and 16.36% in transmittance was recorded. Compared to the ladder method which is the common method employed in the country, the equipment has great potentials as a suitable alternative considering the inherent advantages of faster operation, less labour demand, less load~~s~~ imposed on the roof and increase operator safety. The cleaner is adaptable to various types of greenhouses and it is simple to set-up, operate and maintain.

In order to derive the maximum benefits from this equipment, it is recommended that further research be carried out on the possibility of reducing the self weight of the cleaner through the use of small diameter pipes. The wood base for the brush will be prone to decay after prolonged use because of contact with water. Appropriate timber species and possible preservative treatments to curtail this hazard are recommended.

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THE ESTIMATION OF WIND VELOCITIES CRITICAL TO THE DESIGN AND DEVELOPMENT OF LIFT WING AEROTURBINE (LWAT)

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ABSTRACT

The African continent inhabits more than 0.5 billion people, and approximately 80% of this population resides in remote areas with no access to electricity. This makes the population vulnerable to extreme poverty. The power problem in Nigeria is that of generation and distribution which is becoming more expensive at centralized grid supply. Wind energy which abounds in remote areas of the country isolated from electric network can serve as a veritable alternative source of power for electricity generation. The power so generated can be used to enhance agricultural activities, such as irrigation and post-harvest operations, since most rural dwellers are farmers. In this study, ten year wind data (1994-2003) were subjected to statistical analysis to determine design parameters and wind energy estimation. A steady spectrum of 4.00 - 7.00 km/hr was obtained. The design speeds of 4.00 km/hr, 5.25 km/hr and 6.49 km/hr were drawn from the spectrum using an equation relating mean monthly wind speed and its standard deviation. Power equation was used to compute for the available power of the spectrum at various speeds. A power factor of 0.529 was obtained.

KEYWORDS: Remote areas, off-grid, wind energy, power generation, wind spectrum, irrigation.

1. INTRODUCTION

There are more than 1.5 billion people in the world without access to electricity. One third of this people live in Africa (UNIDO-RC-SHP, 2006). The total primary energy consumption of Africa is only 3% of the total world primary energy consumption (BP Statistical Review of World Energy, 2002). More than 80% of the total population is deprived of electricity.

In Nigeria the conventional sources used in irrigation pumping and water supply are fossil fuels (petrol and diesel). The cost of generating power at hydro-electric and thermal stations and transmitting over long distances, distribution to individual small farm holdings is becoming increasingly high. The remote areas of the country in isolation devoid of electric network are enriched with solar and wind energy. Some of these renewable energy sources can be of immense benefit to the people if properly harnessed.

The global wind patterns are created by uneven heating and the spinning of the earth (Schwartz and Elliott 1995).The warm air rises near the equator and the surface earth moves in to replace the rising air. As a result two major belts of the global wind patterns are created giving rise to circulation of the world wind. Two features of the wind exist; its speed and the direction are used to describe and forecast the weather of a region. The wind speed is measured with an anemometer and the direction by a weather vane. In USA (Elliott *et al.*, 1991) wind speed is reported in miles per hour or nautical miles per hour. In other countries it is reported in kilometers per hour or sometimes in meters per second. Wind is a secondary form of energy. According to Aremu (1991), about 2.5% of the solar energy captured by the atmosphere is converted into wind. This translates to 4.3×10^7 KW energy output much greater than the total output of all the earth power stations (VAWT, 1987).

Having the cubic relation with power, the wind speed is the critical data needed to appraise the potentials of any site. It is never steady at any site. The wind velocity is influenced by the weather system, the local land terrain and the height above the ground surface. Alexiadis *et al.* (1998) have proposed a new technique for forecasting wind speed and power output up to several hours in advance.

In the coastal belt of Orissa State (India) where sufficient wind speed is adequate throughout the year, Mishra and Sharma (1992) reported that wind velocity is a random variable that is reliable in estimating wind energy. They considered wind speed data of a period of ten years in estimating wind energy required for pumping water for irrigation. In a similar study in Bangladesh wind data has been investigated (Islam, 1995) for the application of wind energy for irrigation and for the generation of electricity. A first hand study of wind velocity distribution carried out in different parts of Ethiopia indicated that there is a good scope of utilizing wind power for pumping irrigation water for several parts of the country.

Modern technologies have been developed for extracting wind energy. Suitable mechanisms convert the kinetic energy of the wind to mechanical and electrical energy. In Bangladesh wind turbines are used for manually operated irrigation pumps (Md, Quamrul *et al*., 1995). Mobile wind converters (Irps and Omara, 2003) and the combined electricity system with irrigation system are in use for watering fruits (Omara *et al.*,, 2004). In a more recent development in Nigeria, electricity has been generated from low wind regime (Akinoso and Lucas, 2006).

Hence, this study was to estimate critical wind velocities for the design of Lift Wing Aero-Turbine (LWAT) for isolated power generation.

2. MATERIALS AND METHODS

The National Center for Agricultural Mechanization (NCAM) Ilorin is located close to Idofian town, a suburb about 20 km away from Ilorin metropolis. Wind velocity is the critical data needed to appraise the energy potential of Idofian site.

2.1 Design Data Input

The power P_M in moving air (wind) is the flow rate of kinetic energy per second of the wind (Watts)

Therefore:

$$P_M = \frac{1}{2}\,(mass\ flow\ rate\ per\ second)\,V^2 \qquad (1)$$

Where

$P_M = mechanical\ power\ in\ the\ wind\ (Watts)$

$\rho = air\ density\ in\ kg/m^3$

$\mathrm{A} = area\ swept\ by\ the\ rotor\ blades\ in\ m^3$

$\upsilon = velocity\ of\ the\ wind\ in\ m/s$

Then, the volumetric flow rate is $\mathrm{A}.\upsilon$, the mass flow rate of the wind in kilogram per meter^3 is $\rho.\mathrm{A}.\upsilon$, and the power P_M is given as:

$$P_M = \frac{1}{2}\,(\rho \mathrm{A}\upsilon).\upsilon^2 = \frac{1}{2}\,\rho \mathrm{A}\upsilon^3\ Watts \qquad (2)$$

2.2 Power Extracted from the Wind (Moving Air)

The actual power P_A extracted by the rotor blades is the difference between the upstream and downstream kinetic wind power, from equation (1)

$P_A = \frac{1}{2}(mass\ flow\ rate\ per\ second)(v_E^2 - v_T^2)$ (3)

Where:

$P_A = mechanical\ power\ extracted\ by\ the\ rotor\ i.e\ the\ turbine\ output$

$v_E = upstream\ wind\ velocity\ at\ the\ eentrance\ of\ the\ turbine\ (m|s)$

$v_T = downstream\ wind\ veelocity\ at\ the\ exit\ of\ the\ turbine\ (m|s)$

The mass flow rate of the wind through the turbine is derived by multiplying the wind density with the average velocity, thus

$$mass\ flow\ rate = \rho.\mathrm{A}.\left(\frac{v_E + v_T}{2}\right)\ kg/sec. \qquad (4)$$

Where $\left(\frac{v_E + v_T}{2}\right)$ is average wind velocity in $m/sec.$

The mechanical power P_A extracted by the turbine that will drive the electrical generator, is therefore

$$P_A = \frac{1}{2}\left(\rho.\mathrm{A}\left(\frac{v_E + v_T}{2}\right)\right)(v_E^2 - v_T^2)\ watts \qquad (5)$$

The above equation can be algebraically rearranged as

$$P_A = \frac{1}{2}\rho.\mathrm{A}.v^3\left[\frac{1-\left(\frac{v_T}{v_E}\right)^2\left(1+\frac{v_T}{v_E}\right)}{2}\right] \qquad (6)$$

The power extracted by the turbine is expressed as a fraction of the upstream wind power as thus

$$P_A = \frac{1}{2}\rho.\mathrm{A}.v^3 C_P \qquad (7)$$

Where

$$C_P = \left[\frac{1-\left(\frac{v_T}{v_E}\right)^2\left(1+\frac{v_T}{v_E}\right)}{2}\right] \qquad (8)$$

The C_P is the fraction of the upstream wind power. If C_P is taken as 0.5 representing the practical turbine efficiency, then the maximum power P_{Max} output of the wind turbine becomes a simple and single expression:

$$P_{Max} = \frac{1}{4}\rho.\mathrm{A}.v^3\ \text{Watts} \qquad (9)$$

Wind velocity $v\ is\ measured\ in\ km/hr\ (v_W)$

$$v = \left(\frac{5}{18}v_W\right)m/sec. \qquad (10)$$

Putting equation (10) in equation (9) gives P_{Max} as

$$P_{Max} = 6.688 \times 10^{-3}\rho \cdot \mathrm{A} \cdot v_W^3\ \text{Watts}$$

2.3 Design Velocities($\boldsymbol{v_D}$)

There are three reference wind velocities associated with design of lift wind turbine

$\boldsymbol{v_{C-}}$ cut- in speed; the speed below which the wind turbine does not operate

$\boldsymbol{\nu_{d-}}$ design speed; the speed for which the rotor is to operate

$\boldsymbol{\nu_{r-}}$ is the speed at which the turbine output is maximum

The design speeds bear relationships with the mean wind speed distribution of the site presented in Table1. The wind speed is measured in kilometer per hour at the height of 2m above the ground surface. From the statistical analysis of the data, the modal frequency(ν_F) is 4.30km/hr. The mean speed(ν_M) is 5.25km/hr and a standard deviation(ν_{SD}) speed of 1.24km/hr above and below the mean speed. The statistical parameter.

$$\nu_D = \nu_M \pm \nu_{SD} \qquad (11)$$

Thus, substituting the values of ν_M *and* ν_{SD} in (11) we obtain the following

$\nu_C = 4.00 km/hr$

$\nu_M = 5.25 km/hr$

$\nu_C = 6.49 km/hr$

2.3 Energy Estimation of the Spectrum

For a free flowing wind at the site the power of the wind P_W is expressed as;

$$P_W = 7.7 \times 10^{-3} \times \mathrm{D}^2 \times \mathrm{V}^3 \mathrm{kW} \qquad (12)$$

Where D is the turbine diameter (m)

V is the wind velocity in meters per second

For maximum power that can be harnessed at power coefficient(C_P) of 0.5 and velocity ratio of $\left(\frac{\nu_T}{\nu_E}\right) {}^1\!/_3$

$$P_{Max}\ 3.924 \times 10^{-3} \mathrm{D}^2 V_W^3\ kW \qquad (13)$$

Therefore at various design velocities the power output expected from the turbine of 2m diameters are:
At cut in velocity, the cut in power P_C is given as:

$$P_C = 3.924 \times 10^{-3} \times 2^2 \times 4^3$$
$$= 1.00 kW$$
$$P_D = 3.924 \times 10^{-3} \times 2^2 \times 5.25^3 kW$$
$$\approx 2.271 kW$$
$$P_r = 3.924 \times 10^{-3} \times 2^2 \times 6.49^3$$
$$= 4.296 kW$$

2.4 Power Factor (PF)

The ratio of average power produced to the maximum power of Turbine at site defines the power factor as:

$$\mathrm{PF} = \left[\frac{\nu_M}{\nu_{Max}}\right]^3 \qquad (14)$$

Substituting the values of ν_M *and* ν_{Max} *into equation*(14)*gives*:

PF = 0.529

This value is in agreement with earlier works by Patel (1999).

3. RESULTS AND DISCUSSION

The wind is driven by the sun and the seasons giving rise to a pattern that generally repeats over the period of one year as reported by the mean monthly distribution of Table 1. The pattern of the study area is graphically presented by Fig.1. It declines persistently over the entire period of the year. Three periods of declines have been identified. The first occurs between 0 – 15% of the time with speed range of 6.92 – 9.00km/hr. The duration of the period is 1,340 hr/yr. It is a period of turbulent wind and loss of energy. The second period occurs between 15 – 80% of the time. The wind speed range here is 4.11– 6.92 km/hr for a duration of 5,694 hours per year. The slope of the curve within this period is gentle, an indication of steady state or spectrum. Power can be generated from this period or spectrum. The spectrum closely tallies with high wind speed densities, clustering between 4.00 – 7.00km/hr. Outside this range of speed densities, velocities are relatively very low for energy generation. The final period occurs between 80 – 100% of the time, which has speed range of 1.13 – 4.11km/hr and duration of 1,752 hours per year. The period is characterized by calm wind which cannot permit energy exploitation.

The second plot of Fig. 1 is the mean monthly power. It represents power duration curve which is steep between wind speed of 5.00 – 7.00km/hr. This implies that power will be available more often within this velocity range. The energy output of the range is 0.646 – 1.772kW, for a rotor diameter of 1.0m. The lower part of the power duration curve has a gentle slope between 4.00 – 5.00km/hr. Power available within the range is low, 0.330 – 0.471kW.

Table 1: Mean monthly wind velocity distribution in Idofian, Kwara State, Nigeria.

Year	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec
1994	5.68	5.37	8.36	8.99	6.26	6.13	6.88	6.18	5.68	4.29	4.07	3.63
1995	3.06	4.47	7.93	5.26	2.51	2.33	4.31	3.29	3.10	2.83	2.16	2.46
1996	4.67	5.69	7.30	6.08	6.76	6.60	6.57	6.00	4.99	3.92	4.00	4.69
1997	7.00	5.10	6.36	7.01	4.93	5.14	6.44	4.62	3.30	3.22	1.40	1.34
1998	4.08	4.70	4.74	7.88	6.00	4.28	6.70	6.19	4.43	3.88	3.72	3.34
1999	3.94	5.11	7.69	6.50	5.25	4.34	6.00	5.19	4.23	3.22	3.33	3.32
2000	4.50	4.81	6.20	8.89	7.42	6.38	6.40	5.84	5.02	4.50	3.81	3.00
2001	3.13	4.32	7.83	8.18	6.67	5.21	7.14	7.43	5.71	4.77	4.92	4.71
2002	4.71	5.69	8.28	7.85	6.70	6.52	5.65	6.00	5.66	4.52	4.12	4.50
2003	4.27	5.93	6.06	7.74	7.37	5.74	6.67	6.54	4.17	4.43	3.48	3.48
MEAN	4.50	5.12	7.03	7.44	6.04	5.29	6.28	5.72	4.60	3.96	3.50	3.48
SD	1.24	1.24	1.24	1.24	1.24	1.24	1.24	1.24	1.24	1.24	1.24	1.24

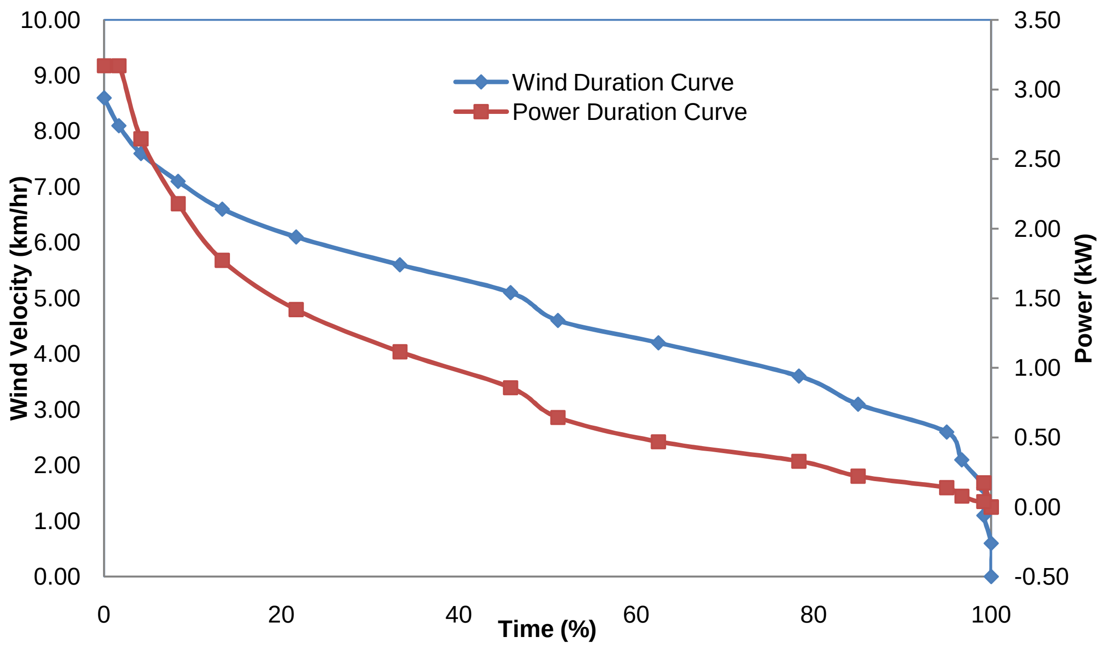

Figure 1: Mean monthly wind and power duration curves for Idofian, Kwara State, Nigeria.

4. CONCLUSIONS

It is evident from the statistical analysis that Idofian is an area of low-wind. This has informed the decision to adopt the Lift-Wing Aero-Turbine (LWAT) design capable of harvesting wind energy at low regime. The design velocities are also low; however, the durations are quite high. At cut-in velocity of 4.00km/hr, the duration is 6,832.8 hours per year. It also coincides with modal velocity of 4.0km/hr, implying that the rotor will operate at this velocity most of the time. The design velocity of 5.25km/hr has a duration of 4,730 hours per year. At the rated velocity (6.49km/hr), the duration is 1,840 hours per year. The maximum attainable velocity of 7.00km/hr last for 1,139 hour per year. Consequently, the annual power output will be sustainably high. At the rated velocity, the power output will amount to 64,934kWh (35.298 KW x 1,840 hours). Power will be converted at an efficiency of 52.9%.

For most domestic water supply in rural areas, 100 W of electricity is required. For typical irrigation, 1kW may be required for 1 – 2.5 hectares. The wind power that is available in this locality is between 8.24 – 35.23kW, which is sufficient to satisfy both domestic and irrigation demands. Therefore, isolated areas of the country with similar wind conditions can adopt the design for off-grid power generation for productive use.

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CHEMICAL AND THERMAL PROPERTIES OF COOKED PIGEON PEA (*CAJANUS CAJAN*)

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ABSTRACT

An effect of cooking duration on chemical and thermal properties of pigeon pea was studied. Cleaned pigeon pea was cooked for three hours. The cooking was done at atmospheric pressure (760-mmHg≈1 bar) and boiling temperature (100°C). Appropriate Association of Official Analytical Chemists standard methods were used to analyze the proximate composition (protein, fat, moisture content, carbohydrate, crude fiber and ash). Thermal properties (thermal conductivity, specific heat and thermal diffusivity) were determined using Choi and Okos models. Crude protein of un-cooked and cooked pigeon pea was 21.23 ± 0.2% and 15.47 ± 0.06%, respectively. The percentage crude fat of raw pigeon pea increased slightly during cooking from 1.36 ± 0.02% to 1.57 ± 0.06%. Carbohydrate content of the raw and cooked pigeon pea ranged from 59.34 ± 0.19 to 19.70 ± 0.44. The ash content of the raw and cooked pigeon pea was 5.20 ± 0.02% to 2.87 ± 0.06%, respectively. Crude fiber content of raw and cooked pigeon pea was 7.56 ± 0.02 to 5.83 ± 0.12%, respectively. Cooking pigeon pea for three hours increased its moisture content from 5.31 ± 0.04% to 54.23 ± 0.06%. Cooking pigeon pea for three hours has significant influence on all the determined chemical properties at 95% confidence level. Cooking pigeon pea increased thermal conductivity by 100%. Specific heat of pigeon pea increased from 1.78 to 1.92 W/m°K after three hours of cooking. Cooking as a treatment significantly influenced thermal diffusivity of pigeon pea at 95% confidence level.

KEYWORDS: Pigeon pea, cooking, proximate composition, thermal properties, chemical properties.

1. INTRODUCTION

Pigeon pea (*Cajanus cajan*), also known as *red gram, Congo pea, gungo pea, no eye pea, dhal, gandul, gandure, frijol de árbol, pois cajan, and otili* occurs in several varieties. Pigeon pea is an important food in developing tropical countries. An excellent source of protein, the seeds of pigeon pea is eaten when cooked and used as a flour additive to other foods. The seed contains 10.1 % moisture, 18.8 % protein, 1.9 % fat, 53.0 % carbohydrates, 6.6 % fiber, and 3.8% ash (Saxena, 2008). In addition, mineral and trace elements found in the crop are calcium (120 mg/g), magnesium (122 mg/g), copper (1.3 mg/g), iron (mg/g) and zinc (2.3 mg/g). Vitamin content is carotene (469.0 mg/g), thiamin (0.3 mg/g), riboflavin (0.3 mg/g), niacin (3.0 mg/g) and ascorbic acid (25.0 mg/g). In spite of the nutritional potential of this crop, it is still classified as under-utilized food. Processing of pigeon pea involves deppoding, cleaning, cooking, drying, and milling. The seed of the pigeon pea is enclosed in a hard, tough, and relatively thick coat that has semi permeable membrane. Movement of water through the mesocarp is restricted, the adhesive strength that binds the mesocarp to the seed is relatively high (Ghadge *et al*., 2008). Hence cooking is necessary to soften the firmly attached seed coat for easy dehulling. However, long hours of cooking limit its uses.

Engineering properties of crops are essential parameters in utilization, development of processing methods and design of equipment (Akinoso and Raji, 2011). Such properties include rheological, thermal, optical, electrical, physical, and mechanical properties. Published works on engineering properties of agricultural products are available on palm nuts (Koya and Faborode, 2005), maize (Chemperek and Rydzak, 2006), faba bean (Altuntas and Yildiz, 2007), pea seed (Andrejko *et al*, 2008), soybean (Kibar and Ozturk, 2008) and barberry (Fathollahzadeh and Rajabipour, 2008). Altuntas and Sekeroglu (2008) and Tavakoli *et al*., (2009) worked on chicken egg and wheat straw, respectively. Findings from these researches clearly showed that engineering properties of biomaterial significantly depend on treatments.

Production of sufficient food at affordable cost is a challenge in most developing countries. Therefore, there is need to ensure that all potential sources of foods are exploited effectively and utilized appropriately. The improvement of technology of processing pigeon pea requires accurate information on chemical and thermal properties of the crop as affected by primary processing. Accuracy of measurement are important factors in determining variation in thermal properties. Several methods are known for measuring thermal properties including computer techniques, experimental and use of mathematical models. Foods show extended variability in composition, and thermo-physical properties depending on the chemical composition of their structures (Barbosa-Canovas et al., 2006). Effective models based on chemical composition of foods for predicting thermo-physical properties of crops have been reported. Estimated values using Choi and Okos (1987), models for thermal conductivity of pork and milk were closer to measured values (Toledo, 2000). Studies on methods of reducing the cooking time without losing the food value of pigeon pea will reduce the energy demand. The research output may encourage renewal of interest on its consumption, thus removing the crop from the list of under-utilized crops.

The objective of this work was to determine the effect of cooking duration on chemical and thermal properties of pigeon pea.

2. MATERIALS AND METHODS

2.1 Determination of Chemical Properties of Pigeon Pea

2.1.1 Proximate Analysis of Pigeon Pea

Cleaned pigeon peas were cooked for three hours. The cooking was done at atmospheric pressure (760-mmHg≈ 1 bar) and boiling temperature (100^{o}C). Appropriate standard methods were used to analyze the proximate composition (AOAC, 2005). Protein (method 988.05), fiber content (method 958.06), fat (method 2003.06), ash (method 942.05), moisture content (method 967.08) and carbohydrate were calculated following the method reported by McClements (2010). All the experimental procedures were repeated three times. Mean of three replicates were recorded as data obtained. The data obtained were subjected to Analysis of Variance (ANOVA) at 5% level of significance.

2.1.2 Determination of Protein Content of Pigeon Pea

Protein was determined by Kjeldahl procedure using a protein factor of 6.25 (AOAC, 2005). About 1.2 g of sample was weighed into a digestion tube and conc. tetraoxosulphate (IV) acid (conc. H_2S0_4) added using a dispenser. The tube was placed in a preheated digester at 420^{0}C for about 30 minutes until a clear solution was obtained. The tube was removed from the digester, cooled and diluted with water before placing in the distillation unit. A conical flask containing 25 ml of boric acid (indicator) was placed under the condenser outlet. About 25 ml of 40% Sodium hydroxide (NaOH) was dispensed in the flask and distillation carried out for 5min. The ammonium borate solution formed was titrated with 0.1M tetraoxosulphate (VI) acid to purplish –grey end and percentage nitrogen (%N_2) was calculated.

2.1.3 Determination of Fat Content of Pigeon Pea

Fat analysis was carried out using soxhlet extraction method (AOAC, 2005). About 25 g from each powdered samples were mixed with about 100 ml of n-hexane. The mixture was vigorously stirred with the separation flask knob opened at intervals to release the accumulated air pressure, which may burst the flask if left covered. The fat in spirit was evaporated to dryness over a soxhlet extraction, which extracts n-hexane from its solution of fat. The fat left behind in the flask was placed in the oven to dry at 105^{0}C for 1½hours. The round bottom flask was cooled in desiccators and weighed. Percentage of fat in sample was calculated.

2.1.4 Determination of Fiber Content of Pigeon Pea

Fiber content of the pigeon pea was measured using the enzyme-modified, neutral detergent fiber (NDF) method of analysis (AOAC, 2005). Dried samples of pigeon pea whose fat content was extracted using soxhlet extraction approach were treated with standard NDF procedures up to the point that fiber-containing residues were filtered and washed with water. The filtered residues were incubated with a porcine α – amylase solution at 37^0C over night. The residues were filtered after incubation, washed thoroughly and dried. The NDF was calculated as filtered residues.

2.1.5 Determination of Ash Content of Pigeon Pea

Ash content of the samples were determined by putting about 25 g of pigeon pea in a dish of known weight (W_4) and dried in an oven for 4 hours at 105^0C. It was removed, cooled in desiccators and weighed (W_5). The sample in dish was ashed in a muffle furnace at 550^0C until white or grey ash resulted. It was cooled and reweighed (W_6) for the determination of percentage ash content.

2.1.6 Determination of Moisture Content of Pigeon Pea

Moisture content of pigeon pea was determined using ASAE (2008) standard method. Three samples each weighing 15 g was placed in an oven set at 130^oC for 6 hrs. The samples were then cooled in a glass jar containing silica gel as desiccant. The dried samples were weighed and the difference in weight before and after drying was taken to be moisture loss. Ratio of moisture loss to weight of wet material in percentage was recorded as moisture content wet basis

2.2 Determination of Thermal Properties of Pigeon Pea

Thermal properties of the samples were determined by fitting experimental data to existing models (Choi and Okos, 1987). Ambient and cooking temperatures of 29^oC and 100^oC respectively were used. Thermal properties determined were specific heat, thermal conductivity, and thermal diffusivity. Thermal conductivity was calculated using (Equations 1 to 16). Specific heat capacity was determined by application of Equations 17 to 23 while equations 24 to 30 were used for thermal diffusivity determination.

$$k = \sum(k_i X_{vi}) \quad (1)$$

$$k_i = k_w + k_p + k_f + k_c + k_{fi} + k_a \quad (2)$$

$$X_{vi} = \frac{X_i \rho}{\rho_i} \quad (3)$$

$$\rho = \frac{1}{\{\sum X_i/\rho_i\}} \quad (4)$$

$$k_w = 0.57109 + 0.0017625T - 6.7306\, x\, 10^{-6}T^2 \quad (5)$$

$$k_p = 0.1788 + 0.0011958T - 2.7178\, x\, 10^{-6}T^2 \quad (6)$$

$$k_f = 0.1807 - 0.0027604T - 1.7749\, x\, 10^{-7}T^2 \quad (7)$$

$$k_c = 0.2014 + 0.0013874T - 4.3312\, x\, 10^{-6}T^2 \quad (8)$$

$$k_{fi} = 0.18331 + 0.0012497T - 3.1683\, x\, 10^{-6}T^2 \quad (9)$$

$$k_a = 0.3296 + 0.001401T - 2.9069\, x\, 10^{-6}T^2 \quad (10)$$

$$\rho_w = 997.18 + 0.0031439T - 0.0037574T^2 \quad (11)$$

$$\rho_p = 1329.9 - 0.51814T \quad (12)$$

$$\rho_f = 925.59 - 0.41757T \quad (13)$$

$$\rho_c = 1599.1 - 0.31046T \quad (14)$$

$$\rho_{fi} = 1311.5 - 0.36589T \quad (15)$$

$$\rho_a = 2423.8 - 0.28063T \quad (16)$$

$$C_p = \sum C_{pi} X_i \quad (17)$$

$$C_{pp} = 2.0082 + 1.2089 x 10^{-3}T - 1.3129 x 10^{-6}T^2 \quad (18)$$

$$C_{pf} = 1.9842 + 1.4733 x 10^{-3}T - 4.8008 x 10^{-6}T^2 \quad (19)$$

$$C_{pc} = 1.5488 + 1.9625 x 10^{-3}T - 5.5399 x 10^{-6}T^2 \quad (20)$$

$$C_{pfi} = 1.3459 + 1.3306 x 10^{-3}T\,T - 4.6509 x 10^{-6}T^2 \quad (21)$$

$$C_{pa} = 1.0926 + 1.8896 x 10^{-3}T\,T - 3.6817 x 10^{-6}T^2 \quad (22)$$

$$C_{pw} = 4.1762 - 9.0864 x 10^{-3}T\,T - 5.4731 x 10^{-6}T^2 \quad (23)$$

$$\alpha = \sum \alpha_i X_i \quad (24)$$

$$\alpha_p = 6.8714 x 10^{-2} + 4.7578 x 10^{-4}T - 1.4646 x 10^{-6}T^2 \quad (25)$$

$$\alpha_f = 9.8777 x 10^{-2} - 1.2569 x 10^{-4}T - 3.8286 x 10^{-6}T^2 \quad (26)$$

$$\alpha_c = 8.0842 x 10^{-2} + 5.3052 x 10^{-4}T - 2.3218 x 10^{-6}T^2 \quad (27)$$

$$\alpha_{fi} = 7.3976 x 10^{-2} + 5.1902 x 10^{-4}T - 2.2202 x 10^{-6}T^2 \quad (28)$$

$$\alpha_a = 1.2461 x 10^{-1} + 3.7321 x 10^{-4}T - 1.2244 x 10^{-6}T^2 \quad (29)$$

$$\alpha_w = 1.3168 x 10^{-1} + 6.2477 x 10^{-4}T - 2.4022 x 10^{-6}T^2 \quad (30)$$

Where
k is thermal conductivity, W/(m.K)
k_i is thermal conductivity of pure component, W/(m.K)
X_{vi} is volume fraction of each component,
k_w is thermal conductivity of water, W/(m.K)
k_p is thermal conductivity of protein, W/(m.K)
k_f is thermal conductivity of fat, W/(m.K)
k_c is thermal conductivity of carbohydrate, W/(m.K)
k_{fi} is thermal conductivity of fibre, W/(m.K)
k_a is thermal conductivity of ash, W/(m.K)
X_i is the mass fraction, %
ρ_i is individual density, kg/m^3
ρ is composite density, kg/m^3
ρ_w is density of water, kg/m^3
ρ_p Is density of protein, kg/m^3
ρ_f is density of fat, kg/m^3
ρ_c is density of carbohydrate, kg/m^3
ρ_{fi} is density of fiber, kg/m^3
ρ_a is density of ash, kg/m^3
C_p is specific, kJ/kg^{o}K
C_{pi} is specific heat of componet, kJ/kg^{o}K
C_{pp} is specific hea of protein, kJ/kg^{o}K
C_{pf} is specific heat of fat, kJ/kg^{o}K
C_{pc} is specific heat of carbohydrate, kJ/kg^{o}K
C_{pfi} Is specific heat of fiber, kJ/kg^{o}K
C_{pa} Is specific heat of ash, kJ/kg^{o}K
C_{pw} Is specific heat of water, kJ/kg^{o}K
α is thermal diffusivity, m^2/s
α_i Is thermal diffusivity of individual componet, m^2/s

α_p Is thermal diffusivity of protein, m^2/s
α_f Is thermal diffusivity of fat, m^2/s
α_c Is thermal diffusivity of carbohydrate, m^2/s
α_{fi} Is thermal diffusivity of fiber, m^2/s
α_a Is thermal diffusivity of ash, m^2/s
α_w Is thermal diffusivity of water, m^2/s

3. RESULTS AND DISCUSSIONS

3.1 Chemical Properties of Pigeon Pea

3.1.1 Proximate Composition of Pigeon Pea

Result of proximate composition of pigeon pea is presented as Table 1. Cooking at three hours has significant influence on all the determined chemical properties at 95% confidence level. Similar observation on wheat cooked at temperatures of 80 ^oC, 100 ^oC, and 120^oC was reported by Chuckwu et al (2011).

Table 1. Proximate Composition of Pigeon Pea[F]

Properties (%)	Un-cooked	Cooked
Crude Protein	21.23 ± 0.20^a	15.47 ± 0.06^b
Crude Fat	1.36 ± 0.02^a	1.57 ± 0.06^a
Carbohydrate	59.34 ± 0.19^a	19.70 ± 0.44^b
Crude Fiber	7.56 ± 0.02^a	5.83 ± 0.12^b
Ash	5.20 ± 0.02^a	2.87 ± 0.06^b
Moisture Content	5.31 ± 0.04^a	54.23 ± 0.06^b

[F] mean of three replicates
[a] and [b] are ANOVA indicators
Values in the same row with different superscript are significantly different at $p < 0.05$

3.1.2 Protein Content of Pigeon Pea

Crude proteins of un-cooked and cooked pigeon pea were 21.23 ± 0.2% and 15.47 ± 0.06%, respectively. Previous work reported decreased in protein content of *Canavalia cathartica* from 32.1 to 28.1% (Seena et al., 2006). In addition, reduction in protein content of banana from 3.21 to 2.48% was reported (Baiyeri et al., 2011). Pigeon pea is a potential of source of plant protein. Protein quality is a measure of the usefulness of a food protein for the purpose of growth and maintenance of tissues. Thermal denaturation results in coagulation and decreased solubility (Ihekoronye and Ngoddy, 1985).

3.1.3 Fat Content of Pigeon Pea

The percentage crude fat of raw pigeon pea increased slightly during cooking from 1.36 ± 0.02% to 1.57 ± 0.06%. The result obtained was in agreement with earlier study of Akinmutimi (2007), who reported an increase in ether extract of velvet beans with increased cooking time. The increase is also similar to the results obtained on pigeon pea (Iorgyer et al., 2009). This may be associated with release of fat from the husk of pigeon pea during the cooking time.

3.1.4 Carbohydrate Content of Pigeon Pea

Carbohydrate content of the raw and cooked pigeon pea ranged from 59.34 ± 0.19 to 19.70 ± 0.44. The remarkable reduction in the carbohydrate content of pigeon pea may be attributed to hydrolysis of starch to simple sugars during the cooking period. Hydrophilic groups in carbohydrate molecules cause it to take up moisture in proportion to the relative humidity of the environment (Ihekoronye and Ngoddy, 1985). This characteristic behaviour encouraged moisture uptake and apparent reduction in percentage of carbohydrate.

3.1.5 Crude Fiber Content of Pigeon Pea

Crude fiber content of raw and cooked pigeon pea were 7.56 ± 0.02 to 5.83 ± 0.12%, respectively. Reduction in the percentage crude fiber content may be resulted from the removal of hull of the seeds during cooking. Cooking soften firmly attached seed coat for easy dehulling (Ghadge et al., 2008). The hull carries a high percentage of crude fiber present in the seed. This result is in consonance with published work that cooking generally reduces crude fiber content of legumes (Aletor and Ojo, 1989). Decrease in crude fiber with increase in duration of cooking was also reported on mucuna species (Akinmutimi, 2007). The decrease in crude fiber content of seeds with boiling is an advantage to monogastrics that lack the ability to utilize high fiber.

3.1.6 Ash Content of Pigeon Pea

The ash content of the raw and cooked pigeon pea was 5.20 ± 0.02% to 2.87 ± 0.06%, respectively. Decreased in ash content of pigeon pea seeds from 5.50% (raw seeds) to 4.00% after 30 minutes of cooking was reported by Amaefule et al. (2006). Similarly, increased in ash content of pigeon pea from 3.6 to 5.40% due to cooking was reported by Adeparusi (1994). The difference in the results of ash content obtained was due the different varieties of pigeon pea used.

3.1.7 Moisture Content of Pigeon Pea

Cooking pigeon pea for three hours increased its moisture content from 5.31 ± 0.04% to 54.23 ± 0.06%. Moisture uptake of 48.92 was recorded for pigeon pea. Significant changes in chemical composition of the crops during cooking may be attributed to re-distribution due to the high moisture uptake.

3.2 Thermal Conductivity of Pigeon Pea

Cooking increased thermal conductivity of pigeon pea by 100% (Table 2). Thermal conductivity of tomatoes puree was reported to be closed to 0.59 W/mK (Choi and Okos, 1987). Rise in thermal conductivity of roselle seed from 1.56 to 1.22 W/mK with increased moisture content of 8.8 to 19.0%, respectively was reported (Bamgboye and Adejumo, 2010). The increase in thermal conductivity is due may be due to the moisture absorbed by seed during cooking. In-addition the adopted model is a function of temperature, therefore increase in temperature might also influenced the results as determined. Thermo-physical properties are significantly dependent on changes in moisture content and temperature (Barbosa-Canovas, 2006). Thermal conductivity is important to predict or control heat flux and processing time. This ensures the efficiency of equipment, improves economics of the process, and enhance quality product.

Table 2. Thermal Properties of Pigeon Pea[Ғ]

Properties	Un-cooked	Cooked
Thermal Conductivity (W/m^{o}K)	0.26 ± 0.00^a	0.53 ± 0.00^b
Specific Heat (kJ/kg^{o}K)	1.78 ± 0.01^a	1.92 ± 0.03^a
Thermal Diffusivity (m^2/s)	0.10 ± 0.00^a	0.14 ± 0.00^b

[Ғ] mean of three replicates

^{a} and ^{b} are ANOVA indicators

Values in the same row with different superscript are significantly different at $p < 0.05$

3.3 Specific Heat of Pigeon Pea

Specific heat is an essential parameter in design of heat exchanger. The information will be useful in choice of heat transfer medium and processing conditions. Specific heat capacity (SPHC) of pigeon pea increased from 1.78 to 1.92 W/mK after three hours of cooking (Table 2). Change in specific heat of pigeon pea was not significant at 95% confidence level. These values are higher than specific heat capacity of 1.39 kJ/kgK for guna seed (Aviara et al., 2008) Nevertheless, SPHC of lower than 5.63 kJ/kgK was reported for roselle seed (Bamgboye and Adejumo, 2010).

3.4 Thermal Diffusivity of Pigeon Pea

Thermal diffusivity relates the ability of the material to conduct heat to its ability to store heat. Cooking as a treatment significantly influenced thermal diffusivity of pigeon pea at 95% confidence level (Table 2). Since thermal diffusivity is ratio of thermal conductivity, density, and specific heat, significant change in moisture content because of cooking earlier mentioned will have resultant effect on density. In addition, thermal conductivity was also affected. This explains the obtained result.

4. CONCLUSIONS

Cooking of pigeon pea for three hours changed its percentage composition of protein, fat, carbohydrate, fiber, ash and moisture contents. This process increased moisture content, a major factor in engineering properties of crop from 5.31 to 54.23%. Thermal conductivity and thermal diffusivity were significantly increased by cooking pigeon pea for three hours while specific heat capacity was not affected. Generated data will be useful in pigeon pea processing and development of cooker.

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SOME PHYSICAL PROPERTIES OF AFRICAN OIL BEAN SEED RELEVANT TO ITS PROCESSING

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ABSTRACT

Studies on some physical properties of African oil bean (*Pentaclethra Macrophylla*) seed at 10.43% moisture content (dry basis) revealed that the major, intermediate and minor diameters were 62.79, 40.20 and 10.98 mm respectively. The seed volume, weight and density were 16.71 cm^3, 18.77 g and 1.12g/cm^3 respectively, indicating the seed as one which cannot float in water. Against steel, wood and plastic as structural surfaces, the coefficients of friction were 0.40, 0.42 and 0.37 respectively, while a repose angle of 18.84° was obtained. Most of these physical properties had a linear relationship and positive correlation with seed weight of which the coefficient of friction on plywood was highest (0.982).

KEYWORDS: African oil bean, physical properties, angle of repose, coefficient of friction.

1. INTRODUCTION

African Oil Bean is a leguminous crop available in Nigeria. It naturally grows and disperses off its pods upon maturity. The number of seed contained is a function of its length. It is of a brownish glossy colour. It is an essential food supplement used in control of cancer and other tobacco related diseases. It is a recommendable remedy for treatment of infertility in men and its back decantation can be effective in the treatment of body itching, wound and lactogenecity (ICRAF, 2004). A photograph of the common variety of African Oil Bean seeds is shown in Figure 1.

Figure 1. Some African oil bean seeds

The mesocarp of the seed serves as food supplement after boiling and preparation for hours. It can be distilled and mixed with palm oil, spiced or eaten with cooked cassava chips and roasted yam. It is a bio-resource crop plant used as wood fuel and construction materials in farmstead building. Its trunk can be utilized to develop wooden household utensils (Okafor, 1987). The oil seed is a considerable integral quest for agro-forestry because of its recognizable features which aids soil improvement (Okafor and Fernadez, 1987). As a result of increased demand of the seed in recent times by the locals for domestic usage and marketability, there is growing need for mechanization (developing machines that will aid its processing) of the seed to enable its vast agricultural, agro-forestry, medicinal, nutritional and industrial potentials to be harnessed to its fullness.

It is necessary to determine some of the physical properties of this seed that will aid design of appropriate machines and systems for processing and storage. Several authors have worked on the physical properties of some agricultural materials: Alonge and Adigun (1999); Sorghum, Olaoye (2000); Castor Nut;

Mijinyawa and Omoikhoje (2005), Palm Kernel; Oje et al. (2001), Shea Butter; Adejumo et al. (2005), Groundnut; Gupta and Das (1997), Sunflower among others. The shape and size of agricultural materials can be determined by a look and measurement from a longitudinal or cross sectional view of the material. They are also relevant in electrostatic separation of undesired materials and development of sizing and sorting machines (Esref *et al.,* 2007).

Alonge (2008), Asoegwu *et. al.* (2006), Paksoy and Aydin (2006) described the size of agricultural materials by measuring their three principal dimensions (major, intermediate and minor diameters) using a vernier caliper. Mijinyawa and Omoikhoje (2005), Oje *et. al.*, (1999) and Alonge (2008) employed Mohsenin's (1986) computed the sphericity of some agricultural materials from the relationship:

$$\Phi = (abc)^{1/3}/a \quad \text{...} \quad (1)$$

where a, b and c are the major, intermediate and minor diameters of the materials respectively.

Adejumo *et. al.*, (2005), Alonge and Adigun (1999), Oloko *et. al*. (2009) described the gravimetrical properties of agricultural materials by obtaining the volume, weight, true and bulk density and porosity. Dutta *et. al*. (1988) postulated a model for determining the coefficient of friction of materials at different structural surfaces (plywood, galvanized steel, plastic and aluminium). This was successfully adopted by Alonge and Adegbulugbe (2005). Sonmez *et. al.* (2007) and Meisami *et. al.* (2009) measured the angle of repose of Gilaburu seed and Apple CV (Golab) respectively.

The objective of the study was to determine some physical properties of African Oil Bean seed relevant to its processing namely: size, sphericity, surface area, roundness, weight, volume, density (true and bulk), coefficient of friction and internal angle of repose at 10.43% moisture content (dry basis).

2. MATERIALS AND METHOD

Hundreds of samples of the seed were bought from a local market in Uyo, Akwa Ibom State, Nigeria. The samples were manually cleaned to remove foreign matter, dust, dirt, broken and immature seeds. The moisture content of the seed was determined by oven drying the seed at a temperature of 105°C for a period of six hours. The moisture content was obtained as 10.43% dry basis. One hundred seeds were randomly selected from the sample. Measurement on the three perpendicular axes (major, intermediate and minor diameters) was carried out by employing a venier caliper of 0.02 mm accuracy. The geometric and arithmetic mean diameters of the seed were determined from expressions (2) and (3) (Mohsenin, 1986).

$$GMD = (abc)^{1/3} \quad \text{...} \quad (2)$$

$$AMD = (a+ b+ c)/3 \quad \text{...} \quad (3)$$

where GMD and AMD are the geometric and arithmetic mean diameters of the seed, while a, b, and c are major, intermediate and minor diameters of the seed respectively. The closeness to sphere (sphericity) and roundness were determined; each seed was placed in its natural resting position on a sheet of graph paper. A sharp edged pencil was used to carefully trace the edges of the seed. The projected area and the diameter of the circles inscribing and circumscribing the projected areas were measured. The surface area was obtained by tracing the outline of each seed. The area of each trace was estimated and averaged. The volume and density of each seed were determined by water displacement model as described by Oje and Ugbor (1991).

Individual seeds were robbed with oil and immersed in water inside a measuring cylinder indicating a noticeable rise in water level. The weight of water displaced was used to compute the volume of water and volume of the seed. The true density was obtained by dividing the seed weight by its volume, while the bulk density was derived from dividing the bulk weight of the seed (measured in a cylindrical container) by the predetermined volume of the container. The static coefficient of friction was determined with respect to three structural surfaces namely; galvanized steel, plastic and polished wood. The seed was placed on each of the structural surface, the incline plane was gently raised and the angle of inclination (θ) at which the seed began sliding was read off the protractor. The equation relating them was given as:

$$\mu = \tan\theta \quad (4)$$

The experiment was replicated ten times. The static angle of repose was evaluated using a folded cardboard paper. The seed were filled in the cardboard, the paper was gradually lifted and it began flowing freely to form a pile. The angle of repose was computed from measuring the vertical depth (h) and the radius of spread (r) of the seed as thus:

$$\tan\theta = 2h/r \quad (5)$$

The experiment was repeated ten times.

3. RESULTS AND DISCUSSION

The results obtained for all the parameters measured for the seed are shown in Table 1. The frequency distribution of the major, intermediate and minor diameters are given in Figure 2. The major diameter ranged between 54.10 to 74.50 mm, with about 78% between 55.00 and 65.00mm. The mean intermediate diameter was 40.20mm with a standard deviation of 0.35 while the minor diameter was between 8.31 to 13.93 mm. The values were higher than those of any oil seed but close to figures obtained by Asoegwu et al. (2006) for the seed at moisture content of 8.37% (d. b.). The surface area of the seed ranged between 4.42 to 5.12 mm^2 with a standard deviation of 0.25. The sphericity of the seed ranged between 0.42 to 0.55 while the lowest and highest roundness values obtained assumed the seed as one to roll with little difficulty on flat surfaces, a requirement necessary for design of hoppers and dehulling equipment (Oje, 1993).

Weight and volume of the seed ranged from 14.40 to 27.00 g, 15.20 to 17.90 cm^3 respectively, while the bulk density values were between 0.49 and 0.53 g/cm^3 and 0.93 to 1.10 g/cm^3 respectively. The true density decreased with increased seed weight, while the reverse was the case for the seed volume and bulk density, indicating the seed as one which cannot float in water. The static coefficient friction for the seed was determined for three structural surfaces (steel, wood and plastic). The value was highest for wood (0.44-0.45) and least for plastic (0.36-0.38), with steel in between. This property is a basic requirement in design of hoppers and other unloading devices (Oje et al. 2001). The angle of repose of the seed was found to range between 18.12 and 19.41^o at 10.43% moisture content (d.b.) which was considerably less than those reported for other Oil Bean seeds (Oje and Ugbor, 1991): Oil Bean seed, Oje (1993); Locust Bean seed and pods. The coefficient of friction showed a positive correlation with seed weight.

They were related as thus: $\mu p = 0.003w + 0.298 \ldots R^2 = 0.964 \quad (6)$

The major diameter and the seed weight were related as given:

$$a = 2.027w + 27.16 \ldots R^2 = 0.933 \quad (7)$$

The seed volume and seed weight aslo showed liner relationship and was represented by:

$$v = 0.351w + 9.742 \ldots R^2 = 0.898 \quad (8)$$

The graphical representation of the relationship between seed weight and some pyical properties of African Oil bean seed are given in Figures 3 to 8.

Table 1: Summary of some physical properties of African oil bean seed

Physical property	No of replication	Minimum value	Maximum value	Mean value	Standard deviation	Variance
Seed weight(g)	100	14.40	27.00	20.70	2.47	6.10
Major diameter(mm)	100	54.10	74.50	64.30	4.53	20.52
Intermediate diameter(mm)	100	34.01	49.10	41.56	3.42	11.70
Minor diameter(mm)	100	8.31	13.93	11.12	1.24	1.54
Geometric mean diameter(mm)	10	27.09	32.07	29.58	1.57	2.46
Arithmetic mean diameter(mm)	10	35.51	41.98	38.75	2.39	5.71
Surface Area(mm^2)	10	4.42	5.12	4.77	0.25	0.06
Roundness	10	0.49	0.55	0.52	0.02	0.00
Sphericity	10	0.42	0.50	0.46	0.02	0.00
Seed volume (cm^3)	10	15.20	17.90	16.55	0.82	0.68
True density(g/cm^3)	10	0.93	1.10	1.02	0.50	0.25
Bulk density(g/cm^3)	10	0.49	0.53	0.51	0.01	0.00
Porosity (%)	10	0.46	0.53	0.49	0.24	0.06
Coefficient of friction						
Steel	10	0.38	0.42	0.40	0.01	0.00
Wood	10	0.40	0.45	0.42	0.01	0.00
Plastic	10	0.36	0.38	0.37	0.01	0.00
Angle of repose(^{o})	10	18.12	19.41	18.77	0.44	0.19

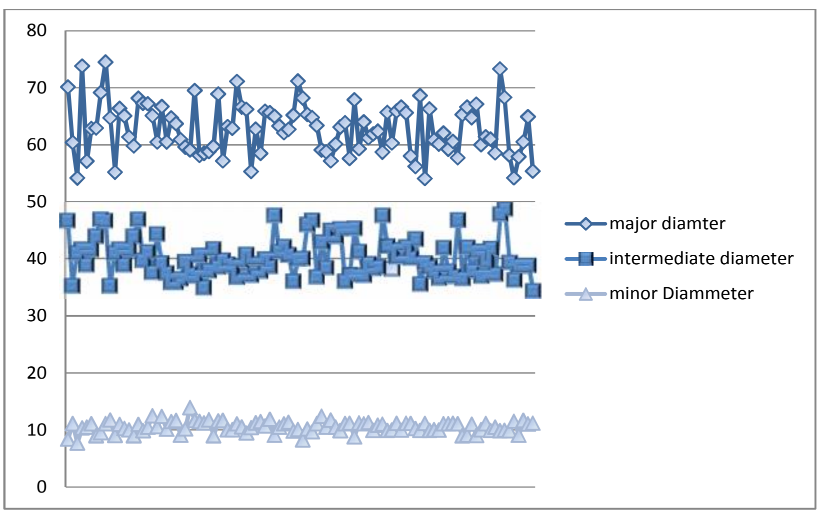

Fig. 2: Frequency distribution of major, intermediate and minor diameter of African oil bean seed.

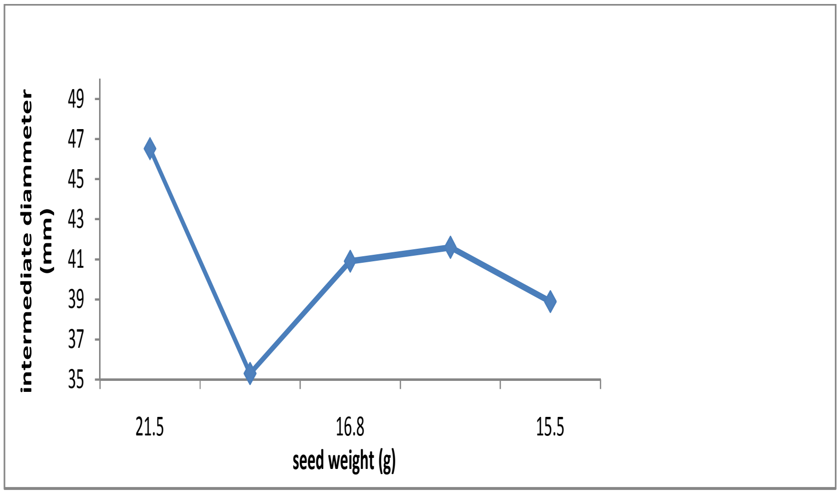

Fig. 3: Relationship between seed weight and intermediate diameter

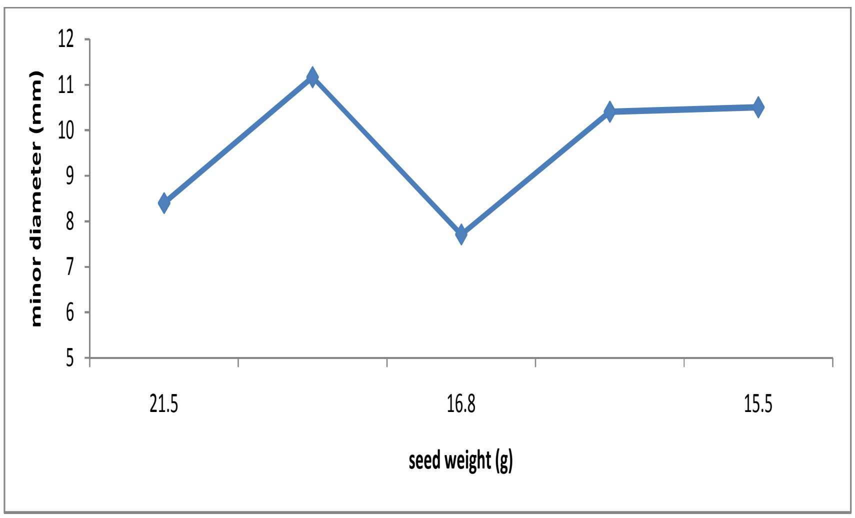

Fig. 4: Relationship between seed weight and minor diameter.

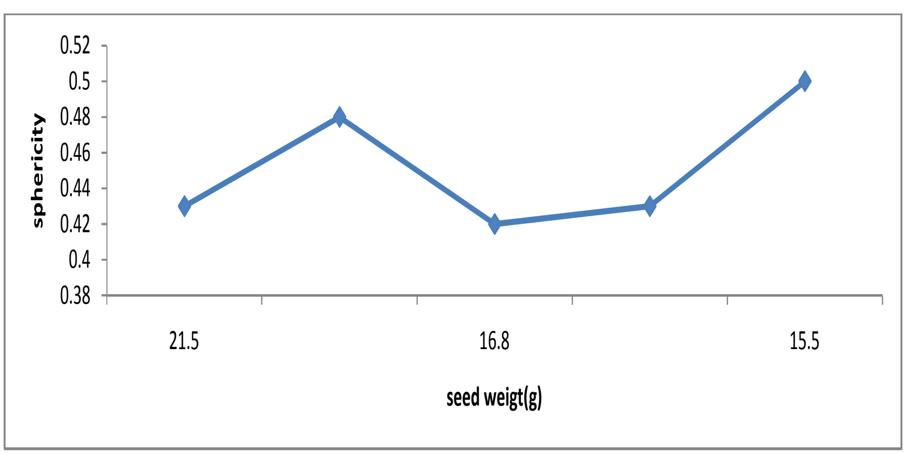

Fig. 5: Relationship between seed weight and sphericity

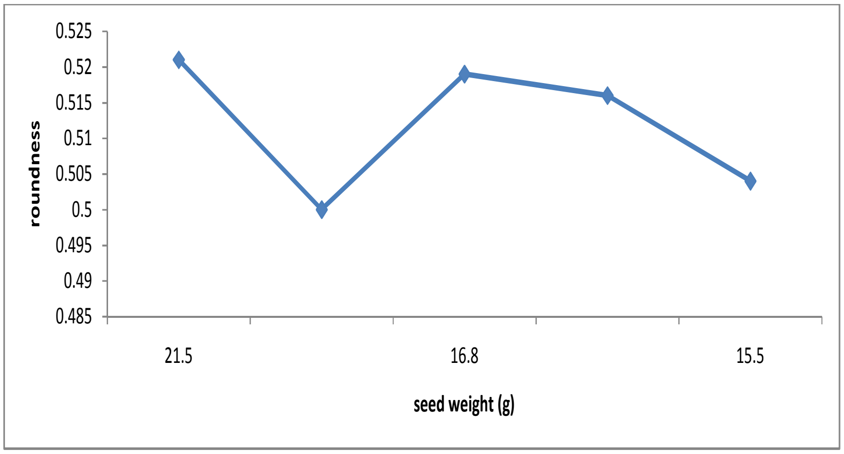

Fig. 6: Relationship between seed weight and roundness

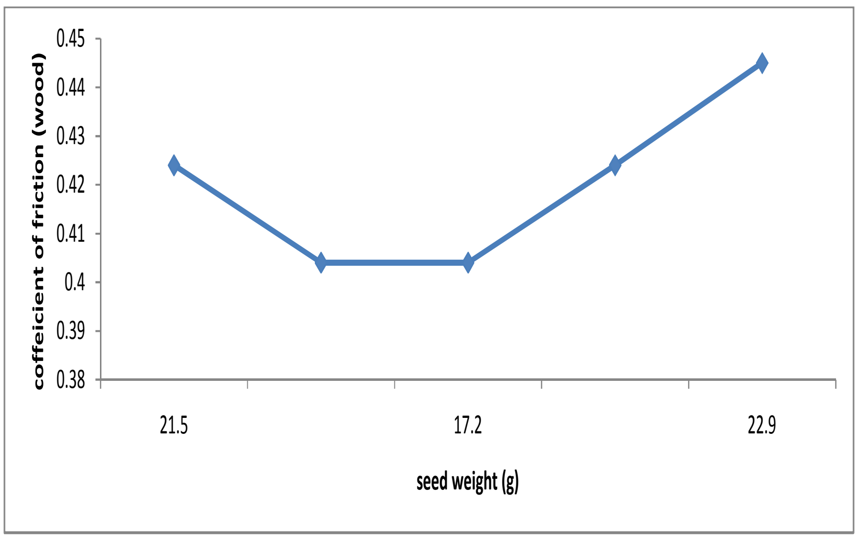

Fig.7: Relationship between seed weight and coefficient of friction (wood)

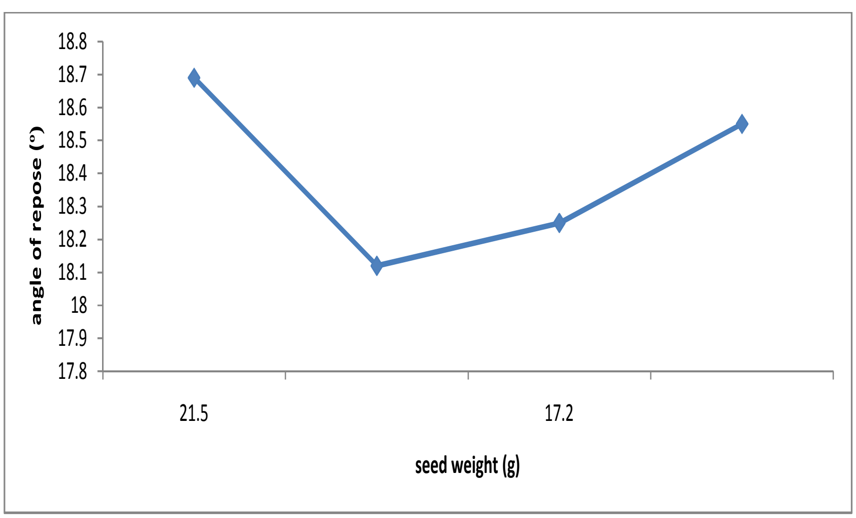

Fig. 8: Relationship between seed weight and angle of repose.

4. CONCLUSION

Investigation on some physical properties of African oil bean seed reveals that at 10.43% moisture content (d. b.):

(a) The values for the major, intermediate and minor diameters were higher than those obtained for other oil seeds.
(b) The surface area, sphericity and roundness suggest the seed as one which will assume some difficulties in rolling.
(c) African Oil Bean seed have gravimetrical properties (weight, volume and density) which do not agree with the law of floatation.
(d) The bulk density and porosity indicates the seed will not form an efficient pile when subjected to a hopper or conveyor on the course of processing.
(e) Hopper and other unloading devices must be built steeply because of its high coefficient of friction and less angle of repose.
(f) These physical properties showed positive correlation and linear relationship with seed weight, except for minor diameter, sphericity and true density which were contrary.

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DEVELOPMENT AND PERFORMANCE EVALUATION OF A CASSAVA CHIPPING MACHINE

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ABSTRACT

Cassava root is highly perishable and therefore cannot be stored in the fresh state after harvesting for more than a few days. A lot of post-harvest losses occur with respect to this commodity during storage due to high physiological activities and the activities of micro-organisms that enter bruises received during harvesting as well as the inherent moisture content of fresh cassava root which promotes both microbial deterioration and unfavourable biochemical changes in the commodity. However, the problems associated with post-harvest losses of cassava could be minimized by processing fresh cassava root into dried cassava chips which can further be processed into other cassava products. As a result of this, there is need to develop a cassava chipping machine to reduce the size of cassava tuber in its present tuber form after peeling into cassava chips for drying. This necessitated the National Centre for Agricultural Mechanization (NCAM), to come up with the development of a motorized cassava chipping machine. The machine component parts consist of main frame, chipping plate, housing and power units. The machine is easy to assemble, easy to operate and easy to maintain. The machine was tested four times using a motor speed of 500 rpm. Test results showed that the machine recorded a maximum machine capacity of 268 kg/hr and a maximum chipping efficiency of 81%.

KEYWORDS: Cassava, post harvest losses, moisture content, chipping machine, tuber.

1. INTRODUCTION

According to Odigboh (1983), cassava certainly remains a major cash crop of the tropical world. It is one of the most popular root crops grown in South America, Africa, South of the Sahara and North of the Zambezi region. In these regions cassava has become the most important crop in terms of total land area developed under cultivation and as a major item of diet.

Presently, cassava is one of the most important and widely grown food crops in Nigeria. Over two-thirds of the total production of cassava goes to the fresh food market for human consumption; the rest is used for animal feed, production of ethanol for fuel, and raw material for starch production industries (Odigboh, 1996). Cassava can be processed into cassava chips, flour, gari and the peels can be used as a source of feed for some class of animals. It is also used to produce ethanol and glucose. Cassava meals from dried root chips have been exported for animal feed purpose (IITA, 1996).

The perishable nature of cassava tubers poses a serious storage problem. Once detached from the growing plant, deterioration sets in, if the cassava tubers are not processed within three to four days after harvesting operation. The deterioration is caused by microbial infections and physiological factors like loss of moisture (Jekayinfa et al., 2003). There is therefore an ever-increasing need to process tubers into some stable form as quickly as they are harvested. Timely processing is also necessary to eliminate or reduce the poisonous cyanide contained in raw cassava, and to give the finished product a good taste (Igbeka et al., 1992).

Chipping is the slicing of tubers to obtain smaller pieces of the tuber (Ofori and Holn, 1971). A chipping machine can be defined as an appliance with parts working together to slice or chip agricultural produce into smaller pieces. Clark (1987) observed that various chipping machines have been developed and tested in various developing countries especially in the Caribbeans and South East countries.

Raji and Igbeka, (1994) developed a pedal operated chipping and slicing machine for tubers. Odigboh and Ahmed (1982) also reported efforts made at Mechanizing tubers processing in the few processing plant in Nigeria. Chipping is done to prevent quick deterioration of cassava tubers. Chipping into thin layer also allows quick drying of the chips to retain maximum quality of the cassava chips and to reach a level of moisture which does not allow the growth of bacteria and fungi. The cassava chips after proper drying could be milled to cassava flour. Cassava flour mixed with wheat flour is used to prepare baked product in the bakery industries. Cassava chips help to reduce the volume to weight ratio which results in lowering shipping or transportation costs. Most foods, exported to South East Asia are now in chipped form. Processing of cassava tuber into chips includes; washing, peeling, size reduction (chipping, slicing or grating), drying and milling.

In Nigeria, there is high demand for cassava both as food and as industrial material. It is therefore very important to design and construct a motorized cassava chipping machine that will be simple to operate and less costly which every individual household in Nigeria can afford. It will serve as a source of livelihood and help to alleviate the high level of poverty in the country today. This paper therefore, discusses the development and performance evaluation of a motorized cassava chipping machine developed at the National Centre for Agricultural Mechanization (NCAM).

2. MATERIALS AND METHODS

2.1 Description of the Machine

The machine consists of main frame, chipping plate, house unit and power unit. Figures 1 and 2 shows the pictorial view of the isometric projection and exploded diagram, respectively, of NCAM developed motorized cassava chipping machine.

2.1.1 The Main Frame

This is the machine part that carries the total load of the machine. It is constructed with a 50 mm by 50 mm by 4 mm mild steel angle bar welded together. The machine frame is 980 mm long, 480 mm wide and 890 mm high as shown in Fig. 1.

2.1.2 Chipping Plate

This is the machine part that does the cutting of the tuber into cassava chips. The chipping plate was formed from a circular plate having a diameter size of 300 mm. This plate was later punched and pushed outward to obtain the chipping plate cutting edges. The chipping plate was riveted to the chipping disc holding the chipping plate as shown in Fig. 2.

2.1.3 Housing Unit

This is the machine part that houses the cassava tubers to be fed into the machine. The machine's housing unit is made of mild steel of gauge 1.5 mm. It serves as a hopper for the cassava tuber during feeding operation. The base of the housing unit is inclined at 45^0 to the frame so as to enable the loaded tuber slide down by gravity.

2.1.4 *Power Unit*

This is the prime mover of the machine. The machine is powered by a 3 hp single phase electric motor via belt and pulley drive. A petrol engine of the same power rating is recommended where there is no power supply to energize the electric motor which powers the machine.

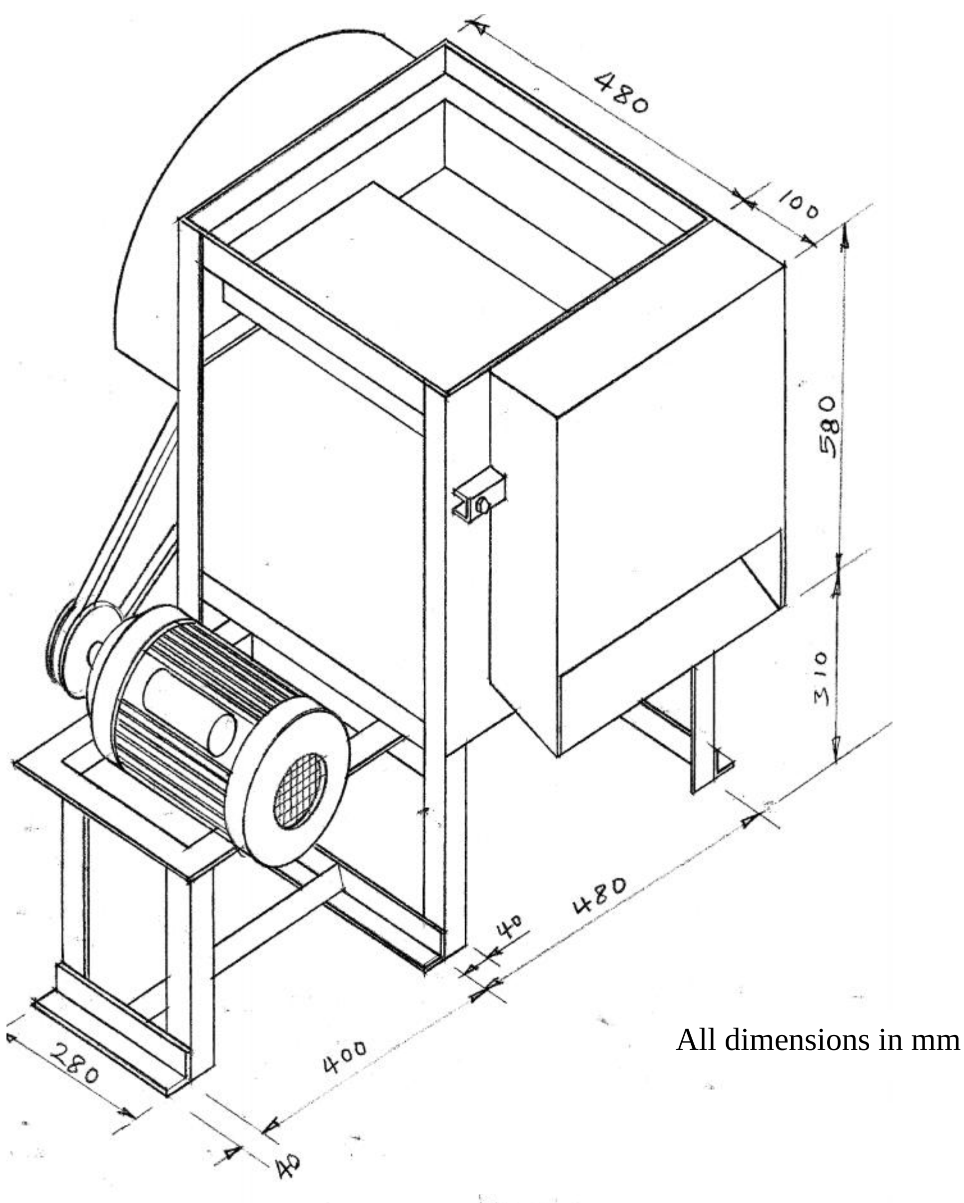
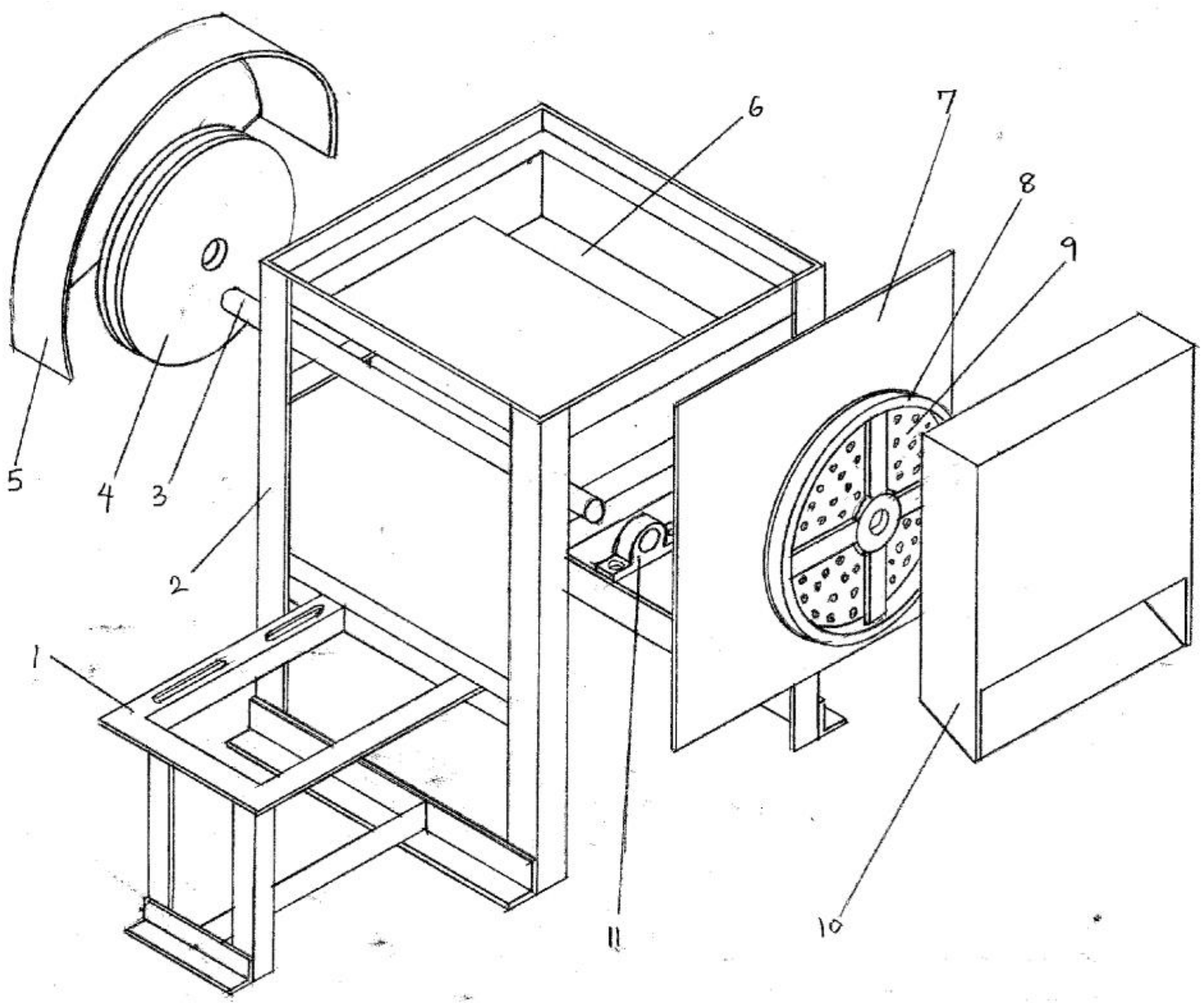


Fig. 1: Isometric Projection of NCAM Motorized Cassava Chipping Machine



Legend	
11.	Pillow bearing
10.	Chipping disc cover
9.	Chipping plate
8.	Chipping disc
7.	Frame cover
6.	Loading tray
5.	Pulley guard
4.	Pulley
3.	Shaft
2.	Main frame
1.	Engine seat
S/No.	Description

Fig. 2: Exploded View of NCAM Motorized Cassava Chipping Machine

2.2 Principle of Operation of the Machine

The machine is simple to operate and so requires only one operator. Before the machine is operated, all parts must be properly set and fixed or bolted together. As the machine is put into operation by energizing the electric motor, which provides the required power to drive the pulley of the chipping machine thereby causing the chipping plate to rotate. Peeled and washed cassava tubers fed into the machine through its housing unit (hopper) where fed against the punched holes (cutting edges) of the rotating chipping plate which resulted in the formation of cassava chips. The resulting cassava chips falls by gravity through the outlet located at the bottom part of the housing unit.

2.3 Design Consideration

The following design criteria were considered when designing the cassava chipping machine:

i. Cassava tubers are of various sizes, therefore this design allows for the use of the largest size of cassava tuber;
ii. The moisture content in the tuber is assumed to be uniform throughout the tuber length thus there is no energy variation during chipping;
iii. The machine chipping plate is designed to produce a cassava chip size that is 50 mm long, 18 mm wide and 3 mm thick;
iv. The machine is targeted for use by agro-processors within the small and medium scale. And for use by the unemployed youths in the country;
v. The strength to weight ratio;
vi. Simple to operate;
vii. Low cost of production; and
viii. Availability of local material for fabrication.

2.4 Design Calculation

2.4.1 Hopper Design

The hopper inclination which is considered an important design factor in hopper design was determined using the expression given by (Ashaolu, 1989). This is expressed as:

$$a = \tan^{-1} \mu \qquad (1)$$

where, a = angle of inclination, μ = coefficient of friction

An angle of 45^o was obtained for the hopper inclination using 0.68 as the value for coefficient of friction between cassava and mild steel as proposed by Ashaolu (1989).

2.4.2 Cutting Unit

Force required to chip is as given by (Akintunde and Akintunde, 2001) as

$$F = S_F + F_F = S_F + \mu S_F \qquad (2)$$

where, $F_F = \mu S_F$ = frictional force between plate and tuber (N), $S_F = S_S$ x A = Shearing force required for chipping (N), S_S = Shear strength for cassava (kN/m^2) = $143 kN/m^2$ as given by Igbeka (1985), A = L x b = Area of contact between plate and tuber (m^2), L = Length of chipping slot (m), = 0.05 m (50 mm), b = width of chipping slot, = 0.018 m (15 mm), μ = 0.68.

Substituting these values into equation (2), the required force to chip cassava tuber is 216.2N.

2.4.3 Design of Drive Mechanism

Power required by the drive mechanism, $P_T = P_R + P_C$ (3)

P_R and P_C could further be expressed as:

$$P_R = T_R + W_R = (W_P \, x \, r_p) \, w_r \quad (4)$$

$$P_C = F \times r_p \times w_r \quad (5)$$

where, P_R = Power to rotate plate (W), P_C = Power needed to chip cassava (W), w_r = Speed of plate (rad/sec), W_P = Weight of plate (N), r_p = Radius of chipping plate (m)

Using a chipping plate having a weight of 7.5 kg (73.6 N), radius of 150 x 10^{-3} m, chipping force of 216.2N, and speed of 50 rad/sec. By substituting these values into equations (3), (4) and (5). Therefore, the corresponding values of P_R, P_C and P_T are 522 W, 1621.5 W, and 2173.5 W (2.914 hp), respectively. A motor of 3 hp was selected for this design.

2.4.4 A Type V-Belt Design

2.4.4.1 Driven Pulley Diameter Size

Table 1 presents values selected for use as basic parameters needed for the design of the machine's V-Belt drive.

Table 1: Basic V-belt parameters

S/N.	Parameter	Value
1.	Electric motor speed	1500 rpm
2.	Follower pulley speed	500 rpm
3.	Centre to centre distance of pulleys	450 mm
4.	Coefficient of friction	0.11
5.	Angle of Groove	45^o
6.	Diameter of driver pulley	100 mm

In determining the size of diameter for the driven pulley, the expression given by Oyelade (2011) was used.

$$N_1 D_1 = N_2 D_2 \quad (6)$$

where, N_1 = speed of the driven pulley (rpm), N_2 = speed of the driving pulley (rpm), D_1 = diameter size of the driven pulley (mm), D_2 = diameter size of the driving pulley (mm).

According to Kempe's Engineers Yearbook and Gates Rubbert Company Manual, the minimum pitch diameter for A – type V-belting transmitting power at a speed of 1500 rpm is 2.2 in (or 55.9 mm). For this reason, a driving pulley diameter of 100 mm was chosen to be used. The calculated value of driven pulley using equation (6) is 300 mm (0.3 m)

2.4.4.2 Maximum Tensile Strength and Mass per unit length of Belt

Adopting the values presented in Kempe's Engineers Yearbook and Gates Rubbert Company Manual, the resulting maximum tensile strength for frictional rubber belting and mass per unit length of belt are 5.5 MN/m^2 and 0.38 kg/m, respectively.

2.4.4.3 Angle of Wrap

The angle of wrap was determined using the expression given by (Oyelade, 2011)

$$\theta_S = \pi - 2Sin^{-1}\ \frac{D-d}{2C} \qquad (7)$$

where, θ_S = Angle of wrap (rads), D = diameter of bigger pulley, d = Diameter of smaller pulley, C= Centre to centre distance between both pulleys.

Substituting these values of D, d and C into equation (7) using the data presented in Table 1 and obtained from equation (6), the resulting value of angle of wrap is 2.92 radians.

2.4.4.4 Belt Cross Sectional Area

The cross sectional area of the belt was best calculated using the description shown in Fig. 3.

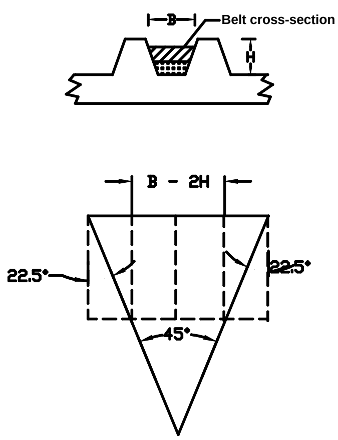


Fig. 3: Belt Cross Section

For A – type V – belts, using a belt with B and H values of 14.17 mm and 7.88 mm, respectively, therefore the cross sectional area of belt BH is given as

$$B \times H \qquad (8)$$

$$= 14.17\,mm \times 7.88\,mm = 111.66\,mm^2$$

From Fig. 1, the cross sectional area of belt, a, is given by

a = BH – XH (9)

The value of X, can be determined from X = H tan 22½ ^{o} (10)

This implies that X = 7.88 tan 22½ ^{o} = 3.26 mm

Therefore, from equation (9), belt cross sectional area, a

2.4.5 Transmission Calculations

The relationships that exist between tensions in belts in V-belt design is given as follows:

$$T_1 = \pm\ a \qquad (11)$$

$$T_c = mv^2 \qquad (12)$$

$$\frac{T_1 - T_c}{T_2 - T_c} = \ell^{\alpha^{-}\ \cos ec} \qquad (13)$$

where, β = semi-angle of the grove, T_1 = Tight side tension (N), T_2 = slack side tension (N), T_c = centrifugal tension (N), m = mass per unit length or the belt (kg/m)

From equation (11), $T_1 = \sigma a$, where, $a = 8.6 \times 10^{-5}\ m^2$ and $\sigma = 5.5 N/m^2$ from previous values obtained. Therefore, the resulting value of T_1 is = 473N

From equation (12), $T_c = mv^2$

Recall that m = 0.38kg/m, from previous value obtained

In determining the value for the belt speed, v, the expression used by Oyelade (2011) was used.

$$V = \frac{\pi D N}{60} \qquad (14)$$

Substituting the value of N_2 as shown in Table 1 as 1500 rpm, the calculated value of V is 15.17 m/s

Therefore, $T_c = 0.38 \times 15.71^2$
$= 93.76N$

In calculating for the value of T_2, using equation (13), recall that

$$\text{«} = 0.12, \bar{\ } = 2.92\,radians, \quad = \frac{45^0}{2} = 22.5^0. By \ \ substitution,$$

$$\ell^{\text{«}\bar{\ }\cos ec} = \ell^{0.12 \times 2.92 \times \cos ec 22.5^0}$$

$$= 2.498$$

$$\frac{T_1 - T_c}{T_2 - T_c} = 2.498$$

$$\frac{473 - 93.76}{T_2 - 93.76} = 2.498$$

$$T_2 = 245.58N$$

2.4.6 Shaft Design

Shaft is usually subjected to torsion, bending and axial loads.
For torsional loads, the torsional stress is as given by Hall et al. (1961) as

$$T_{xy} = M_t\, {}^r\!/_J = 16M_t / \text{®}d \ \ for \ \ solid \ \ shaft \qquad (15)$$

For torsional loads, the bending stress (tension and compression) is as given by Hall et al. (1961) as

$$S_b = M_b\, {}^r\!/_I = 32M_b / \text{®}d^3 \ for \ solid \ shaft \qquad (16)$$

For axial loads, the tensile or compressive stress is as given by Hall et al. (1961) as

$$S_a = 4fa / \text{®}d^2 \ \text{for solid shaft} \qquad (17)$$

The parameters considered for determining the shaft diameter is presented in Appendix I.

2.4.6.1 Determination of Forces Acting on the Shaft

A. Vertical Loading

A vertical load equivalent to the weight of the follower pulley W_{fp} acts at point A as shown in Fig 4. In Fig. 4, $W_{fp} = M_{fp}.g$ (18)

Therefore, $W_{fp} = 5.6 \times 9.81 = 55N$

The vertical component of the belt tensions T_1 and T_2 inclined at 60^0 to the horizontal on the pulley downwards, implies that $T_1 + T_2 = 473 + 245.58 = 718.58$N. Therefore, vertical component of the tension is given by 718.58 $\sin 60^0 = 622.31$N. Meaning that the total downward load at the left end of the shaft is 622.31N + 55N = 677.31N

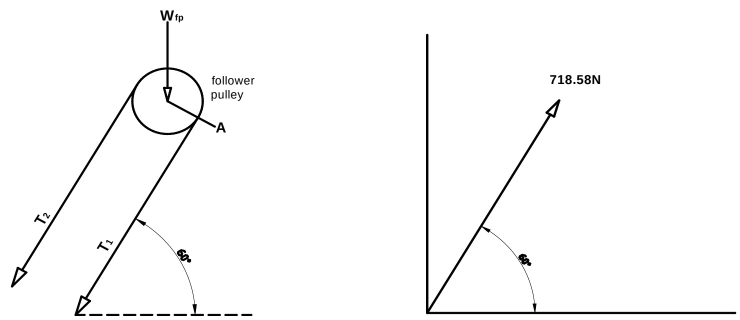


Fig. 4: Force Resolution

A vertical load equivalent to the weight W_{cd} of the chipping disc acts at point D of the shaft, where the hub carrying the load is bolted.
Therefore, $W_{cd} = N_{cd}.g$ (19)

This implies, W_{cd} = 6.5 x 9.81 = 65N. There are vertical reactions R_B and R_C at the bearings located at points B and C, respectively on the shaft.

B. Horizontal Loading
The horizontal component of the belt tensions $T_1 + T_2$ inclined at 60^0 to the horizontal acts on the pulley sideways. Therefore, the horizontal component of the tensions is given by 677.31Cos60^0 = 338.66N

2.4.6.2 Determination of Maximum Bending Moments

A. Vertical Loading
To establish equilibrium of forces for the vertical loads, $R_B + R_C$ = 55N + 65N = 120N as shown in Fig. 6.

Taking moments about B, gives 55 x 0.06 = $-R_C$ x 0.4 + 65 x 0.54
i.e 3.3 = $-0.4R_C$ + 35.1

$0.4R_C$ = 35.1 – 3.3 = 31.8
R_C = 79.5N
R_B = 119 – R_C = 120 – 79.5
R_B = 40.5N

Bending moment at C is given by M_C = 65 x 0.14 = 9.1Nm
Bending moment at B is given by M_B = 55 x 0.06 = 3.3Nm
Note: The sign convention used is as shown in Fig. 5

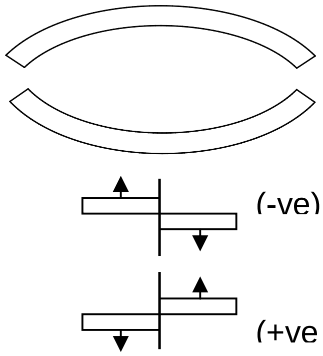


Fig. 5: Sign Convention

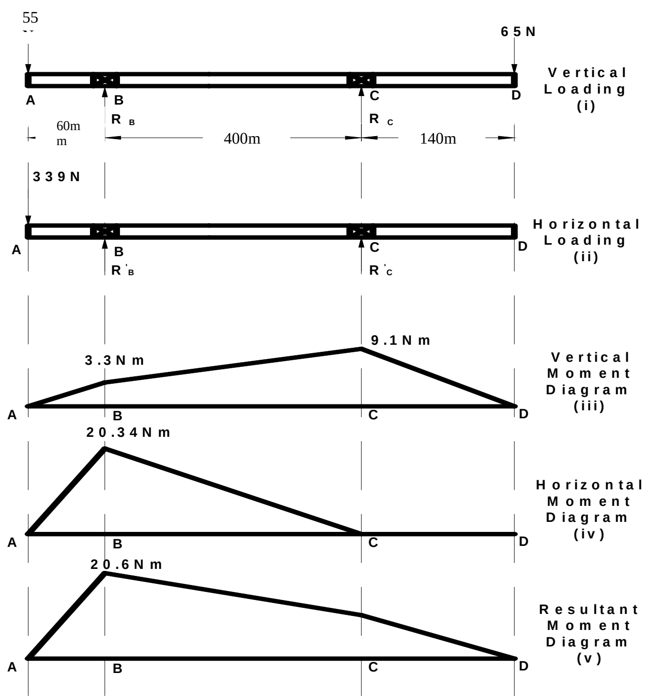


Fig. 6: Loading and Moment Diagram

B. Horizontal Loading

To establish equilibrium of forces for the horizontal load, $R_B + R_C = 338.66 \approx 339$ (as shown in Fig. 6)

Taking moments about B, we have $339 \times 0.06 + R_C \times 0.4 = 0$
Which gives, $R_C = -50.85$ N (i.e. it acts downwards)
By substituting for R_C in the above expression gives, $R_B = 338.66 + 50.85 = 389.51$ N
Bending moment at B is given by $M_B = 339 \times 0.06$ Nm
$= 20.34$ Nm
$M_A = 0$, $M_C = 0$

2.4.6.3 Determination of the Diameter of the Steel Shafting

The ASME code equation for a solid shaft with little or no axial loading is as given by Hall et al (1988) as:

$$d^3 = \frac{16}{®S_s}\sqrt{(K_b M_b)^2 + (K_t M_t)^2} \qquad (20)$$

where, d = diameter of shaft, m, S_s = allowable shear stress for the shaft, N/m^2 (40MN/m^2 for shaft with keyway), M_t = torsional moment, Nm, M_b = bending moment, Nm, K_b = combined shock and fatigue factor applied to bending moment (taken as 1.5 for suddenly applied load on the rotating shaft), K_t = combined shock and fatigue factor applied to torsional moment (taken as 1.0 for suddenly applied load on the rotating shaft).

The torsional moment M_t, acting on the shaft is as given by (Hall et al., 1988) as

$$M_t = (T_1 - T_2)r_f$$

where, T_1 = tension on the tight side of V-belt, T_2 = tension on the slack side of V-belt, r_f = radius of follower pulley

Therefore, $M_t = (473 - 245.58)0.15 = 34.11$Nm

Maximum bending moment $M_{b\,(max)}$ is given by:

$$M_{b(\max)} = \sqrt{(20.34)^2 + (3.3)^2}$$

$$= 20.6Nm$$

Substituting these values into equation (20), gives

$$d = 0.018028m = 18mm$$

A factor of safety of 1.3mm was used. For the purpose of this design a diameter shaft of 25 mm was used.

2.5 Machine Cost

The fabrication of a single unit of this motorized cassava chipping machine during the period of study cost a total of ₦75,625 as shown in the Bill of Engineering Material and Evaluation (BEME) presented in Appendix II.

2.6 Performance Evaluation Test

2.6.1 Test Procedure

Peeled cassava tubers were weighed and loaded into the machine manually. The maximum and minimum length size of cassava tubers used during machine testing was 700 mm and 200 mm, respectively. The maximum and minimum diameter size of the cassava tubers used during machine testing was 120 mm and 50 mm, respectively. Analysis the overall samples of cassava tuber sizes used during machine testing gave an average tuber length and diameter size of 300 mm and 100 mm, respectively. The chipping plate rotates at a speed of 500 rpm after which the machine hopper was filled up with peeled and washed cassava tubers. These tubers were pressed with the use of a small wooden plank to increase the contact between the plate and tuber.

2.6.2 Machine Capacity

This is defined as the amount of tuber chipped by the machine per unit time expressed in kg/hr. This is mathematically expressed as:

$$\text{Machine Capacity (kg/hr)} = \frac{w_1}{t}$$

where, w_1 = input weight (kg), t = time (hr)

2.6.3 Chipping Efficiency

This is expressed as the amount of cassava root chipped out of the total quantity of cassava root fed into the machine usually expressed in percentage. This is mathematically expressed as:

$$\text{Chipping efficiency (\%)} = \frac{w_2}{w_1} \times \frac{100}{1}$$

where, w_1 = input weight (kg), w_2 = output weight for fine or normal chip (kg)

2.6.4 Percentage of Crushed Cassava Chips

This is the percentage of the amount of crushed cassava chips found present after chipping operation out of the total amount of cassava root fed into the machine for chipping. This is mathematically expressed as:

$$\text{Percentage of crushed cassava chips} = \frac{w_3}{w_1} \times \frac{100}{1}$$

where, w_1 = input weight (kg), w_3 = output weight for crushed product (kg)

2.6.5 Percentage of Unchipped Cassava Root

This is the percentage of the amount of unchipped cassava chips found present after chipping operation out of the total amount of cassava root fed into the machine for chipping. This is mathematically expressed as:

$$\text{Percentage of unchipped cassava root} = \frac{w_4}{w_1} \times \frac{100}{1}$$

Where, w_1 = input weight (kg), w_4 = weight of cassava not processed (kg)

3. RESULTS AND DISCUSSION

The result of the performance of the machine is presented in Table 1.

3.1 Machine Capacity

The highest machine capacity obtained during machine testing using a chipping speed of 500 rpm in the four trials was 268.16 kg/hr. This occurred when it took the machine 127 seconds to chip 9.46 kg of peeled and washed cassava root fed into the machine as shown in Table 1. The lowest machine capacity obtained during machine testing at that same chipping speed (500 rpm) in the four trials was 252.46 kg/hr. This also occurred when it took the machine 78 seconds to chip 5.47 kg of peeled and washed cassava root fed into the machine (see Table 1). It was also observed in Table 1, that the higher the quantity of cassava roots fed into the machine the more time it takes to get the cassava chipped. This signifies that both weight input and time taken to chip during cassava chipping operation are directly proportional to one another and vice versa.

3.2 Chipping Efficiency

The highest chipping efficiency obtained during machine testing using a chipping speed of 500 rpm in the four trials was 80.8%. This occurred when it took 4.42 kg out of 5.47 kg of peeled and washed cassava root fed into the machine to be chipped within 78 seconds as shown in Table 1. The lowest chipping efficiency obtained during machine testing using the same chipping speed (500 rpm) in the four trials was 79.6%. This also occurred when it took 7.53 kg out of 9.46 kg of peeled and washed cassava root fed into the machine to be chipped within 127 seconds (see Table 1).

3.3 Percentage Crushed Cassava Chips

The highest and lowest percentage of crushed cassava chips obtained during machine testing using a chipping speed of 500 rpm was 10.14 % and 9.51%, respectively. These values of percentage crushed cassava chips obtained (Table 1) may be regarded as a loss to the agro-processor in terms of weight lost during products packaging after drying operation. This could be minimized or eradicated by reducing the chipping speed of operation of the machine so as to minimize the high number of crushed cassava chips. Bolaji et al. (2008), reported that using a high chipping speed during cassava chipping operation results in low chipping efficiency of the machine.

3.4 Percentage Unchipped Cassava Root

The highest and lowest percentage of unchipped cassava root using a chipping speed of 500 rpm was 10.36% and 9.69%, respectively. These values of percentage unchipped cassava root obtained (Table 1) were found to be higher than the values obtained for the percentage crushed cassava chips. This may be attributed to the irregular shape of cassava roots most especially the smaller shaped cassava root which may easily pass through the space existing between the rotating chipping plate and housing unit cover without making contact with the rotating chipping plate.

Table 1. Performance evaluation results

Replicate	Input weight of tuber (w_1) Kg	Weight of fine/normal chips (w_2) kg	Weight of crushed chips (w_3) kg	Weight of cassava root unchipped (w_4) kg	Time (sec)	Machine Capacity (kg/hr)	Chipping Efficiency (%)	Percentage of crushed cassava chips (%)	Percentage of unchipped cassava root (%)
1	5.46	4.42	0.52	0.53	78	252.46	80.80	9.51	9.69
2	9.46	7.53	0.95	0.98	127	268.16	79.60	10.04	10.36
3	6.21	4.96	0.63	0.62	84	266.14	79.87	10.14	9.98
4	7.49	6.02	0.74	0.73	105	256.80	80.37	9.88	9.75
MEAN	7.16	5.73	0.71	0.72	98.5	260.89	80.16	9.89	9.95
STD	1.75	1.37	0.18	0.19	22.25	7.49	0.53	0.28	0.30

4. CONCLUSION AND RECOMMENDATION

At the National Centre for Agricultural Mechanization (NCAM) a motorized cassava chipping machine was developed and tested. During machine testing, the machine was found to perform satisfactorily by producing cassava chips which could be used for both human and animal consumption. The motorized cassava chipping machine when tested at 500 rpm at four trials produced a maximum machine capacity and maximum chipping efficiency of 268 kg/hr and 81%, respectively.

The manual chipping method of chipping cassava tubers in Nigeria through the use of hand cutting knives is labour intensive and time consuming. Because of the quick and fast deteriorating nature of cassava tubers immediately after harvesting operation makes this NCAM motorized cassava chipping machine recommendable for use as a substitute for the manual process of chipping cassava tubers in Nigeria.

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EFFECT OF MACHINE VARIABLES ON THE PERFORMANCE OF A LOCALLY BUILT CASSAVA CHIPPING MACHINE

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ABSTRACT

A cassava chipping machine designed and fabricated at the Agricultural Engineering Department of Rufus Giwa Polytechnic, Owo, Nigeria was used for the experimental evaluation. The machine capacity, functional efficiency and quality performance efficiency are the parameters studied for the machine performance. The chipping machine was evaluated at three different thickness of cutting blade (2, 4 and 6mm) and five levels of machine speed (300, 350, 400, 450 and 500rpm). The test result indicated a maximum of 18.5Kg/hr machine capacity, 98% functional efficiency and 96% quality performance efficiency when 2mm blade was used at a machine speed of 350mm. The performance was found to be influenced by the studied machine variables.

KEYWORDS: Blade thickness, speed, performance, cassava, chipping machine

1. INTRODUCTION

Cassava (*Manihot esculenta*) is a perennial tuberous root crop of the family Euphorbiaceae which is characterized by the production of latex or milky juice (Kochlar, 1981). It is believed to be of South American origin and was taken to the West Africa by the Portuguese in the sixteenth century (Purseglove, 1984). It is the most important food crop grown in the tropical Africa because of its efficient production of food energy, year-round availability and tolerant of extreme environmental stresses that make it eminently suitable for farming (IITA, 1989).

Cassava is primarily a source of carbohydrate and contains very little protein or fat. The approximate composition of the cassava tuber is starch, 20-30%; protein, 2-3%; water, 75-80%; fat, 0.1%; fibre, 1.0%; ash, 1-1.5% (Iherekonye and Ngoddy, 1985).Cassava starch has excellent agglutinant properties which make it especially suitable for shrimp and fish feed, replacing expensive artificial agglutinants (FAO,1986). The potential disadvantages of cassava roots are their bulk and rapid perishability, their low protein content and the presence of cyanogenic, glucosides, linamin and lotaustralin in variable proportions that is toxic (Bolarin et al, 2004). Therefore, cassava needs to be processed before they can be consumed or marketed.

Many different processing techniques are employed to convert raw cassava tubers into various useable products according to local customs and preferences (Nweke, 1996; Saliyo et al, 2007; Igbeka et al, 1992; Nwagugu and Onwualu, 2004). Table1 gives a list of some of the traditional foods produced by processing cassava. Compared with fresh cassava, the processed products have increased shelf life, are easier to transport and market, contain less cyanide and are more palatable. One important intermediate product making up a major proportion of marketed cassava is the cassava chips.

The objective of chipping is to expose the maximum surface of the starch flesh and encourage a rapid drying. The quality of the chips depends greatly on the thickness of the slices and the age of the crop (Gomez, 1991; Odigboh, 1983; Kurup et al, 1995). Traditionally, chips are made by a wide range of methods but the use of heavy knives does not make slices sufficiently thin for rapid drying. Also the operation is tedious, time consuming and there is always the risk of the operators cutting their fingers. Therefore, various chipping machines have been developed and tested in many developing countries to facilitate the drying process (Clarke,1987), but the use of heavy steel plates has made most of the imported machines too expensive for Nigerian rural farmers (Odigboh, 1983).

Table 1. Examples of Processed Cassava

Name of Product	Country	Aspect of the Product	Length of Storage
Chips	Nigeria Cameroon Benin Togo Ghana	Small pieces of sun-dried cassava sometimes fermented, and marketed before being ground into flour. The flour is mixed into paste with hot water to form a thick, sticky mass known as "*fufu*" in West Africa or "*ugali*" in East Africa.	Several months
Gari	Nigeria Ghana, Togo, Benin, Cameroon	A dry fermented and gelatinized coarse meal. It is mixed into a paste with hot or cold water and eaten with soups or stews. Also used as snack when mixed with milk and sugar.	Can be stored for up to 2 years if kept below 12% mc
Farinha	Brazil	A yellowish coarse meal very similar to *gari*. It is used in many Brazilian dishes, especially in the north-east region.	Several months or if kept dry for up to 2 years
Attieke	Côte d'Ivoire	Attieke resembles wet "*cuscus*". A fermented, pre-gelatinized meal generally consumed with milk or meat and vegetables. It swells much less than *gari* and *farinha*.	3 to 4 days
Cassava bread	Haiti, Dominica Rep. Venezuela,.	A white, flat, circular, light textured bread baked from moist cassava pulp. Thickness varies from 1 to 5 mm and diameter from 10 to 90 cm. Called *casabe* in Spanish, *cassava* in French and *beiju* in Portuguese	One week
Chicouangue	Congo Zaire Central African Rep.	A pre-gelatinized cassava paste usually in the form of balls wrapped in leaves. In Congo and Zaire chicouangue is steamed before being sold.	3 to 4 days
Baton	Cameroon Congo Zaire Gabon	Basically a fermented and pounded cassava mash but with wide regional variation Often shaped as 30-50 cm long and 2 to 4 cm diameter sticks. They are tied in leaves for cooking, they may be eaten alone or with a side dish.	Few weeks
Fufu	Cameroon Congo Zaire	The name used for the paste made from cassava starch, flour and grated roots.	3 to 4 days

(Source: FAO 1998)

Therefore the difficulties encountered in the traditional methods and the high cost of imported machines necessitated the development of a local cassava chipping machine whose performance evaluation is presented in this paper.

2. MATERIALS AND METHODS

2.1 Machine Description

The machine consists of the feeding chute, chipping unit, discharge unit, frame and the prime mover. The feeding chute (hopper) is trapezoidal in shape and made of 16mm gauge galvanized iron sheet to withstand vibration as well as prevent contamination of the chips. The trapezoidal shape facilitates easy movement of tubers into the chipping unit and holds the tuber in place.

The chipping unit consists of a shaft on which the blades are attached concentrically. The chipping blades are made of galvanized iron sheet cut into rectangular shapes with sharpened edges. The frame supports the machine and consists of two v-shaped structure made of 38mm x 38mm angle iron that is firmly fastened together with bolts and nuts to allow dismantling for easy transportation. The prime mover is one horsepower (1hp) electric motor of 1200rpm maximum speed. Fig.1 shows a pictorial view of the cassava chipping machine.

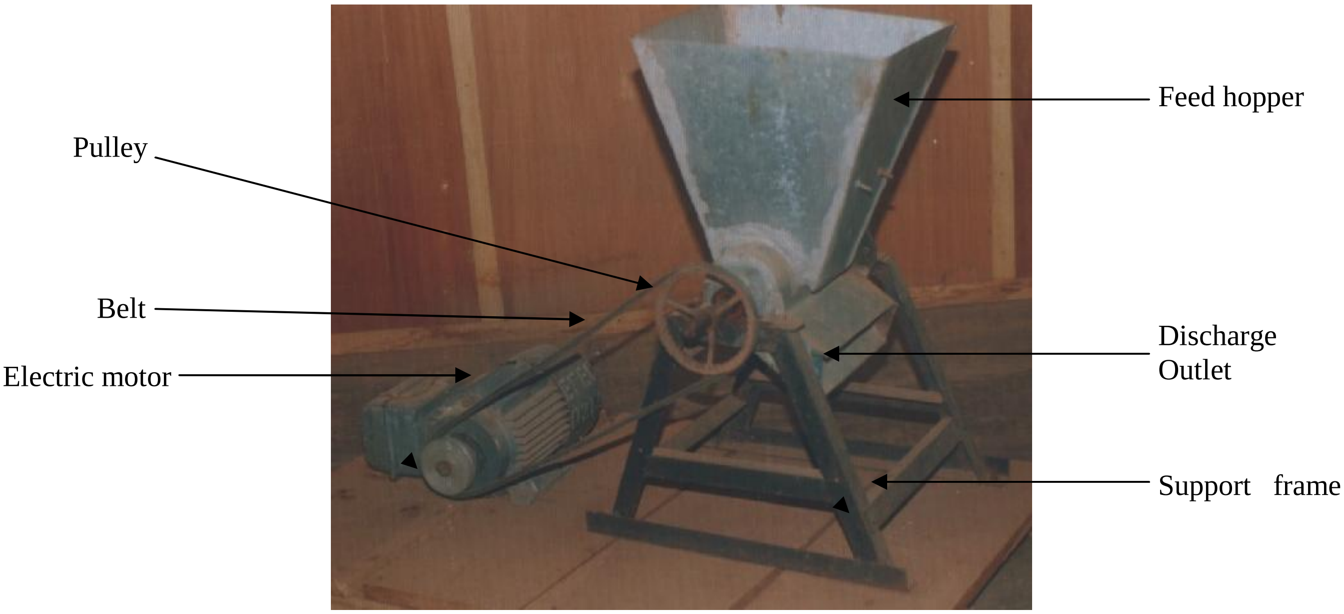

Figure1. Pictorial View of Cassava Chipping Machine

2.2 Performance Evaluation

Freshly harvested cassava tubers were bought from the local market (Ikoko market). These tubers were peeled neatly and thoroughly washed for the experiments. A total of 150Kg of the peeled cassava tubers were fed into the hopper (2 kg for each test run). The parameters that were varied for the experimentation are the thickness of the cutting blades and the speed of the machine. The thickness of the cutting blades used were 2mm, 4mm and 6mm. The speeds of the machine were varied by varying the pulley sizes. The diameter of the pulley used were 625mm, 563mm, 500mm, 438mm and 375mm corresponding to 500, 450, 400, 350 and 300 rpm respectively.

After each operation, the weight of cassava chipped, the weight of unchipped and weight of damaged chips were recorded. Each experiment was carried out in five replicates and the average was recorded and used for analysis in order to evaluate the effect of the cutting blade thickness and speed on the capacity, functional efficiency and quality performance of machine. The machine capacity was determined using the equation (ASAE, 2003; Hunt, 1983)

$$M_p = \frac{W_C}{T} \quad \text{.......... (1)}$$

Where Mp= Machine capacity,W_C = weight of cassava chipped in one operation, T = time taken to complete the operation.

The functional efficiency of the machine was determined using the equation.

$$E_f = \frac{W_C}{W_T} = \frac{W_C}{W_{C+W_N}} \times 100\% \quad \text{.......... (2)}$$

Where:E_F = Functional efficiency, W_T = Weight of total cassava presented for chipping

W_N= Weight of cassava not chipped

The quality performance efficiency of the machine was determined using the equation.

$$E_Q = \frac{W_C - W_D}{W_T} = \frac{W_G}{W_{C+W_N}} \times 100\% \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots (3)$$

Where: E_Q = Quality performance efficiency, W_D= Weight of damaged chips

W_G = Weight of good quality chips.

3. RESULTS AND DISCUSSION

Investigation was carried out on a locally fabricated cassava chipping machine. The mean values of the results obtained from the five replicate of the samples are graphically represented in Fig. 2-4. The effect of thickness of cutting blade and machine speed were studied.

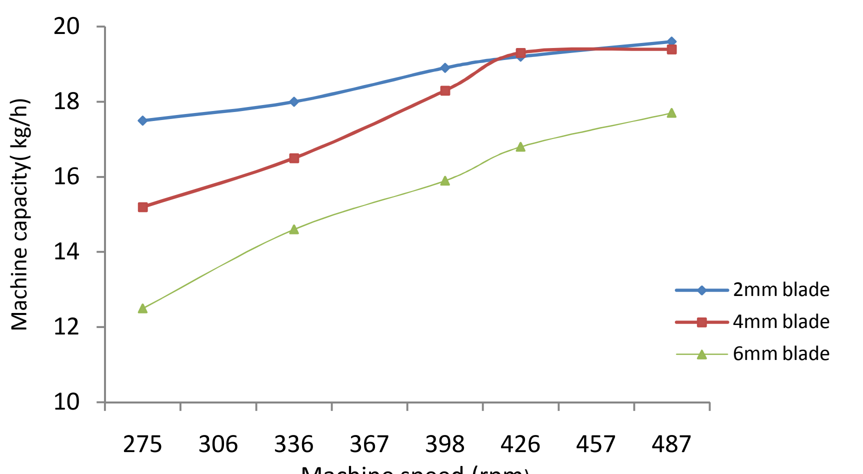

Fig. 2. Effect of machine speed on machine capacity

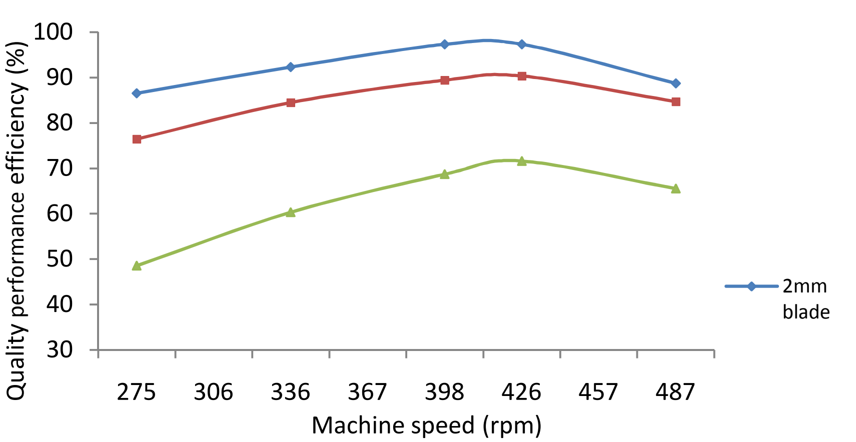

Fig. 4. Effect of machine speed on machine quality performance efficiency (%)

3.1 Thickness of Cutting Blades

With freshly harvested cassava tubers, the thickness of the cutting blades significantly affected the output and the performance efficiencies of the chipping machine. From Fig. 2 to 4, the 6 mm blade appears to be the least efficient blade. Its capacity ranged from 12.2 kg/h to 16.4 kg/h; the functional efficiency ranged from 60.2% to 82.5%, while the quality performance efficiency ranged from 48% to 77%. Both 2 mm and 4 mm blade at very high speed of 425 and 450 rpm have the same chipping capacity of 18.5 kg/h and functional efficiency of 96% respectively. The 2 mm blade thickness has the highest quality performance efficiency of 98%. The 2 mm blade thickness is therefore the most efficient of the three selected blades.

3.2 Speed of Machine

Using freshly harvested cassava tubers, Fig. 2 to 4 showed that the speed of chipping machine seems to have significant effect on the performance of the machine especially when using the 4 mm blade. Generally, high speed of the machine resulted in a high machine capacity and functional efficiency. It is clear from Fig 4 that the highest efficiency of 98% was obtained at the machine speed of 398 rpm, when 2 mm blade was used. Beyond the machine speed of 400 rpm, the efficiency begins to fall. This is as a result of more chips being damaged because they are being re-chipped again at very high machine speed.
In the analysis of Variance, it was observed that there was significance difference in the means of the blade thickness and machine speed for the machine capacity, machine functional efficiency and the quality performance efficiency (Tables 2, 3 and 4).

Table 2: Analysis of Variance of Machine Capacity

Source of Variation	SS	df	MS	F	P-value	F crit
Blade thickness	26.14533	2	13.07267	30.6271	0.000178	4.45897
Machine speed	29.58933	4	7.397333	17.33073	0.000526	3.837853
Error	3.414667	8	0.426833			
Total	59.14933	14				

Table 3: Analysis of Variance of Machine Functional Efficiency

Source of Variation	SS	df	MS	F	P-value	F crit
Blade thickness	531.796	2	265.898	22.56943	0.000514	4.45897
Machine speed	1081.229	4	270.3073	22.9437	0.000193	3.837853
Error	94.25067	8	11.78133			
Total	1707.276	14				

Table 4: Analysis of Variance of Machine Quality Efficiency

Source of Variation	SS	df	MS	F	P-value	F crit
Blade thickness	2357.665	2	1178.833	132.9361	7.28E-07	4.45897
Machine speed	477.5267	4	119.3817	13.46258	0.001255	3.837853
Error	70.94133	8	8.867667			
Total	2906.133	14				

4. CONCLUSIONS

Comparing the performance of the three blades, the 6 mm blade is least efficient for use on the machine. The 2 mm blade is preferred to 4 mm blade. This is because at 425 rpm and 450 rpm the 2 mm blade yielded 96% and 98% of both functional and quality performance efficiency. However, at 425 and 450 rpm the two blades (2 and 4 mm blades) are recommended for use on the machines.

Capacity and functional efficiency of the machine increased with increase in the speed of the machine. It is not advisable to increase the speed of 4 mm and 2 mm blade beyond 400 and 425 rpm as the quality performance efficiencies fall beyond this point.

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PROMOTING SUSTAINABLE SMALL-SCALE FOOD PROCESSING ENTERPRISES FOR POVERTY REDUCTION AND FOOD SECURITY IN NIGERIA

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ABSTRACT

The first and primary goal of the Eight- Millennium Development Goals is the reduction of poverty by 2015. Poverty, has along with food insecurity ravaged the entire developing nations of the world over the years. Appropriate food and crop processing and preservation techniques are vital to solving food insecurity problems encountered globally. Developmental efforts to promote sustainable small – scale food and crop processing enterprises need to be based on sound understanding of appropriate and current technologies, technical and socio-economic environment as well as a clear vision of appropriate intervention strategies. Women constitute over 60% of Agricultural workforce in Nigeria and are involved in primary crop and food processing aimed at reducing crop losses and adding value to the raw materials. Majority of these women live in the rural areas and are not skilled.

This paper reviews small-scale food processing in Nigeria, its importance and limitations with particular reference to rural areas. When properly developed, food processing enterprises can provide income and improved livelihood as well as employment for rural people. It can provide for value added industrial raw materials, ensure food security, fast track technology development and generally take rural people out of the cycle of poverty they currently find themselves. However, these potentials are currently limited by: low skill, poor access to information, ineffective government policy, poor finance and business management, low technology input, poor infrastructure and unfair competition from imported products.

A strategy is proposed, towards overcoming the constraints. This involves a participatory, programme approach that will ensure the creation of at least 1000 knowledge based technologically empowered small scale entrepreneurs in each of the 36 state of Nigeria. These SMEs should be provided with skills, technology, access to markets, functional infrastructure and flexible financial packages that will enable them produce high quality goods that can compete in the global market.

KEYWORDS: Poverty reduction, food security, women, crop and food processing enterprises.

1. INTRODUCTION

The Millennium Development Goals (MDGs) of 2000 is a fifteen (15) years global agenda compact for development which every member nation of the global community must aim at and fulfill by 2015. At the beginning of these 15 years global agenda hopes were high and the entire world was strongly committed. More than half-way through the time frame, according to the President of Nigeria, many countries are off track while some are struggling to maintain the successes that have been achieved (Yar-Adua, 2008).

Eradication of extreme poverty and hunger is the first of the 8 MDGs. Poverty is defined as a state of insufficient income to take care of basic needs such as food, clothing and housing (Corbett, 2008). Extreme poverty means having not just food, but not having adequate nutritious food along with other needs. Extreme poverty also referred to as absolute poverty in terms of income is described as a state of having household income less than half of the official poverty line, which in developing countries is US $1 per day. This situation which threatens people's lives and health is a core issue on the MDGs.

Globally, poverty affects the rural area with a disproportionate effect on women and children. The issue of rural poverty has become endemic in Sub-Saharan Africa (SSA), and has attracted much attention. It is becoming intractable especially in the face of global economic crisis.

Food insecurity is an issue that is related to poverty. Food security is defined as a state “when all people at all times have physical and economic access to sufficient, safe and nutritious food for a healthy and productive life” (FAO, 2006). Food security has three (3) components which are: (i) Food availability, which is the amount of food that actually exists; (ii) Food accessibility which is the capacity to acquire food and the stability of this access over time; (iii) nutritional adequacy (quality) of available and accesses food. (Alleborne -Webb, 2006).

One serious consequence of poverty is malnutrition, which is a state of not being able to obtain nutritious food for healthy living. Rosegrant (2005) reported that the increase rate of poverty in Sub-Saharan Africa since 1970 has resulted into continual decline in per capital consumption of food. The ability of the poor to be food secured is reduced. Hunger as used to in MDG 1 refers to poverty and food insecurity (Alleborne -Webb, 2006).

Statistics show that undernourished global population reduced by only 3% (20 to 70%) between 1990 and 2003. It is reported that many regions of the world may not reach the 10% target of MDG by 2015 particularly Sub-Saharan Africa where one third of the population is food insecure (FAO, 2006). The availability and nutritional components of food security is directly related to agricultural activities. A 1% rise in per-capita agricultural output can lead to 1.6% rise in the income of the 20% poorest people in the world (Alleborne -Webb, 2006). However, large increase in agricultural production is not sufficient for poverty reduction and food insecurity. Food crops produced must be processed and preserved to ensure availability, accessibility and quality at all times. Reducing cost and improving quality through value-addition, post-harvest processing and storage, packaging and marketing using labour-saving technology are required to reduce rural poverty and food insecurity.

The African leaders food security summit of 2006 gave birth to the special program for food security which had a major objective of national food security through increase food production on an economically sustainable-basis, reduce variability in food availability and cost and improve people access to food. Economic development plays an important role in the growth of any society. The need to promote small-scale food processing enterprises stems from these needs. Firstly, to empower the rural dwellers and women in particular by bringing them into the mainstream of development, improving their economic status thereby alleviating the poverty and food insecurity they face. Secondly, to provide employment opportunities by way of income generation, self- employment and entrepreneurship to women, whose preoccupation is agriculture.

The development of food processing enterprises at micro and small scale levels in the rural area is important in enhancing availability, accessibility and quality of agricultural food products. Reduction in post-harvest losses of food crops through timely and adequate processing is crucial in creating an escape from rural poverty and household and national food security.

This paper takes a look at poverty and food insecurity in Nigeria. It discusses micro and small-scale food processing as the preoccupation of the rural poor particularly women, and highlights the importance and constraints of this sector in the rural sector. The development of sustainable small-scale food processing enterprises requires effective technical and entrepreneurial skill acquisition. Since over 70% of rural population are women and over 60% of this group are involved in food processing activities in Sub-Saharan Africa including Nigeria, this paper concludes that the development of skills through proper training plays a key role in alleviating extreme poverty and food insecurity, and promote economic growth of the rural areas.

2. POVERTY AND FOOD INSECURITY IN NIGERIA

Available statistics show that 62.6% of households in Nigeria are poor (NBS, 2006). However, the summary of Nigeria MDG report card 2006 shows that the trend in poverty is on the decline with 54.4% of the population living in relative poverty. The proportion of population living in extreme poverty was expected to have fallen to 28.78% in 2007, if the MDGs target is to be met, it was put at 35% (Ibrahim, 2007). However, the midpoint assessment of MDGs in September 2008 reveals that about 50% of the population still lives in poverty, six years to the attainment of the MDGs. (Ibrahim, 2008).

Similarly, analysis of poverty by sector shows that poverty is more pronounced in the rural area (65.6%) compared to the urban 56.8%; on agenda basis, rural poverty and urban poverty rate among women is put at 74.7% and 60% respectively compared to 64.2 and 56.2% for men. Rural poverty has been due to low level of education while urban poverty is due to income inequality (NBS, 2006, Ibrahim, 2008). It has been reported that about 17 percent of Nigeria's population suffer from food insecurity in 2004 and 34 percent in 2007 (Aniyi, 2004, DFID2008). Poverty reduction in Nigeria is still very slow. Nigeria is said to be off-track to meet the 2015 target. (DFID2008). Despite several Presidential initiatives, such as the National Program on Food Security, the Community Based Agricultural Development Program and other safety nets to alleviate poverty; several challenges still face Nigeria in reaching the MDG target on poverty reduction.

Agriculture which is the largest contributor to National GDP and crucial to achieving the poverty eradication goals is faced with many challenges which boils down to food insecurity. The slow rate of poverty eradication is the weak production base of the country. With a monolithic economy and dependence on oil for export, the agro-processing sector which is the primary source of industrial raw material for manufacturing at all scales has been neglected. While several government policies on poverty alleviation have overriding objective to broaden opportunities for poor to have access to basic economic and social needs as reiterated in the MDGS; poverty with its attendant impact on other MDGs cannot be eradicated without ensuring that rural dwellers particularly women have access to vital resources required for growth in their pre-occupation. (Musa-Makama, 2008)

As presently practiced, Nigerian agriculture cannot guarantee food security for the ever increasing population. The sector is still characterized by: subsistence level of production, resource poor farmers, low technology input, very poor yields per unit area, near absence of commercial farmers, poor management, small land holdings, etc. As a result of the above, Nigeria has moved from an exporter of some food products (palm oil and kernel, groundnuts, cocoa, etc) in the 1960s o the situation today where the country is a net importer of foods. Recent estimates give the level importation as 635, 356, 217 an 97 billion Naira annually for wheat, rice, sugar and fish respectively.

This situation is definitely unsustainable and has made agriculture in Nigeria to fail in playing its traditional role of providing materials for food and raw materials for food processing industries. Even with the low production, it has also been found that most of what is produced is lost to deterioration as a result of poor handling and transportation systems, poor preservation and storage techniques and poor processing. Of all the challenges facing agriculture, poor processing appears to be the most important. It is therefore important that this sector be resuscitated and made to operate in a sustainable manner.

3. STATUS OF SMALL SCALE FOOD PROCESSING ENTERPRISES IN NIGERIA

In general, industries can be classified into four categories namely Micro, Small Scale, Medium Scale and Large Scale Industries. This classification is usually based on the size of the firms with respect to the number of employees, volume of annual turnover (in monetary terms) and how formalized the management structure is. The classification varies from country to country. In Nigeria, most food processing industries of the micro scale size employ between one and 5 persons, with annual turnovers of less than 250,000 Naira. These are usually sole enterprises or family business and the owners would normally be engaged in other businesses. The next level in size are small scale enterprises that employ between 5 and 20 people with annual turnovers of about one million Naira. Medium scale enterprises are more formulated and can employ over 20 people with annual turnovers in excess of one million Naira but not above 250 million Naira. For large scale food processing enterprises, annual turnovers can be in excess of 250 million Naira with employees more than 100 people. These are usually formulated companies with well defined structures. In Nigeria, most of the food processing, especially at the farm gate are carried out by small scale processors.

The products of these small scale processors can be classified into two major categories namely those that come from primary processing and those from secondary processing. Some of the products from primary processing include different grades of grains, (rice, beans, millet) vegetables, root crops (yam, cassava, cocoyam, potato, fruits (mango, orange, pine apple, tomato). Those from secondary processing include products like moi-moi, akara, fried yam, yam flour, cassava flour, plantain chips, groundnut cake, bread, vegetable oil (palm oil, palm kernel oil, groundnut oil), cake, chinchin, wire meat, poultry, fish, honey etc.

The sector (small scale food processing) is characterized by a number of features including low technology input, manual operation, poor quality products, poor management and accounting skills, poor packaging, challenges of market access and dominated mostly by resource poor women. As a result, the sector needs serious interventions in order to improve the operations and hence achieve improvements in the products and sustainability of the businesses.

For this improvement to be sustainable, the entire value chain for each of the food products must be studied and improved upon. There is need for technology interventions in the entire value chain including input supply, production of the crops or animal, post harvest handling and preservation, storage, transportation, processing, marketing and consumer feed back mechanism. Each of these components of the value chain requires intervention in three major areas – technology, finance and training. These can be achieved by a joint and collaborative action by the major stakeholders including the small scale operators, government (policy) regulatory agencies (standards and quality, financial institutions (money), research institutes and development partners (technology).

4. IMPORTANCE OF SMALL SCALE FOOD PROCESSING ENTREPRISES

Small – scale food processing enterprises are important to sustaining livelihoods among the poor in the following ways.

4.1 Income and Employment Generation

It is estimated that 60% of the labour force in sub-Saharan Africa particularly women find work in small scale food processing (Spore 2005). In Nigeria, majority of women operate at the micro to small scale levels such as fish smoking in the coastal areas (Lagos Delta, Rivers, Niger, Kogi, Kwara and Sokoto States); Garri, Fufu and starch processing from cassava (southern and Eastern States); Groundnut oil and groundnut cake (kulikuli) production in Niger State; 'warankashi' (cheese) production by the Fulani women, maize, cassava and yam flour by Gbagi tribe; vegetable (pepper, okra, amaranth drying), soybean processing into cheese, milk and beverage drinks and so on. Opportunities are created for production of goods and services targeted at local market, thus creating wealth and ultimately reducing the level of poverty. The value –added through processing as well as marketing is often greater than the value of the raw material itself (World Bank, 2003; IFPRI, 2004).

4.2 Production of Industrial Raw Materials

The small scale food processing serves as a feed point for large manufacturing sector through conversion, handling, and processing (e.g. Ground Nut cake is a feed –product for poultry feed manufacturers). This helps boost manufacturing sector hence economic growth. Most industries that are agro-related are involved in processing one type of agricultural product or the other into another raw material or finished product. These include flour mills, breweries, fruit juice industries, noodles making industries, bakeries, etc. For most of these industries, some secondary raw materials are required. Small scale enterprises involved in food processing sometimes are the only industries that carry out preprocessing activities before the products are accepted by large scale firms as raw materials.

4.3 Food Security

About one third of Nigerian population does not have food to eat sufficiently throughout the year despite increased crop production. The optimum health and nutrition of an individual depends on not just amount of food eaten, but regular eating of food and a balanced diet. Food processing primarily improves food security by increasing availability through, conversion, preservation and storage as well as access to food throughout the year. Processing food stretches the utility and productivity of farm produce which are often wasted during peak season, and also helps to preserve the nutritional characteristics of food. This help to stabilize house hold income and food security, health and nutrition. The maintenance of the nutritional qualities of raw food is a primary target of food processing. The poor growth and development of this sector directly robs the rural people of these benefits.

4.4 Technology Development

A sustainable food processing industrial landscape requires different types of technology to be successful. The technologies include store for sorting, cleaning, sterilization, heating, drying, steaming, destining, mixing, pasteurization, canning, bagging, packaging etc. These machines must be powered by electricity or generators with an accessory of intermediate machines such as electric motors, gear systems bearings, sprockets etc. Once the food industry is thriving, it also creates new service industries for fabricating, servicing, installation, etc of the ancillary components. All these will lead to growth of technology within the economy.

5. CHALLENGES OF SMALL-SCALE FOOD PROCESSING ENTERPRISES IN NIGERIA

Small-scale food processing entrepreneurs face a number of challenges which constrain the growth and development of the sector and prevent them from making the most of opportunities available through government polices and programmes and from development partners. These constraints which can be intrinsic or extrinsic are described below.

5.1 Low Skill

Small-scale food processors are constrained disproportionally by either lack of or low skill in food and hygiene, poor processing methods, poor quality control and packaging. This makes their product of low standard compared with large local companies, multi-national companies or imported products, not exportable and often earn little profit and managerial skills. The additional skill needed to make indigenous techniques more viable, appropriate and competitive for successful development of sustainable small scale food processing enterprises are beyond the reach of the poor people, who are the ones to establish and run the SMEs.

5.2 Poor Access to Information

Local and indigenous food stuff in sub-Sahara Africa have potential resources that are currently being underutilized. This is compounded by lack of information in these following areas: data base on indigenous and traditional processing methods, nutritional information and effect of processing on bio availability of nutrients in foods food safety issues, quality assurance procedures, equipment and packaging sources and information on markets, business management techniques. Although several research Institutes have been conducting research on these plants, the information does not get to local farmers due to challenges of extension.

5.3 Ineffective Government Policy Environment

Government policies and programmes over-time in sub-Sahara Africa including Nigeria have been biased in favour of medium to large scale investors and entrepreneurs. The small-scale food processors receive less government support in form of foreign exchange, importation of equipment and subsidies, specialist advice from the large companies. Yet this sector serves as a feed-net to the bigger ones. In Nigeria, this sector which is dominated by the rural poor and particularly women has no political influence and suffer the vagaries of both national and international economic climate.

Stable political conditions, favourable economic climate and government policies which practically support import substitution are essential to the development and success of small-scale food processing enterprises and causes them to grow into large scale. Sometimes even when the policies are in place, they are poorly implemented. Many small scale operators have also complained of multiple taxation and levies by different arms of government.

5.4 Poor Food Packaging

Low quality, unattractive, and poor handling characterize small scale processed food products. Poor access to appropriate material and equipment are obstacles to growth as traditional packages such as leaves and jute bags do not perform technically well, are less attractive and perceived by consumers as inferior. On the other hand modern packaging materials and equipment are costly and beyond the reach of small scale operators. Common facility packaging centres can solve this challenge.

5.5 Credit and Financial Constraints

Small-scale food processors belong to the marginalized sector (rural poor) and do not have disposable income. Disabilities in securing credit are commonly cited constraints. These continue to hinder the development of this sector. Problems such as lack of collateral, prejudices and marginalization have been hindering such operators from having access to loan and financial support.

5.6 Poor Finance and Business Manpower

Many small scale food processors are illiterates and poor in terms of resources. They do not have the relevant entrepreneural skills that can enable manage finances and business very well. At the same time, they cannot engage the services of business and financial experts because of lack of funds. This they do not have the advantage of entrepreneural skills such as product diversification, use of technology, marketing and skills that can make them to be more competitive. All these contribute towards making them operate at subsistence level and give the impression that food processing is not a lucrative business.

5.7 Low Technology Input

To become competitive and meet global standards, modern technology in form of machines must be used. These are required in areas of process control, packaging, quality control and equipment of regulatory authorities like NAFDAC. Most SMEs food processors do not have the financial resources to acquire technology in order to meet these standards and also produce large quantities of products per unit time thus bringing down the unit cost of production and increasing profit. This is also not helped by the fact that most food processing machine are manufactured abroad, making their costs way beyond the reach of small scale operators.

5.8 Competition from Imported Products

One of the major challenges facing the small scale food processor in Nigeria is the excessive and uncontrolled importation of processed food into Nigeria. In addition to this, many Nigerians prefer the imported products to the locally processed products. Part of the problem is that the imported once are cheaper and better packaged than the locally produced ones. This problem lead to low effective demand, with the result that the few small scale processors who are producing cannot easily sell their products thus leading to discouragement of both those producing and the potential entrepreneurs who may prefer importation.

5.9 Poor Infrastructure

For a viable food processing sector, there must be good and functional infrastructure. The problem currently is that the entire infrastructure – electricity, roads, railways, water, market, etc are not functioning optimally. This results in the SMEs operators having to invest in infrastructure such as standby generators, making cost of production to be too high, and hence the business not being profitable.

6. STRATEGIES FOR SUBSTAINABLE SMALL SCALE FOOD PROCESSING ENTERPRISES (FPEs)

So far, we have shown that for Nigeria's quest for agricultural development to succeed, all components of the Agricultural Value Chain must be developed. The small scale food processing sector is currently dominated by small resource poor operators, mostly women. To revive the sector and make it sustainable, there must be a conscious strategy to create enterprises that are viable, profitable, fulfilling and enduring over a long time. The following strategies are proposed:

6.1 Creation of a New Generation of Knowledge Based FPEs

Nigeria is blessed with many food products of plant and animal origin from different parts of the country. There should be a programme to create at least 1000 small scale knowledge based food processing enterprises (FPEs)in each of the 36 states of the federation including the Federal Capital Territory in the next 5 years. Actually, the processors are already there. What is required is to tactically select the promising ones and equip them with the necessary "tools" that they require to succeed and become sustainable. This package of "tools" can be given to them on loan sine most of them cannot afford it, probably through any of the development banks such as Bank of Agriculture or Bank of Industry. Each one of them will specialize in processing one particular commodity to produce a finished product or secondary raw material for another small scale or a medium or large scale industry. The package of tools include: Capacity Building; Access to Technology; Access to Markets; Functional Infrastructure and Flexible Financial Packages and Commercialization of R&D Results.

6.2 Capacity Building

One of the main issues that emerged out of Food Africa discussions in 2003 was the need to train small and medium scale food processing enterprise operators in Sub-Saharan Africa in management and technical skills (Quirien et al, 2003).

Training is a crucial tool in addressing the needs of entrepreneurs and to achieve the aims and objectives of government policies and programs as well as efforts of development partners. Training has two objectives, firstly to impact specific skills and secondly to raise awareness and encouragement. Skill acquisition training is important for entrepreneurs in small scale food processing to alleviate poverty. On the other hand, raising awareness can help improve food security and nutrition.

The aim of training in the context of development of small scale food enterprises herein is to provide practical skill and information on technical, legal, political business and marketing aspects of food processing that will make entrepreneurs run a sustainable business. Such training must promote value-added local food products for national and export markets, enable and contribute to economic development of individuals, rural communities and the nation, economically, empower predominant population in food processing (i.e. women) hence combat poverty and improve nutritional status and life style of families through proper processing and improved household income, hence food security. Training needs depend on the types of food and existing skill level. However, the following areas are critical to producing high quality marketable products:

1. Specific food processing techniques
2. Use of machinery, simple equipment and their maintenance
3. Hygiene and quality assurance ;
4. Packaging, labeling and nutritional information
5. Marketing, business and financial management
6. Food legislation and safety
7. New products development

Training should be used to address one of these specific areas or can be a complete package designed for one or more special agricultural products such as fish, fruits, vegetable, dairy, oil palm, cassava, ginger, groundnut, etc.

In order to make this capacity building to work and be sustainable, government should facilitate the emergence of at least one skill acquisition centre in each agricultural zone of each state of the Federation. Where they are already in existence, they should be strengthened. These training centres should be run as private enterprises and potential trainees should be empowered to attend the training programmes after which they can be empowered with the technology and financial resources they require to practice what they have learned.

6.3 Improved Access to Technology

For a food processing enterprise to succeed, modern technology must be used. These include machines for the actual processing and storage, machines for packaging and labeling, machine for quality control and Information and Communication Technology (ICT) for having access to information. These technology components are expensive to acquire, use and maintain. The can be provided to the entrepreneurs on lease with favourable interest rates. Since most of the technologies can serve other purposes, the multi use will make them financially feasible. Some of these technologies can be acquired from different Research Institutes in Nigeria, fabricators or from vendors of imported equipment. The implication is that efforts should be made to strengthen the Research Centres and local fabricators. In addition, development partners and NGOs should increase assistance in acquiring and giving these technologies to the operators.

6.4 Imported Access to Markets

As a way to encourage local processors, efforts should be made towards increasing the tariff for processed food products that cannot be produced in Nigeria. For the ones our SMEs can produce, government should consider outright ban on importation. This shall be followed by government sponsored campaigns for made in Nigeria goods as well as procurement policy that gives preference to locally produced processed food. There should be competitions among state governments on the products they have promoted.

The efforts of Nigerian Export Promotion Council (NEPC) in promoting made in Nigeria goods abroad should be strengthened using Nigerians in Diaspora. In addition, specialized marketing channels like whole sale and retail chains should be encouraged to stock made in Nigeria food product.

6.5 Functional Infrastructure

For these industries to be sustainable there must be constant power supply, good roads, rail system, public water supply, adequate sousing and indeed other infrastructure that are required. These include technology based infrastructure such as Technology Parks, Incubation Centres, Skill Acquisition Centres, Industrial Clusters, etc. Some of these will provide initial soft take off points for some of the enterprises, especially those who cannot provide their infrastructure.

6.6 Flexible Financial Packages

Even when all the infrastructure is in place, these is need for a sustainable flexible financial system that can make it possible for good business to have access to good financial plans that will enable them acquire infrastructure, technology training and indeed working capital for raw materials and other consumables. Some of these are already in existence through Central Bank of Nigeria (CBN), Bank of Industry (BOI), Nigerian Export-Import Bank (NEXIM), Nigeria Economic Reconstruction Fund (NERFUND), and other donor agencies (World Bank, International Financial Corporation, African Development Bank) and in fact Commercial Banks. What is required is a special mechanism to make the financial products more easily accessible by the small scale entrepreneurs.

6.7 Commercialization of R&D Results

Almost every knowledge centre in Nigeria has some up with at least one commercializable Research and Development (R&D) result that can lead to a small scale industry for food processing. These institutions include Universities, Polytechnics, Colleges of Agriculture, Research Institutes, Colleges of Education. A special fund should be created to enable these Institutions work with private entrepreneurs towards commercialization of these results to use them for food processing business. This will not only build the capacity of Nigeria to innovate but improve the capacity of the Institutions to impact on the society.

7. CONCLUSIONS

Combating poverty especially in rural areas has been a difficult and a slow process in Nigeria and indeed other Sub-Saharan African countries. The lack of education, access to infrastructure (land, water, energy transportation) information, technical and managerial skills has trapped rural people in a poverty cycle with no immediate end in view. Women who constitute over 70% of the rural population, 80% of food processors and 68.7% of rural poor are more affected; lack the skill in practical knowledge of modern and adequate technology to add value to their products. For this problem to be solved the small scale food processing sector needs to be developed.

Development of sustainable small –scale enterprises requires that the sector overcome the inherent, intrinsic and extrinsic constraints. One primary way of achieving this is to improve the knowledge of the operators in the sector through training and skill acquisition (both technical and managerial). Well planned and appropriate training can help achieve high quality and marketable product, to generate income, alleviate poverty and ensure food security.

Training for Food Processing entrepreneurs cannot be done in isolation, but should form part of an overall food production and poverty eradication strategy of government, where an improved range of food products and value-adding skills are addressed. This will help the poorest poor and promote sustainable livelihood for poverty eradication. Therefore, other strategies identified include the creation of a new generation of knowledge based food processing entrepreneurs (at least 1000 per state). These entrepreneurs who should be mostly (70%) women should be equipped with relevant technology, functional infrastructure, flexible financial packages and access to markets. This can lead to production of high quality goods that can uplift them out of the cycle of poverty they are currently trapped in a programme base, participatory approach should be adopted in implementing the strategies involving government at all levels, development partners, Research Institutions, NGOs and other stakeholders.

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SOME PHYSICO-CHEMICAL CHARACTERISTICS OF PALM KERNEL OIL MECHANICALLY EXPRESSED AT DIFFERENT TEMPERATURES UNDER UNIAXIAL LOADING

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ABSTRACT

Operative processing variables like heating temperature, pressure, heating time and pressing time generally affect mechanical oil expression. But heating temperature has tremendous effect on the physico-chemical characteristic of the expressed oil. Mechanical oil expression from palm kernel was studied under a piston-cylinder rig in association with an instrumented hydraulic press (model 52773703, Denmark) of 15 tonnes capacity. The effects of heating temperature on the physico-chemical characteristics of mechanically expressed palm kernel oil obtained from ground palm kernel samples was investigated at heating temperatures of 70, 90, 110, and 130 °C at an applied pressure of 15 MPa. The oil expressed from each temperature level was subjected to laboratory analysis using AOAC 1991 recommended method at the analytical and quality control laboratory of the Global Soaps and Detergents Industries, Ilorin, Nigeria. The result of the physico-chemical characteristics of the palm kernel oil at temperature range of 70-130 °C are: Free fatty acid 4.02 - 4.63 %; Acid value 11.29-12.0mgKOH/g; rancidity index 2.4R.21Y–1.9R.10Y; saponification value 246.57-243.80mgKOH/g; viscosity 140 – 60cps and specific gravity 0.908-0.894. The result indicates that the quality of the expressed oil decreases as the heating temperature increases. Also palm kernel oil expressed at heating temperature ranging from 70 °C to 110°C has many industrial applications.

KEYWORDS: Palm kernel oil, physico-chemical characteristics, mechanical expression, uniaxial loading, and heating temperature.

1. INTRODUCTION

Oils for food, nutraceuticals, skin care, aromatherapy and industrial lubricants can be produced from many kinds of seeds, nuts or mesocarps. The increase in the world's population has no doubt increased the demand for fats and oils obtained from oil bearing crops. Oil-bearing crops are classified into three, namely: *Oil seeds and beans*; *nuts*; and mesocarps or fruits. The Oil Palm, which gives both Palm Oil (PO) and Palm Kernel Oil (PKO), is Elaeis guineensis (Hartley, 1988). The Palm Oil (PO), which is reddish in colour, is obtained from the Orange colour mesocarp, while the PKO is obtained from the hard-liquefied cell within the nut, called the kernel.

Modern Processing of Oil bearing crops (seeds or nuts) into edible or industrial oil is practiced using different methods, which may be categorized into two. One is the solvent extraction method in which a solvent, when brought in contact with the preconditioned oil seed or nut, dissolves the oil present in the oil bearing material and the separated mixture is later heated to evaporate the solvent and obtain the oil. Mechanical oil expression is the second method. In this process, the preconditioned oil seed or nut is passed through a screw press, a hydraulic press or a ram press, where a combination of high temperature and pressure is used to crush the oil bearing material to release the oil. Literatures on palm oil expression from oil palm abound, but not much work has been done on palm kernel oil expression from ground palm kernel at different heating temperatures (Ozumba, 2012).

RMRDC, (2004) reported that palm kernel oil has a greater preponderance of saturated fatty acids than palm oil (80% compared to 60% for palm oil) with the major fatty acid being Lauric oils. It also contains the low molecular weight fatty acids, caprylic and capric acid. Oil world, (2000) also reported that Lauric acid is the major fatty acid in the composition of Palm Kernel and Coconut oil at about 50%, while no other major oil contains more than about 1% (butter fat contains 3%).

Pantzaris and Ahmad, (2001) reported that about 90% of the oil and products from it are used for food applications, while about 10% goes into non-food applications. Although small in volume, the non-food sector is of increasing importance because of the higher added value of the derived products. The cake residue obtained after extraction is used in livestock feeds while the palm kernel oil are used in soap and cosmetics industries, vegetable oil and margarine. (Ekpa, 1995). According to NIFOR (2005), the Nigerian palm kernel oil production industry has been characterized by low production capacity, low extraction rate of (12 – 18)%, low quality of produced oil (FFA greater than 10%). These problems can be reduced to the barest minimum by using the correct processing techniques, conditions and equipment.

This study is therefore aimed at investigating the physico-chemical characteristics of palm kernel oil expressed at various temperatures in order to ascertain their suitability in consumption, industrial application and ability to meet local and international market demands.

2. MATERIALS AND METHODS

All experimental investigations were carried out in the Engineering Materials Testing laboratory of the Engineering and Scientific Services (ESS) department of the National Centre for Agricultural Mechanization (NCAM), Ilorin, Nigeria. The room temperature of the laboratory throughout the duration of the experimental works was averagely 30 ^{0}C.

2.1 Material Preparation

Palm Kernel (Dura Variety) used in this experiment was obtained from the Nigerian Institute for Oil Palm Research (NIFOR), Benin City, Nigeria. Moisture content of the palm kernel at the point of procurement was determined and found to be 11.5 %. The kernels were further dried to 4.5% moisture content using sun drying method. The kernels were cleaned to remove stones and other foreign materials; after which they were firstly crushed using a hammer mill, and later the crushed meal was further reduced using an attrition mill as reported by Olaniyan, (2006). They were later packed into air tight containers and stored in the laboratory.

2.2 Experimental Machines and Instrumentation

Oil expression process normally involves the application of compressive force on the oil seed flakes enclosed in a suitable retaining envelope. In this study, laboratory mechanical oil expressing piston-cylinder rig was modified and fabricated, and used for this investigation (Fig. 1).

The mechanical oil expression rig, which is similar to the one used by Olaniyan (2006) and Mrema 1979 (and reported by Mrema and McNutty 1980, 1984 and 1985 on mechanical expression of oil from rape seed, cashew and Shea butter) is made up of three major components: the compression piston, the press cage cylinder and the supporting platform (Olaniyan 2006). A 600 W electric band heater was installed round the press cage cylinder to serve as a heating device for the expression process. The rig was adequately instrumented with a temperature controller to control the expression temperature, while the pressure for oil expression was obtained from the hydraulic press (made in Denmark Stenhous A/S hydraulic press with model number; 52773703 of 15 tonnes capacity and actuated using a lever) via the instrumentation system. The temperature controlling exercise was achieved with thermocouple connected to an Electronic Temperature Controller (Model JTC-902), which was designed and manufactured in Japan. Heat sensing was achieved by inserting the thermocouple probe into the oil seed sample through a hole on the press cylinder. A complete assembly of the Hydraulic press, the mechanical oil expression rig and the instrumentation system used throughout for the experimental investigation is as shown in Figure 1.

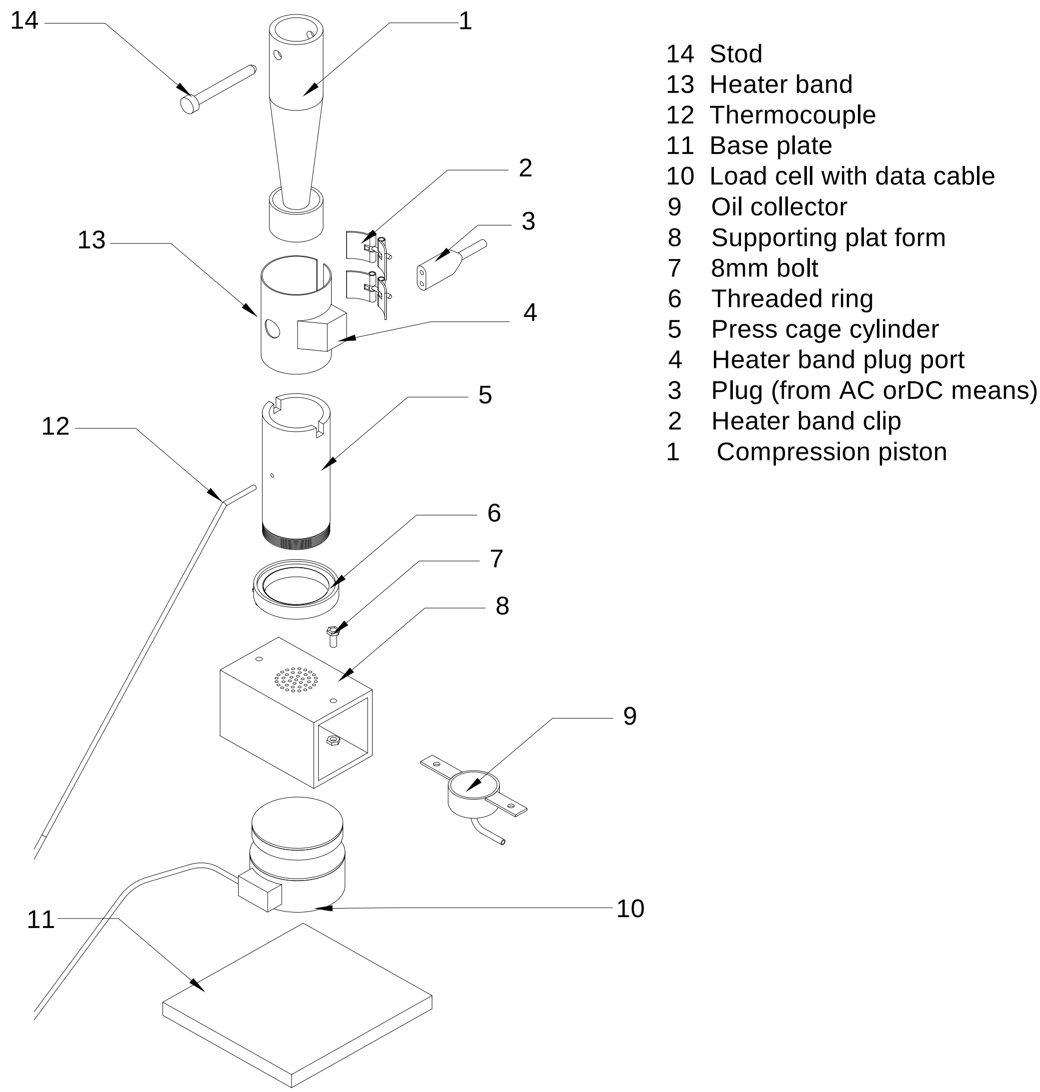

Fig. 1: Exploded view of the Model laboratory Mechanical Oil Expression Rig.

2.3 Experimental Investigation Procedures

2.3.1 Moisture Content Determination

Moisture content of the sample was determined by oven drying 100g of ground sample at 130°C for 6 hours; as recommended for oil seeds by Young et al (1982) and used by Tunde-Akintunde et al (2001).

2.3.2 Heating of Sample

Heating of the sample (ground palm kernel) was achieved by weighing 200g of the sample in line with Olaniyan (2006), and transfer of the weighed sample into the press cage already encircled with the temperature controlled heater band (see Fig. 2). The samples in the press cage where heated to temperatures of 70 °C, 90 °C, 110°C and 130 °C respectively for 30 minutes before expression begins. The lower limit of 70 °C and upper limits of 130 °C heating temperature was selected based on preliminary laboratory investigations, which revealed that heating milled palm kernel sample below 70 °C did not give good oil yield during expression; while heating above 130 °C results in excessive burning and darkening of the oil.

Fig. 2: Assembly of the heating system
A - press cage cylinder, B - heater band, C - thermocouple, D - temperature controller

Also, the heating time of 30 minutes used in this study was chosen based on preliminary investigations and also on the fact that the period allows for temperature uniformity and equilibration of the oil seed cake as reported by Hamzat and Clarke (1993).

2.3.3 Sequence of Mechanical oil Expression

The complete assembly of the hydraulic press, the mechanical oil expression rig with the temperature regulator, and the compressive force measuring device used in this experiment is as shown in Figure 3. Before coupling the mechanical oil expression rig, a stainless steel wire mesh was placed at the bottom of the cylinder guide in order to cover the drainage area and at the same time serve as a filter during the oil expression process.

After the coupling, a sample of 200g weight of milled palm kernel was poured into the press cage cylinder. The sample was then heated for 30 minutes at heating temperature of 70 °C. Using the actuating lever of the hydraulic press, the compression piston was moved down to touch the sample and pre-compact it to a height of 70mm (Olaniyan, 2006) inside the press cage cylinder. After the pre-compaction, the sample was further compressed by the hydraulic press via the compression piston to a pressure of 15.0 MPa for 10 minutes. The oil expressed drains into the oil collector and was collected through the outlet pipe.

The same procedure was followed to carry out the experiment for three other heating temperature levels of 90 °C, 110 °C, and 130 °C at 15 MPa.

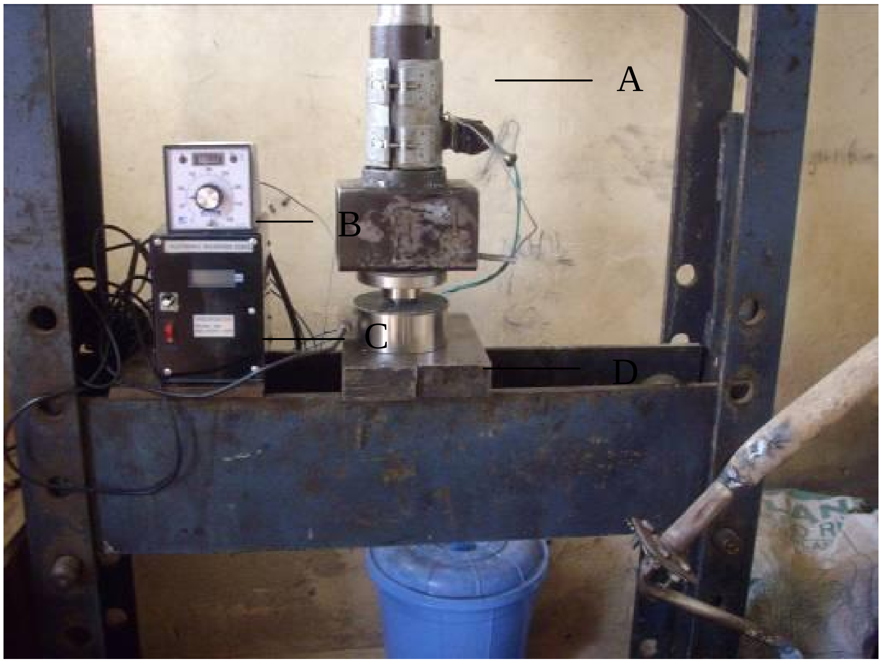

Fig. 3: Complete Assembly of the Force Measuring Device, the Mechanical Oil Expression Rig with the Temperature Controller on Hydraulic Press.
A - Mechanical Oil Expression Rig. B - Temperature Controller. C - Amplifier with display Unit (Force Measuring Device). D - Load Cell.

2.3.4 *Determination of Physico-Chemical Characteristics of expressed Oil at different Temperatures*

The physico-chemical characteristics of the expressed oil determine the quality of the oil. The physico-chemical analyses of each sample of oil expressed at heating temperatures of 70 °C, 90 °C, 110 °C, and 130 °C were carried out using the AOAC (1991) recommended method at the Analytical and Quality Control Laboratory of the Global Soaps and Detergents Industries Limited, Asa Dam Road, Ilorin, Nigeria. The physico-chemical properties of the expressed oil determined are: free fatty acid, acid value, rancidity index, saponification value, viscosity, and specific gravity.

3. RESULTS AND DISCUSSION

3.1 Effect of Heating Temperature on Free Fatty Acid

Figure 4 shows the effect of heating temperature on free fatty acid of palm kernel oil mechanically expressed from palm kernel under Uniaxial loading. Ishiwu and Iwouno (2006) reported that Free Fatty Acids are usually formed during decomposition of glycerines in the oil on the application of heat on the oil bearing seeds before expression. From the figure, it can be observed that the Free Fatty Acid increases with an increase in heating temperature from 70^0C to 130^0C. At higher heating temperatures, thermal decomposition of the glycerines' takes place more rapidly leading to the formation of more Free Fatty Acid compared to at lower heating temperatures during the course of the study. Also, increasing the heating temperature results to the destruction of more oil cells, thereby resulting to the formation of more Free Fatty Acids. Fashina and Ajibola (1989) carried out investigation on Conophor oil expression; they reported that high levels of Free Fatty Acids in oils may also be related with degradation by hydrolysis. Olaniyan (2006) carried out an investigation on mechanical expression of oil from Shea Butter; he reported that high percentage of Free Fatty Acid in oils and fats renders them unfit for consumption. This is due to the breaking of bonds of short carbon chain, which invariably increases the acidity of the oils and fats.

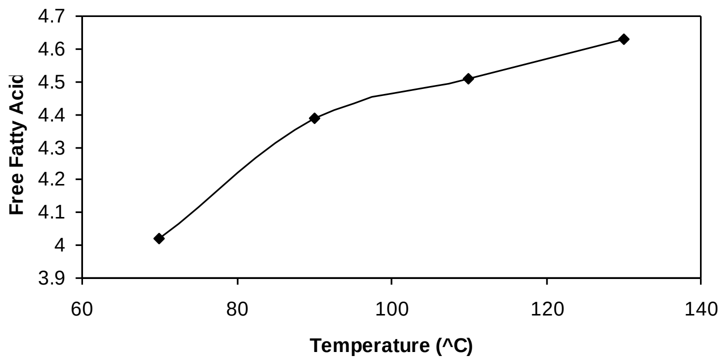

Fig. 4. Effect of Heating Temperature on Free Fatty Acid

The progressive increase in heating temperature from 70^{0}C to 130^{0}C, which resulted to a corresponding increase in Free Fatty Acid, goes a long way to suggest that the levels of heating temperature used in this study were not high enough to make the enzyme lipase inactive. Meanwhile, Ohlson (1979) in Olaniyan (2006) was reported to have observed such inactivation to dry heat to be at 140^{0}C – 160^{0}C. This trend was corroborated by Adeeko and Ajibola (1989) for groundnut oil.

Increase in the Free Fatty Acid values with increase in temperature, in this study, could also be due to thermoxidation and thermolytic cleavage of the oil as heating temperature was increased. Therefore, effective control of heating temperature during thermal pre-treatment of palm kernel for palm kernel oil extraction is imperative.

The Free Fatty Acid of 4.02, 4.39, 4.51 and 4.63 were obtained from palm kernel samples at 70^{0}C, 90^{0}C, 110^{0}C and 130^{0}C respectively. This shows that the oil expressed at these temperatures are of good quality based on the recommendations of UNIDO (1977) in Olaniyan (2006) that the values should be about 5%. From the result obtained from this study, it can be suggested that palm kernel oil extracted from palm kernel heated at 70^{0}C to 130^{0}C can be used in food industries, and can also be said to meet international market standards.

3.2 Effect of Heating Temperature on Acid Value

The effect of heating temperature on the total acid value of palm kernel oil mechanically expressed from palm kernel under Uniaxial loading is as shown in Figure 5. The figure shows that acid value increased with increasing heating temperature. The acid value increased from 11.29 to 13.0 when the temperature was increased from 70 ^{0}C to 130 ^{0}C. This suggests that the higher the pre-treatment heat given to the palm kernel samples, the higher the acid value of the palm kernel oil extracted from the samples.

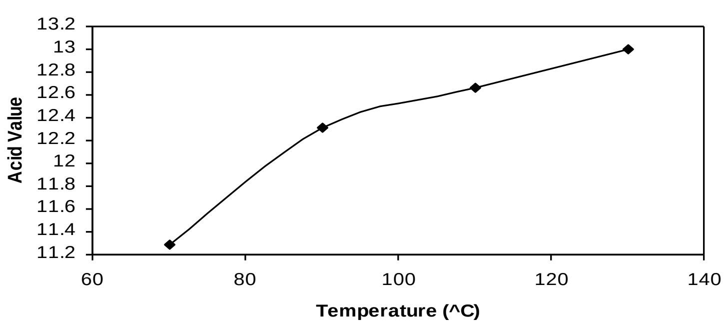

Fig. 5. Effect of Heating Temperature on Free Fatty Acid

A closer look at the figure reveals that the rate of acid formation was higher when the heating temperature was increased from 70 ^{0}C to 110 ^{0}C, but reduces as the heating temperature was increased from 110 ^{0}C to 130 ^{0}C. This suggest that heating palm kernel above 110 ^{0}C is likely appropriate for palm kernel oil extraction. However, there was no significant difference between the acid value obtained at 110 ^{0}C and at 130 ^{0}C, this might be attributed to the fact that the increase in temperature from 110 ^{0}C to 130 ^{0}C could not effect much changes. Low acid value obtained from this study might be due to the freshness of the palm kernel used for this experiment. Because the samples were not stored for long, degradation by hydrolysis was insignificant.

The acid value is a measure of the total acidity of the oil. It is directly proportional to the Free Fatty Acid of the oil. This was why the acid value obtained in this study increased as the heating temperature increases since the Free Fatty Acid increased with increasing temperature as seen earlier. This is in agreement with the findings of Olaniyan (2006) on Shea Butter extraction.

According to Bamikole (2009), the standard acid value for any commercial vegetable oil for soap making is from 10-20. Based on this, it can be concluded that palm kernel oil extracted at heating temperature ranging from 70^{0}C to 130^{0}C is suitable for industrial soap making.

3.3 Effect of Heating Temperature on Rancidity Index

The effect of heating temperature on rancidity index of palm kernel oil mechanically expressed from palm kernel under Uniaxial loading is as shown in Figure 6.

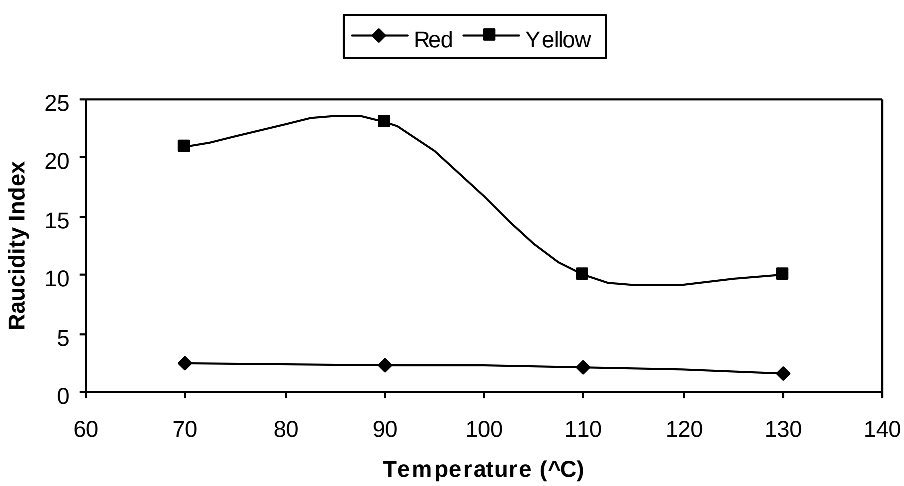

Fig. 6. Effect of Heating Temperature on Rancidity Index

The non appearance of the blue colour curve in the figure shows that there was little or no deterioration of fats and oils within the heating temperature ranges used for this experiment. According to Olaniyan (2006), the more the appearance of blue colour in oils and fats, the higher the degree of rancidity. Base on this fact, it could be suggested that the palm kernel oil extracted from the samples at 70 °C, 90 °C, 110 °C and 130 °C are not rancid.

From the figure, it could be seen that the appearance of the yellow colour increased from 21 to 23 as the heating temperature was increased from 70 °C to 90 °C, but as the heating temperature was further increased from 90 °C to 110 °C and to 130 °C, the appearance of the yellow colour decreased to 10 and remained steady at 130 °C. This high value of rancidity index for colour yellow shows that the dominant colour of palm kernel oil after extraction in liquid form is yellow. This is in agreement with Olaniyan (2006) who ascertained that the colour of most vegetable oil and fats in pure state immediately after extraction is golden yellow.

This result tends to suggest that less rancid palm kernel oil can be obtained at a preheating temperature of between 90 °C and 110 °C. Rancidity index is expressed as unit of the red moribund. According to Bamikole (2009), the maximum permissible red colour appearance for industrial palm kernel oil is 8. From figure 3.3, it can be observed that at all temperatures used for this study, the red has a maximum value of 2.4 at 70 °C, and minimum value of 1.6 at 130 °C. The red colour appearance decrease as the temperature increases, thus, it can be concluded that the palm kernel oil extracted at 70 °C, 90 °C, 110 °C and 130 °C is suitable for industrial application.

3.4 Effect of Heating Temperature on Saponification Value

The effect of heating temperature on the saponification value of palm kernel oil mechanically expressed from palm kernel under uniaxial loading is as show in Figure 7. From the figure it can be observed that there was a decrease in the saponification value from 246.57 to 243.80 as the heating temperature was increased from 70 °C to 130 °C.

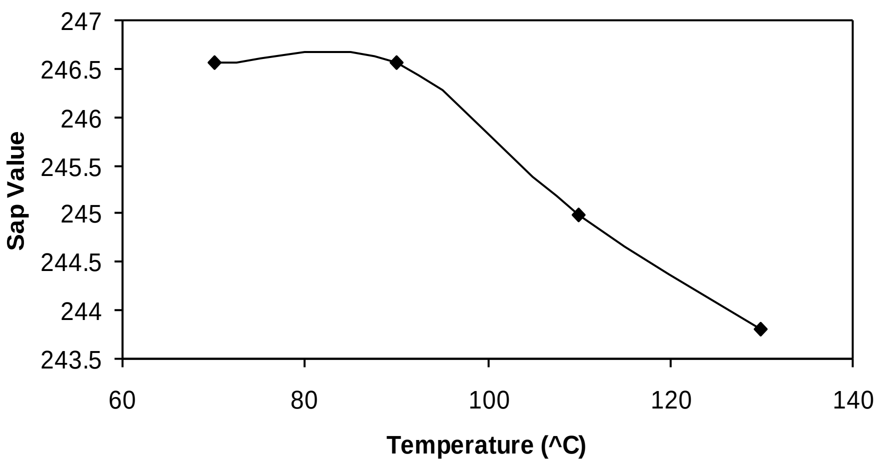

Fig. 7. Effect of Heating Temperature on Sap Value

This was due to the formation of short chain fatty acid that was not taken care of in saponification determination as heating temperature was increased. Saponification value is one of the two most important chemical constituent of fats and oils useful for the identification of unknown sample. Saponification value is a measure of the average molecular weight of the mixed triglycerides constituting the oil. Oils with higher saponification value are most suitable for soap making industries. From the result of this study, it can be deduced that palm kernel oils obtained from samples subjected to heating temperatures of 70 °C and 90 °C with saponification value of 246.57 each is most suitable for soap making industry.

Mital and Dove (1971) in Olaniyan (2006) reported that the saponification value of most fats and oils lies between 180 and 200. Contrary to this assertion, Fasina and Ajibola (1989) obtained saponification value of 200 – 260 for Conophor oil, Adeeko and Ajibola (1989) obtained 233 – 238 for groundnut oil and Olaniyan (2006) obtained 237.76 to 261.33 for Shea butter. Therefore the saponification values of 243.80 to 246.57 obtained for palm kernel oil in this study compares favourably with values for most vegetable oils as reported by some researchers seen above.

3.5 Effect of Heating Temperature on Viscosity

The effect of heating temperature on viscosity of palm kernel oil mechanically expressed from palm kernel under Uniaxial loading is as shown in Figure 8. From the graph, the viscosity increased to 140cps and remained constant as the heating temperature was increased from 70 °C to 90 °C. It then decreased from 140cps to 120cps and further to 60cps as the heating temperature was increased from 90 °C to 110 °C and then to 130 °C. Lubricating properties of oil generally are assessed based on their viscosity. Vegetable oils that are more viscose have better lubricating qualities.

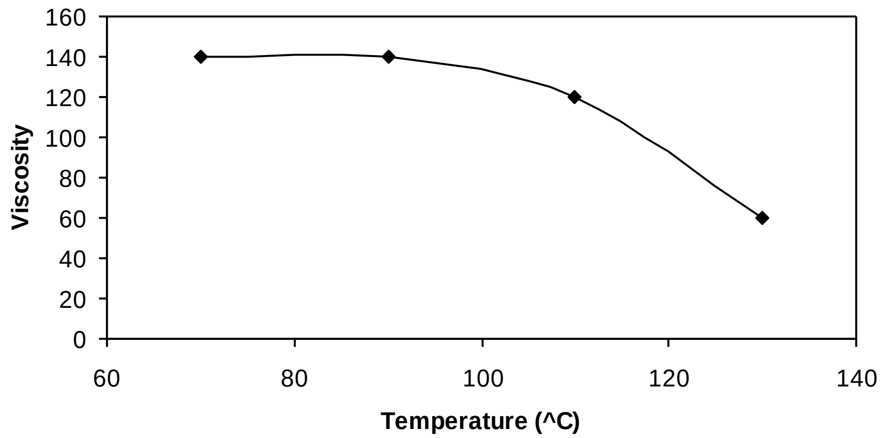

Fig. 8. Effect of Heating Temperature on Viscosity

This study then shows that palm kernel oil expressed from palm kernel that has been pre-heated at temperature between 70 °C and 110 °C will have high lubricating properties. The significant decrease in viscosity value observed when the heating temperature was increased from110 °C to 130 °C could be attributed to denaturing of the oil as a result of excessive burning due to high heating temperature. At heating temperature of 130 °C, excessive burning of oil and cake occurred in addition to thermo-oxidation of oil. All these reduced the viscosity of the palm kernel oil expressed at this temperature, thus making it unfit to be used as a lubricant.

3.6 Effect of Heating Temperature on Specific Gravity

Figure 9 shows the graph of the effect of heating temperature on palm kernel oil mechanically expressed from palm kernel under Uniaxial loading. From the graph, it can be observed that the specific gravity decreased from 0.908 to 0.894 as the heating temperature was increased from 70°C to 130°C. This trend may be attributed to the burning of the oil as heating temperatures were increased. It could also be attributed to the expansion of the oil which resulted in the increase in oil volume, which invariably resulted in decrease in the specific gravity.

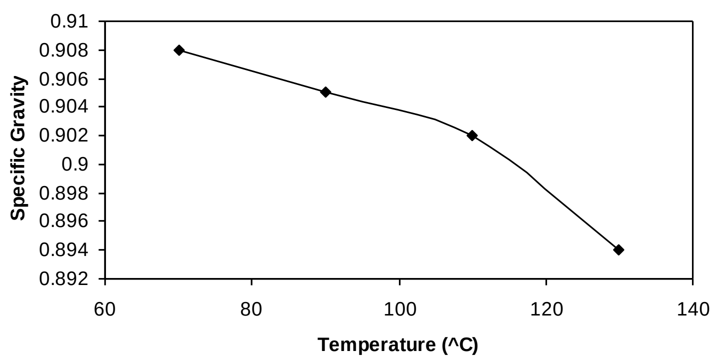

Fig. 9. Effect of Heating Temperature on Specific Gravity

The weight of oil in bulk shipments are assessed based on the specific gravity of the oil. Therefore, palm kernel oil expressed at heating temperatures of 110 °C and below will be appropriate for bulk shipment during commercial transactions. Interestingly, maximum oil yield and oil recovery efficiency and minimum process loss have been observed at temperature between 90^0C and 110 °C in this study during the expression process.

The values of specific gravity obtained for palm kernel oil in this study compares favourably well with those of other related vegetable oils expressed at about 70 °C – 90 °C. Examples are, Olaniyan (2006) obtained an average value of 0.91 for Shea butter, Ready and Bohle (1993) obtained 0.901 for Mustard seed oil, Ajibola et al obtained an average of 0.926 for Rubber seed oil, and Fashina and Ajibola (1989) obtained 0.9323 for Conophor nut oil.

4. CONCLUSIONS

This study reveals that palm kernel oil mechanically expressed at different heating temperature are rich in important industrial properties. The physico-chemical characteristics of the expressed oil showed that the quality of oil obtained reduces as the heating temperature increases. Heating temperatures of between 70 °C –110 °C were found to be most appropriate for expressing palm kernel oil required for industrial applications.

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TESTING THE WEPP MODEL FOR A SINGLE EVENT RUNOFF AND SOIL LOSS FROM A PLOT IN NSUKKA, SOUTHEAST NIGERIA

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ABSTRACT

Soil erosion as a form of land degradation has become a major problem in agricultural production and development in many parts of the world. Mathematical modelling of runoff and sediment transport has proven to be a cost effective technology to predict and control soil erosion. The Water Erosion Prediction Project (WEPP) model is a process-based model which predicts soil loss at different spatial and temproral scales. This study applied the WEPP model to estimate runoff and soil loss from a single storm rainfall event. Runoff and soil loss were measured from an agricultural plot in Nsukka during a rainfall event on 29th August, 1997. Soil, topography, landuse and rainfall event data were obtained and inputted into the model. Predicted runoff and soil loss values were compared to corresponding measured ones. Results showed that the WEPP model over-predicted runoff and under-predicted soil loss from the plot for the single rainfall event studied.

KEYWORDS: WEPP, model, runoff, soil loss.

1. INTRODUCTION

Soil erosion is a serious problem which stems from a combination of agricultural intensification, soil degradation, and intense rainstorms. In combination with unimpeded runoff, soil erosion generates considerable amount of sediment yield, changes streamflow regimes, deteriorates aquatic ecosystems, and reduces reservoir capacities. Soil erosion by water is a major threat to long term productivity of hillside agriculture as valuable soil nutrients are lost via runoff water. Soil erosion due to water has assumed serious proportions globally, especially in developing countries (Michael and Ojha, 2003). In India, an estimated 150 Mha of land suffer from active erosion caused by water and wind (Reddy, 1999). Gete (2001) also reported that various studies carried out in Ethiopia considered soil erosion as a major cause of land degradation, but noted that most of such studies described soil erosion based upon qualitative observations. Demeny et al. (2010) pointed out that though soil loss reaches smaller extents in Hungary, it still remains an ongoing problem on agricultural fields. The authors observed that the prevailing rainfall of 600 mm/yr in Isaszeg, Hungary, resulted in high erodibility and soil loss especially on arable farms with gullies covering 11.19 ha of the area.

Unlike point-source pollution, reliable monitoring of the rate of sediment from the land surface is difficult, expensive and time consuming as it occurs over a landscape that typically exhibits heterogeneous biogeochemical properties (Tagfur and Singh, 2004). Existing plot/watershed scale studies do not provide a systematic representation of the heterogeneity of different physical and biogeochemical properties of a watershed due to the spatial and temporal constraints which limit studying overland flows and erosion/deposition in experimental watersheds (Abaci and Papanicolaou, 2009). Nowadays, computer-based models that integrate the effects of climate, soil, topography and management are commonly used to predict runoff and soil erosion, and to evaluate a variety of management scenarios without costly and lengthy field tests (Pieri et al., 2007).

The USDA-ARS developed the Water Erosion Prediction Project (WEPP) (Flanagan and Nearing, 1995) model, which is based on physical processes, to replace empirically based erosion prediction models (USLE, RUSLE, and MUSLE). The WEPP model simulates many of the formerly missing physical processes important in soil erosion (e.g. infiltration, runoff, raindrop and flow detachment, sediment transport, deposition, plant growth, and residue decomposition) as input parameters (Demeny et al., 2010). The WEPP model to posses the state-of-the-art knowledge of erosion science, and thus an analytical tool for soil conservation studies (Favis-Mortlock et al. 1996). It has been successfully applied in many parts of the world (Tiwari et al., 2000; Gete, 2001; Cochrane and Flanagan, 2003; Pandey et al., 2008). However, the application of the WEPP model in Sub-Sahara Africa is grossly lacking in the literature. Gete (2001) applied the WEPP model to the traditional farming systems of the Ethiopian highlands.

The aim of this study is to apply the WEPP model to estimate runoff and soil loss from a single storm event in Nsukka, southeastern Nigeria. This will be done by comparing model predictions of runoff and soil loss to data measured from an agricultural (mixed cropping) plot.

2. MATERIALS AND METHODS

2.1 The Water Erosion Prediction Project (WEPP) Model

The Water Erosion Prediction Project was initiated in 1985 to develop a new generation water erosion prediction technology for use in soil and water conservation and in environmental planning and assessment (Abaci and Papanicolaou, 2009). The WEPP model is a physically-based, continuous simulation computer program that calculates runoff and erosion on hillslopes or watersheds on a daily basis, and for agriculture, forestry and rangeland management (Flanagan and Nearing, 1995). The hillslope version of the WEPP contains nine components: climate generator, winter processes, irrigation, surface hydrology and water balance, subsurface hydrology, soils, plant growth, residue decomposition, over-land flow hydraulics and erosion (Pieri et al., 2007).

The WEPP model employs the steady state sediment continuity equation to estimate soil erosion and deposition. Soil erosion on hillslopes is represented as two components in the WEPP model: soil particle detached by raindrop and transported by thin sheet flow, known as interrill erosion component and soil particle detached by shear stress and transported by concentrated flow, known as rill erosion component (Pudasaini et al., 2004). Foster et al. (1995) expressed the steady state sediment continuity equation used to compute estimates of net detachment and deposition as:

$$\frac{dG}{dx} = D_f + D_i \qquad \text{……………………………………………………………}1$$

Where x is distance downslope (m), G is sediment load (kg/s/m), D_i is interrill erosion rate (kg/s/m^2) and D_f is rill erosion rate (kg/s/m^2). Interill erosion function of the above equation (D_i) is given as (Foster *et al.* 1995):

$$D_i = K_{iadj} I_e \pm_{ir} SDR_{RR} F_{nozzle} \frac{R_s}{w} \qquad \text{………………………………………………}2$$

where: K_{iadj} =Adjusted interrill erodibility (kgs/m^4), I_e=Effective rainfall intensity (m/s), σ_{ir} = Interrill runoff rate (mm/h), SDR_{RR} = Interrill sediment delivery ratio, F_{nozzle} = Adjustment factor for sprinkler irrigation nozzle impact energy variation(natural rainfall = 1) , R_s= Rill spacing (m), w = Width of rill (m). Rill erosion function. (*Df*) is given as (Foster *et al.* 1995):

$$D_f = D_c \left[1 - \frac{G}{T_c}\right] \qquad \text{…………………………………………………………}3$$

Where: D_c = detachment capacity by rill flow (kg/s/m^2) and T_c = sediment transport capacity in the rill (kg/s/m). When hydraulic shear stress of the rill flow exceeds the critical shear stress for the soil, Dc is expressed as (Foster et al., 1995):

$$D_c = K_r(\tau_f - \tau_c) \quad \text{……………………………………………………………4}$$

Where: K_r = rill erodibility parameter (s/m); τ_f = flow shear stress acting on soil particle (Pa); and τ_r = rill detachment threshold parameter (Pa). Sediment transport capacity of the rill flow is given as (Flanagan et al., 1995):

$$T_c = K_{tr} q_w S \quad \text{………………………………………………………………5}$$

Where: K_{tr} = constant parameter, q_w= flow discharge per unit width (m^2/s) and S = slope (%). For the case of deposition (when sediment load, G, is greater than sediment transport capacity), net deposition is computed from:

$$D_f = \left[\frac{V_f}{q}\right]\left[T_c - G\right] \quad \text{…………………………………………………………..6}$$

Where: V_f is effective fall velocity for the sediment (m/s), and q is flow discharge per unit width (m^2/s)

The hydrologic variables that drive the erosion component of the WEPP model are: (a) effective rainfall intensity, (b) peak runoff per unit area, and (c) effective runoff duration (Foster et al., 1995). The climate generator (CLIGEN) component of the WEPP model is used to generate the rainfall intensity while the runoff peak and duration are computed by the hydrologic component of the WEPP model. The effective duration of runoff is given as:

$$t_r = \frac{V_t}{P_r} \quad \text{……………………………………………………………………7}$$

Where t_r is the effective runoff duration (s), V_t is the total volume for the rainfall event (m), and P_r is peak runoff per unit area (m/s)
Effective rainfall intensity which is used to estimate interrill soil loss is calculated from the equation

$$I_e = \left[\frac{\int I^2 dt}{t_e}\right]^{1/2} \quad \text{………………………………………………………………8}$$

Where I_e is effective rainfall intensity (m/s), t is time (s), t_e is total time (s) during which rainfall exceeds infiltration rate and I_e is effective rainfall intensity (m/s).

Detailed descriptions of model components and processes considered in the WEPP model can be found in Flanagan and Nearing (1995). Pandey et al. (2008) and Flanagan et al. (1995) noted that the WEPP model most notable advantages include: (i) capabilities for estimating spatial and temporal distributions of soil loss; (ii) since the model is process-based, it can be extrapolated to a wide range of conditions that may not be practical or economical to field test; and (iii) identifying zones of sediment deposition and detachments. Studies (Brazier et al., 2000; Tiwari et al., 2000; Gete, 2001; Rosewell, 2001, Cochrane and Flanagan, 2003; Laflen et al., 2004; Pandey et al., 2008) have shown that the WEPP model has become one of the most utilize tool for studying runoff and sediment transport all over the world. However, the application of the WEPP model in Africa is grossly lacking in the literature except for a study (Gete, 2001) that applied WEPP model to the traditional farming systems of the Ethiopian highlands.

2.2 The Study Area

The study location is Nsukka located on Latitude 06º87'N and Longitude 07º43'E. Ofomata (1975) described the topography of the study area as undulating with a mean elevation ranging from 440 m – 450 m above sea level. Nsukka is located within the savannah eco-climatological zone. The climate of the study area is characterized by mean annual rainfall of about 1600 mm and an average temperature of 28ºC (Igwe, 2005). The soil organic matter content of the study location is low, and soil erosion by water remained a major constraint to agricultural production (Igwe, 2005).

2.3 Runoff Plot Study

Measurement of runoff and soil loss was obtained from a runoff plot study during a single rainfall event in Nsukka, Southeastern Nigeria. In this study, a hillslope plot 6.7 m long and 1m wide with an average slope of 14% was cultivated with cassava, okro and corn. Runoff and soil loss were measured after a single storm event (29.4 mm) which occurred on 29^{th} August, 1997. Depth of water in millimeter collected with a rainguage was recorded at five minute intervals. The rainfall intensity distribution is plotted in Fig. 1.

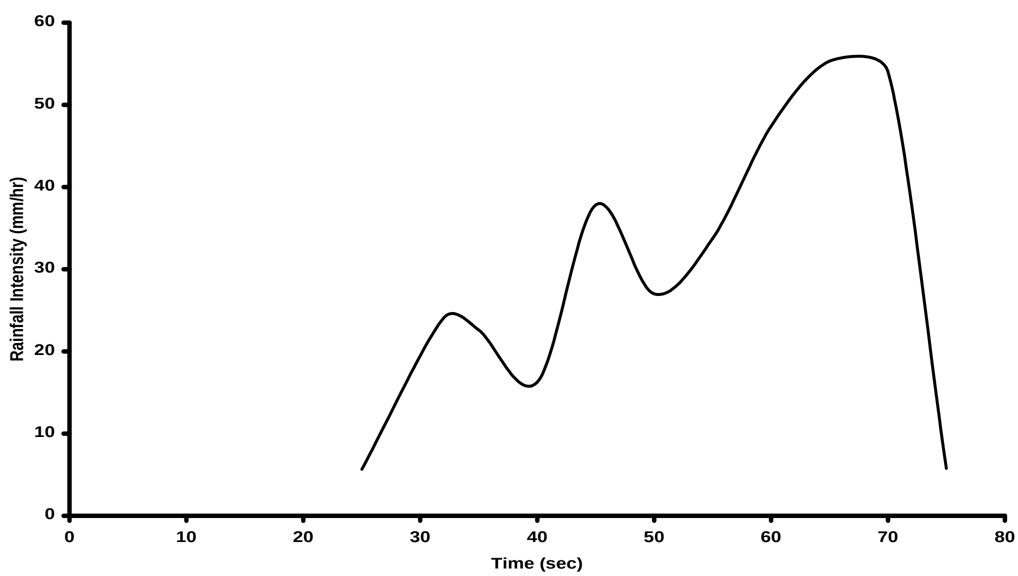

Fig. 1**:** Rainfall Intensity Distribution for the Storm Event of 29 August, 1997

At the end of the storm event, the volume of runoff was measured and the depth of runoff over the experimental plot was observed to be 7.86 mm. Total sediment load in the runoff was determined by oven-drying method and measured to obtain 0.059 kg/m^2 of the plot.

2.4 Model Implementation

A WEPP simulation requires climate, plant/management, soil, and topographic data as inputs (Flanagan and Livingston, 1995). In this study, the WEPP model (hillslope version 2010.100) was applied on an experimental plot in Nsukka, Southeastern Nigeria.

There are two ways in which slope data input for the WEPP model can be created: non-dimensional distance to point and slope and by adopting the slope length and steepness pairs (Flanagan and Nearing, 1995). The latter approach was adopted in this study. Table 1 show the required data for creating a slope file while Figure 2 is a plot of elevation (m) against distance from the hillslope top to bottom.

Table 1: Topographic Input Data

Number of overland flow element (OFE)	1
Aspect	34.1°
Field width	1m
Length of OFE	6.7m

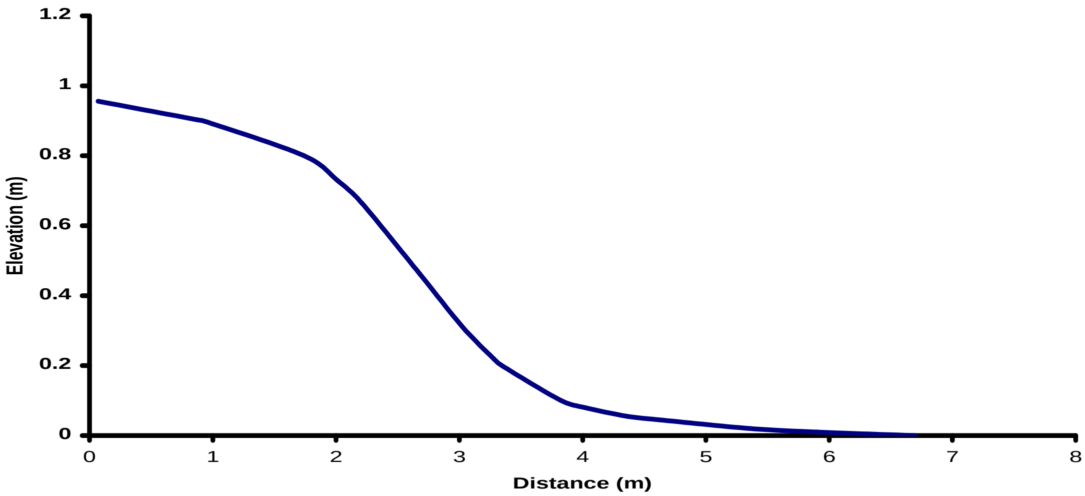

Fig. 2: The Elevation versus Distance of the Hillslope Profile from Top to Bottom

The textural composition of the soil was obtained by particle size analysis carried out in the Soil Science Laboratory of the University of Nigeria, Nsukka. Soil input parameters were determined as shown in Table 2. Soil albedo was mathematically evaluated using the relation given by Nicks *et al,* (1989). Interrill erodibility, rill erodibility, critical shear stress and effective hydraulic conductivity were computed internally by the WEPP model.

Table 2: Soil Input Data

Depth (mm)	Sand (%)	Clay (%)	CEC (meq/100g)	Organic matter (%)	Rock (%)	Texture
0-200	62	8.9	4.8	7.4	5	Sand loam

All information about management was obtained from the farmer together with field observation. The farmer used hand tools and practiced mixed cropping (cassava, okro, and corn). However, lack of cassava and okro in the WEPP model crop database limited this study to the use of only corn. All management parameters were left at default settings and did not represent the actual operation scenario in the field.

Information on the storm event on 29th August, 1997 is as shown in Table 3. Daily precipitation and daily maximum and minimum temperature for ten years were obtained from the Agrometeorological Station, Faculty of Agriculture, University of Nigeria, Nsukka.

Table 3: Single Storm Event Input Data

Day of simulation	29th August, 1997
Precipitation amount	29.4mm
Duration of rainfall	1.15hr
Time to peak intensity	65min
Maximum intensity	55.32mm/hr
Total time of rainfall	75min

3. RESULTS AND DISCUSSION

The result of soil loss from the top of the hillslope profile to the bottom is as shown in Table 4.

Table 4: Soil Loss Along Hillslope Profile

Distance (m)	Soil Loss (kg/m^2)	Distance (m)	Soil Loss (kg/m^2)	Distance (m)	Soil Loss (kg/m^2)
0.07	0.005	2.35	0.007	4.62	0.007
0.13	0.007	2.41	0.007	4.69	0.007
0.20	0.007	2.48	0.007	4.76	0.007
0.27	0.007	2.55	0.007	4.82	0.007
0.34	0.007	2.61	0.007	4.89	0.007
0.40	0.007	2.68	0.007	4.96	0.007
0.47	0.007	2.75	0.007	5.03	0.007
0.54	0.007	2.81	0.007	5.09	0.007
0.60	0.007	2.88	0.007	5.16	0.007
0.67	0.007	2.95	0.007	5.23	0.007
0.74	0.007	3.02	0.007	5.29	0.007
0.80	0.007	3.08	0.007	5.36	0.007
0.87	0.007	3.15	0.007	5.43	0.007
0.94	0.007	3.22	0.007	5.49	0.007
1.01	0.007	3.28	0.007	5.56	0.007
1.07	0.007	3.35	0.007	5.63	0.007
1.14	0.007	3.42	0.007	5.70	0.007
1.21	0.007	3.48	0.007	5.76	0.007
1.27	0.007	3.55	0.007	5.83	0.007
1.34	0.007	3.62	0.007	5.90	0.007
1.41	0.007	3.69	0.007	5.96	0.007
1.47	0.007	3.75	0.007	6.03	0.007
1.54	0.007	3.82	0.007	6.10	0.007
1.61	0.007	3.89	0.007	6.16	0.007
1.68	0.007	3.95	0.007	6.23	0.007
1.74	0.007	4.02	0.007	6.30	0.007
1.81	0.007	4.09	0.007	6.37	0.007
1.88	0.007	4.15	0.007	6.43	0.007
1.94	0.007	4.22	0.007	6.50	0.007
2.01	0.007	4.29	0.007	6.57	0.007
2.08	0.007	4.36	0.007	6.63	0.007
Distance (m)	Soil Loss (kg/m^2)	Distance (m)	Soil Loss (kg/m^2)	Distance (m)	Soil Loss (kg/m^2)
2.14	0.007	4.42	0.007	6.70	0.007
2.21	0.007	4.49	0.007		
2.28	0.007	4.56	0.007		

The WEPP model predicted a maximum soil loss of 0.007 kg/m^2 at 3.42 m along the hillslope profile and a minimum soil loss of 0.005 kg/m^2 at 0.07 m along the hillslope profile. The summary of the results obtained in the field measurement and that from the WEPP model prediction is presented in Table 5.

Table 5: WEPP Predicted /Observed Runoff and Soil Loss

	Runoff (mm)	Total Soil Loss (kg)	Average Soil Loss (kg/m^2)
Observed	7.86	0.396	0.059
WEPP prediction	9.05	0.0469	0.007

From the results obtained in the WEPP model application and that of the experiment (Table 5), the WEPP model over-predicted runoff by 15% and under-predicted soil loss by 88%. The variation between measured data and model prediction especially for soil loss could be attributed to poor representation of soil and crop management parameters in the model. Field operation scenarios assumed for the simulation were that of engine powered technology while the hand tool technology was actually used by the farmer. Also, in the experimental plot, the farming system was mixed cropping (cassava, okro and corn), but Cassava and Okro were not included in the WEPP crop database, which led to the adoption of only corn for input to the WEPP model. Default corn management parameters in the WEPP model database were also adopted. Therefore, variations in the results compared are to be expected.

4. CONCLUSION

The necessity of an accurate prediction model for soil erosion cannot be over emphasized as soil loss calculations provide important information for planning, design and management. The WEPP model is a valuable tool as it quantifies relations and interactions between soil, climate, topography, and management factors that determine runoff and soil loss/deposition on site specific basis. This study tested the WEPP model for a single event on a plot scale for Nsukka conditions. More rigorous testing of the model will be needed which will require more experimental data and better representation of model parameters.

The WEPP hillslope model was applied on an experimental plot in Nsukka, southeastern Nigeria for a single storm event. The 75-min storm event produced an observed runoff volume of 7.86mm and soil loss of 0.05kg. Input data for the WEPP model application were rainfall (amount = 29.40mm, duration = 75min, time to peak intensity = 65min), topographic parameters (determined from a topographic map of the area and by using GPS), soil parameters (determined from laboratory analysis), and default corn management parameter. A single storm simulation was performed and predicted results were compared with observed results of runoff and soil loss.

The WEPP model over-predicted runoff by 15% and under-predicted soil loss by 88%. The results of this study represent a first attempt at working with the WEPP model in a local Nigerian environment.

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PHYSICO-CHEMICAL QUALITY STATUS ASSESSMENT OF GROUNDWATER RESOURCES IN AGBANI SANDSTONE OF ENUGU STATE, NIGERIA

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ABSTRACT

Field and laboratory studies were carried out to evaluate the quality of groundwater potentials in Agbani Sandstone of Enugu State. The studies involved evaluation of groundwater quality data of six communities within the area to determine water quality status across the geological formation. Sixty water samples, ten from each of the communities were evaluated and all available water quality information on each borehole were collected and collated. A total number of twenty (20) water quality parameters were analysed for the various water boreholes. Results showed pH range of (6.6 – 8.8), electric conductivity (0.02 - 24μS/cm), temperature (28 – 30^{o}C), total solids (40 – 66mg/l), total alkalinity (28 – 40mg$CaCO_3$/l), sulphates (3 – 7mg/l), iron (0 – 3mg/l) and total hardness (30 – 44mg$CaCO_3$/l). There were no presence of nitrates, chlorides, copper, zinc and cyanide in the sampled waters. These values conform to the limits established by both national and international water quality standards. The few exceptions can be easily treated to make them wholesome. Generally, these waters are adequate for drinking and domestic purposes.

KEYWORDS: Water quality standards, Groundwater, Physico-chemical, Sandstone, Potable

1. INTRODUCTION

Portability of drinking water has continued to be a major global concern towards achievement of sustainable water supply and improved sanitation. Generally, potable water to an area is dependent on the availability, both in quantity and quality. Oftentimes, water is not naturally available in the required quantity and quality to satisfy man's numerous needs. It thus becomes imperative that the combination of safe drinking water and hygienic sanitation facilities is a precondition for successful provision of potable water for man's needs (Cairncross et., al, 1991). Consequently, this situation of inadequate quality and quantity of water supplies permits the continuous increase in water borne diseases particularly in the endemic areas. Water quality embodies all factors that make water wholesome and "safe" for drinking and domestic purposes as well as other activities of man. Various water quality standards have been established, mostly as guides towards achieving safety status for water supplies (AWWA, 1975; APHA, 1980; WHO, 1971, 1983, 1985).

According to a United Nations Report (1997) over 1.2 billion people in the world do not have access to safe fresh water and over 80% of this is found in the developing countries. Studies conducted by World Health Organization (WHO/UNICEF, 2004) also showed that about 80% of ill health in developing countries is related to inadequate quality and quantity of water as well as sanitation; only 60% of people in developing countries have access to water supply; and only about 35% had access to sanitation facilities. Khan (1997) reported a study in Pakistan (Karachi), which found that the people living in areas without sanitation or hygienic education spent 6 times more money on medical care than people living in areas with access to sanitation and knowledge of hygienic practices. Idika, (2003) showed that some water development projects that included disease control programmes along with construction facilities as found in Philippines indicated a reduction of water borne related diseases from 24% to 9% between 1979 and 1985. This resulted in average increase in productivity of 19 days of work per person per year, culminating in an additional US$ 1million in wages. Idika (2003) also reported that the International Fund for Agricultural Development (IFAD) supported rural development in Katsina State of Nigeria in an agricultural and development project, which ended in 1998 achieving its primary objective of improving the living standards of 40,000 of poorest households. This was actualized by incorporating health concerns in the development programmes. The report further showed that about 50% of the population in the project location had access to potable water compared to 25% in 1990 with a corresponding decrease in water borne disease, such as guinea worm, which virtually disappeared at the end of the project.

Potable water supply should be safe to drink, easily accessible, available at all times in sufficient quantity and quality for all domestic purposes. It should also be affordable and satisfy local standards for taste, colour and odour. The combination of safe drinking water and hygienic sanitation facilities is a precondition for health and for success in other human endeavours. The Report of the World Health Organization, (WHO)/United Nation International Children's Educational Fund, (UNICEF) Joint Monitoring Programme on world-wide water and sanitation for the period 1999 – 2002 showed that 83 per cent of world's population of about 5.2 billion people used improved drinking water sources provided under improved sanitation, accessibility and portability (WHO/UNICEF, 2004).

Nigeria has been classified as one of the 20 poor countries in the world, with more than 70% of its population of about 150 million people classified as poor and more than 35% living below the US$1 per day poverty level, particularly in the rural areas (Idika, 2003). More than 50% of the population do not have access to potable water. Available information shows that there existed over 1000 urban and semi-urban water supply schemes in Nigeria by 1990, which were all in poor condition and deteriorating rapidly (Ogunleye, 2003). In a quarterly report, the Federal Ministry of Water Resources and Rural Development, FMWRRD, (1999), showed that the various State Water Supply Agencies were at the low level of development characterized by poor funding and organizational structures. This has resulted in a fast decline of urban /semi-urban water supply delivery systems bringing water supply coverage for Nigeria to about 39% (Idika, 2003). While cost of building potable water supply systems and sanitation facilities is quite high, the cost of not doing so could be staggering.

Most parts of the Southeastern Nigeria, inclusive of Enugu State, depend on rainwater for their water supply needs, harvested from rooftops and stored in earthen pots, collection pits, plastic and concrete reservoirs. However, the capacities of such storage facilities usually do not meet the water requirements/needs of the people. In most places, the people resort to digging/constructing shallow wells to draw water without adequate and proper consideration for health implications of such exercise. In areas with rivers and streams, the women and children trek distances varying from 500m to as much as more than 10km to fetch water thus investing so much man-hours in search of water whose portability is even questionable. Consequently, there is an urgent need to develop and maintain sustainable water supply systems and adequate sanitation facilities within the area to mitigate against the widespread prevalence of water related disease amongst the poor population (Jacobs et al., 1989).

A report by the Enugu State Ministry of Human Development and Poverty Reduction (SEEDS, 2004) shows that about 40% of all the households in Enugu State, which includes half of the rural population were more than 30 minutes away from the nearest source of drinking water. The report further stated that only 25% of all households and 15% of the rural households had access to safe drinking water, defined as pipe borne water. In rural areas, most of those who do not have access to safe drinking water rely on sources such as unprotected hand dug wells, rivers or ponds. In urban areas, a third of the population has to buy water which quality maybe doubtful from water vendors in addition to use of hand dug wells.

This study evaluated the quality of available groundwater resources in the Agbani Sandstone covering Nkanu East and Nkanu West Local Government Areas of Enugu State. Currently, many urban centers and rural villages in the study area are using groundwater as potable water source. However, there is no well organized and integrated groundwater resources database system at National and Regional levels.

This study is an effort to begin to fill this gap.

2. MATERIALS AND METHODS

2.1 Materials

The plastic containers (of one litre capacity) used for sampling were washed with detergent, rinsed with distilled water and were properly dried before rinsing thoroughly with the sample water.

2.2 Sampling Period

The water sampling were carried out both during the dry months of January and March, 2007, and rainy months of June and July of the same year for all the communities. Samples of groundwater (boreholes) were collected across the geologic formation using the already prepared sampling containers.

2.3 Methods

To avoid changes caused by storage, such parameters as temperature, electric conductivity (EC) and pH were determined immediately and recorded at the sampling locations. Other analyses were conducted in the laboratory. Totally, 20 water quality parameters were evaluated for the available data. Standard methods were applied during sample analyses using the Hach One Water Quality Testing Kit. All equipment were operated using standard procedures. The parameter values were compared against World Health Organization (WHO, 2006) and Nigerian water quality standards (Tarafdar, 1990).

3. RESULTS AND DISCUSSION

The results of the physico – chemical analyses of water quality parameters of the water samples are presented in the Tables 1 - 6.

Table 1: Physico – chemical Quality Status of Groundwater Sources from Ugbawka Community

Parameters	Minimum Value	Maximum Value	Mean Value	WHO Standards	Nigerian Standards
pH	6.6	6.8	6.7	6.5 - 9.2	6.5 - 9.2
Temperature (^oC)	28	30	29.1		
Electric conductivity (µS/cm) 3.6		4.2	4.02	1250	
Turbidity (FTU)	0.3	0.55	0.46	5 – 25	40
Colour (Pt.Co)	4	8	6.3	5 – 50	5 – 50
Copper (mg/l)			0	1.0 – 1.5	
Total Solids (mg/l)	44	56	51.2	500 – 1000	
Iron (mg/l)	0	3	1.7	0.3 – 1.0	0.1 – 2
Manganese (mg/l)	0	0	0	0.1 – 0.5	
Sulphates (mg/l)	3	7	5.3	250 – 1000	150
Total Hardness (mg$CaCO_3$/l)	36	42	39.3	100 – 500	60
Calcium Hardness (mg/l)	13	24	18.5	100 – 300	
Magnesium Hardness (mg/l)	18	25	20.8		
Nitrates, NO_3 (mg/l)	0	0	0	50	50
Chlorides (mg/l)	0	0	0	600	250
Total Alkalinity (mgCaCO3/l)	30	35	32.2	80	40
Calcium	30	34	31.7	75 – 200	200
Magnesium (mg/l)	4	7	6	0 – 150	200
Zinc (mg/l)	0	0	0	5	
Cyanide (mg/l)	0	0	0	0.2	0.2

The pH values of the water samples ranged from 6.6 – 8.8, indicating that waters from the area are almost neutral to alkaline. The pH values fall within 6.5 – 9.2, the range set by WHO and other water quality standards. The pH values which indicate the level of acidity or alkalinity of the water show that the groundwater in the area is safe for drinking and domestic purposes. Although pH usually has no direct impact on consumers, it is one of the most important operational water quality parameters. The optimum pH required varies according to construction materials used (WHO, 2006). The mean pH values of the waters from each of the community as compared to the WHO water quality standards are shown on Figure 1.

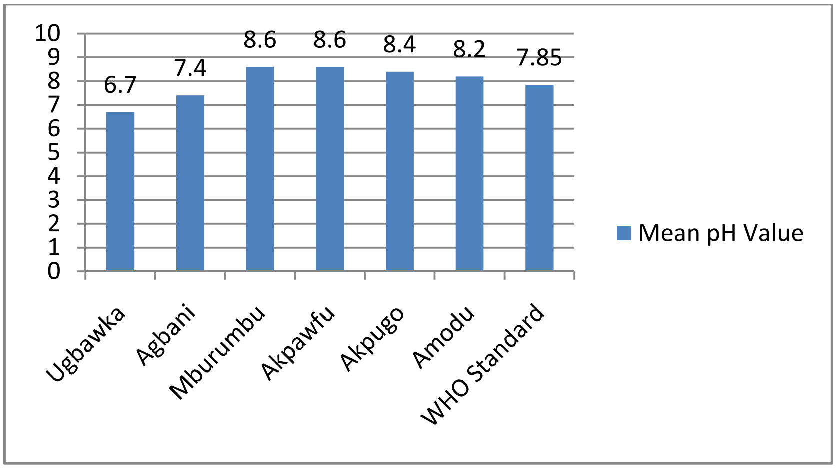

Figure 1: Mean values of pH from the Communities and WHO water quality standards.

Table 2: Physico – chemical Quality Status of Groundwater Sources from Agbani Community

Parameters	Minimum Value	Maximum Value	Mean Value	WHO Standards	Nigerian Standards
pH	6.8	8.2	7.6	6.5 - 9.2	6.5 - 9.2
Temperature (^{o}C)	29	30	29.1		
Electric conductivity (μS/cm) 20		24	23	1250	
Turbidity (FTU)	0.3	0.5	0.48	5 – 25	40
Colour (Pt.Co)	4	7	6.5	5 – 50	5 – 50
Copper (mg/l)	0	0	0	1.0 – 1.5	
Total Solids (mg/l)	50	54	51.6	500 – 1000	
Iron (mg/l)	0	3	1.6	0.3 – 1.0	0.1 – 2
Manganese (mg/l)	0	0	0	0.1 – 0.5	
Sulphates (mg/l)	4	6	5.3	250 – 1000	150
Total Hardness ($mgCaCO_3/l$)	36	44	38	100 – 500	60
Calcium Hardness (mg/l)	14	24	22	100 – 300	
Magnesium Hardness (mg/l)	18	26	22.8		
Nitrates, NO_3 (mg/l)	0	0	0	50	50
Chlorides (mg/l)	0	0	0	600	250
Total Alkalinity (mgCaCO3/l)	28	40	36	80	40
Calcium	30	34	32	75 – 200	200
Magnesium (mg/l)	2	8	6	0 – 150	200
Zinc (mg/l)	0	0	0	5	
Cyanide (mg/l)	0	0	0	0.2	0.2

Table 3: Physico – chemical Quality Status of Groundwater Sources from Mburumbu Community

Parameters	Minimum Value	Maximum Value	Mean Value	WHO Standards	Nigerian Standards
pH	6.8	8.8	7.2	6.5 - 9.2	6.5 - 9.2
Temperature (^oC)	28	30	29		
Electric conductivity (µS/cm) 3.05		5.02	4.22	1250	
Turbidity (FTU)	0.4	0.53	0.48	5 – 25	40
Colour (Pt.Co)	6	8	6.4	5 – 50	5 – 50
Copper (mg/l)	0	0	0	1.0 – 1.5	
Total Solids (mg/l)	48	66	58	500 – 1000	
Iron (mg/l)	0	3.3	1.6	0.3 – 1.0	0.1 – 2
Manganese (mg/l)	0	0	0	0.1 – 0.5	
Sulphates (mg/l)	4	7	5.6	250 – 1000	150
Total Hardness ($mgCaCO_3/l$)	30	40	36	100 – 500	60
Calcium Hardness (mg/l)	13	22	18.5	100 – 300	
Magnesium Hardness (mg/l)	16	28	22		
Nitrates, NO_3 (mg/l)	0	0	0	50	50
Chlorides (mg/l)	0	0	0	600	250
Total Alkalinity (mgCaCO3/l)	30	36	34.2	80	40
Calcium	32	34	32.6	75 – 200	200
Magnesium (mg/l)	2	7	4	0 – 150	200
Zinc (mg/l)	0	0	0	5	
Cyanide (mg/l)	0	0	0	0.2	0.2

Table 4: Physico – chemical Quality Status of Groundwater Sources from Akpawfu Community

Parameters	Minimum Value	Maximum Value	Mean Value	WHO Standards	Nigerian Standards
pH	6.9	8.8	7.8	6.5 - 9.2	6.5 - 9.2
Temperature (^oC)	28	30	28.8		
Electric conductivity (µS/cm) 3.0		4.8	4.22	1250	
Turbidity (FTU)	0.3	0.55	0.48	5 – 25	40
Colour (Pt.Co)	5	8	5.9	5 – 50	5 – 50
Copper (mg/l)	0	0	0	1.0 – 1.5	
Total Solids (mg/l)	44	52	48.2	500 – 1000	
Iron (mg/l)	0.2	2.5	1.7	0.3 – 1.0	0.1 – 2
Manganese (mg/l)	0	0	0	0.1 – 0.5	
Sulphates (mg/l)	3	7	5.3	250 – 1000	150
Total Hardness ($mgCaCO_3/l$)	36	42	39.3	100 – 500	60
Calcium Hardness (mg/l)	13	24	18.5	100 – 300	
Magnesium Hardness (mg/l)	18	25	20.8		
Nitrates, NO_3 (mg/l)	0	0	0	50	50
Chlorides (mg/l)	0	0	0	600	250
Total Alkalinity	29	35	32.8	80	40

(mgCaCO3/l)					
Calcium	30	32	31.4	75 – 200	200
Magnesium (mg/l)	2	6	4.8	0 – 150	200
Zinc (mg/l)	0	0	0	5	
Cyanide (mg/l)	0	0	0	0.2	0.2

Table 5: Physico – chemical Quality Status of Groundwater Sources from Akpugo Community

Parameters	Minimum Value	Maximum Value	Mean Value	WHO Standards	Nigerian Standards
pH	6.6	8.8	7.4	6.5 - 9.2	6.5 - 9.2
Temperature (^{o}C)	28	30	29		
Electric conductivity (μS/cm)	0.02	3.03	1.82	1250	
Turbidity (FTU)	0.3	0.5	0.44	5 – 25	40
Colour (Pt.Co)	4	8	6	5 – 50	5 – 50
Copper (mg/l)	0	0	0	1.0 – 1.5	
Total Solids (mg/l)	40	52	50	500 – 1000	
Iron (mg/l)	0	3	1.9	0.3 – 1.0	0.1 – 2
Manganese (mg/l)	0	0	0	0.1 – 0.5	
Sulphates (mg/l)	3	6	4.4	250 – 1000	150
Total Hardness ($mgCaCO_3/l$)	32	42	36.5	100 – 500	60
Calcium Hardness (mg/l)	22	24	22.8	100 – 300	
Magnesium Hardness (mg/l)	18	26	22		
Nitrates, NO_3 (mg/l)	0	0	0	50	50
Chlorides (mg/l)	0	0	0	600	250
Total Alkalinity (mgCaCO3/l)	32	34	32.6	80	40
Calcium	28	32	30.4	75 – 200	200
Magnesium (mg/l)	3	7	5.6	0 – 150	200
Zinc (mg/l)	0	0	0	5	
Cyanide (mg/l)	0	0	0	0.2	0.2

Table 6: Physico – Chemical Quality Status of Groundwater Sources from Amodu Community

Parameters	Minimum Value	Maximum Value	Mean Value	WHO Standards	Nigerian Standards
pH	6.6	8	7.2	6.5 - 9.2	6.5 - 9.2
Temperature (^{o}C)	28	30	29.2		
Electric conductivity (μS/cm)	0.03	0.05	0.032	1250	
Turbidity (FTU)	0.3	0.52	0.44	5 – 25	40
Colour (Pt.Co)	4	8	6.2	5 – 50	5 – 50
Copper (mg/l)	0	0	0	1.0 – 1.5	
Total Solids (mg/l)	40	52	48.2	500 – 1000	
Iron (mg/l)	0	3	1.7	0.3 – 1.0	0.1 – 2
Manganese (mg/l)	0	0	0	0.1 – 0.5	
Sulphates (mg/l)	3	6	5.4	250 – 1000	150
Total Hardness ($mgCaCO_3/l$)	36	42	38.6	100 – 500	60
Calcium Hardness (mg/l)	14	24	18	100 – 300	

Magnesium Hardness (mg/l)	18	26	21.4		
Nitrates, NO_3 (mg/l)	0	0	0	50	50
Chlorides (mg/l)	0	0	0	600	250
Total Alkalinity (mgCaCO3/l)	30	38	32.8	80	40
Calcium	29	34	32.4	75 – 200	200
Magnesium (mg/l)	2	5	4	0 – 150	200
Zinc (mg/l)	0	0	0	5	
Cyanide (mg/l)	0	0	0	0.2	0.2

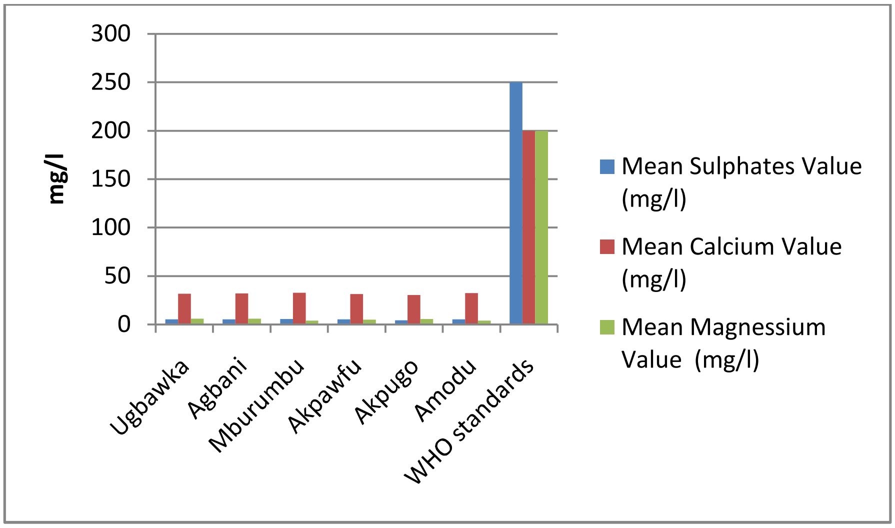

Figure 2: Mean values of Sulphates, Calcium and Magnessium from the Communities and WHO water quality standards.

Figure 2 shows the mean values of sulphates, calcium and magnesium as compared with WHO water quality standards. The highest sulphates, calcium and magnesium values of 5.6mg/l, 32.6mg/l and 6mg/l respectively were obtained from the water samples. All these values fall below the recommended maximum concentrations for drinking water, 250mg/l, 200mg/l and 200mg/l respectively (WHO, 2006).

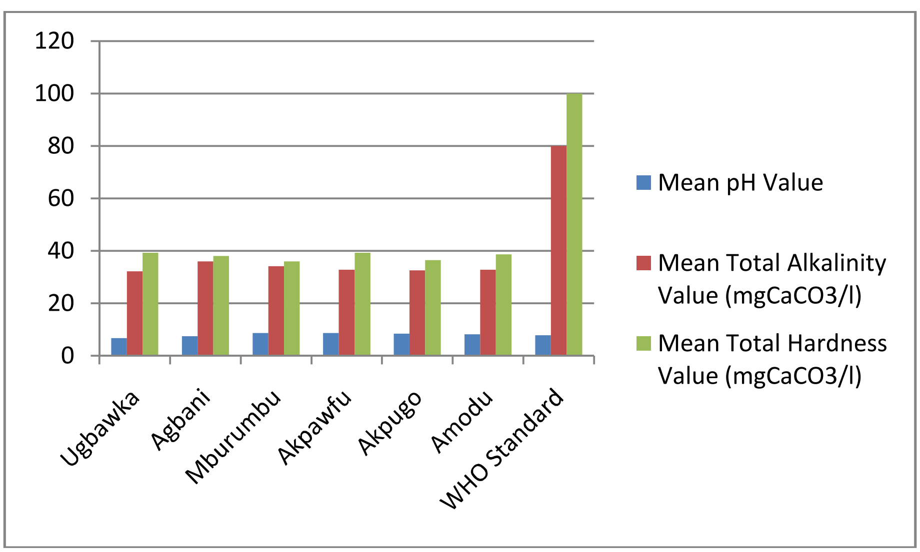

Figure 3: Mean values of pH, Total Alkalinity and Total Hardness from the Communities and WHO water quality standards.

Total hardness and total alkalinity as $CaCO_3$ in mg/l shown on Figure 3 above have maximum values of 8.6, 36 and 39.3 as $CaCO_3$ in mg/l respectively. These values indicate that groundwater of the study area conform to the permissible range of total alkalinity and total hardness (80 and 100 $CaCO_3$ in mg/l respectively) for drinking water purposes (WHO, 2006). Hardness in water is caused by dissolved calcium and to a lesser extent, magnesium and usually expressed as the equivalent quantity of calcium carbonate. Depending on pH and alkalinity, hardness above 200mg/l can result in scale deposition, particularly when heat is applied. Soft waters with hardness of less than 100mg/l have low buffering capacity and may be more corrosive to water pipes (WHO, 2006). Although a number of studies have indicated that very soft waters may have adverse effect on mineral balance, there is no health based guideline value proposed for hardness. However, the degree of hardness may affect its acceptability to the consumer in terms of taste and scale deposition (WHO, 1998; 2006).

The mean values for total dissolved solids are 51.2 mg/l, 51.6mg/l, 58mg/l, 48.2mg/l, 50mg/l and 48.2mg/l for Ugbawka, Agbani, Mburumbu, Akpawfu, Akpugo and Amodu communities respectively. These values are well within the range (500 – 1000mg/l) set by WHO water quality standards. Total dissolved solids/total solids affect the palatability of drinking water. Water with value less than 600mg/l is generally considered to be good while drinking water becomes significantly and increasingly unpalatable at levels greater than 1000mg/l.

Electrical conductivity is one of the major chemical parameters that indicate potential health risk impacts on humans. The mean values of electrical conductivity ranges from 0.02 to 24 µS/cm. The study shows that groundwater of the study area are very potable with respect to electrical conductivity of the groundwater.

4. CONCLUSIONS

From the physico-chemical water quality results, groundwater from the various sources in the study area are generally potable or can readily be rendered potable by appropriate water quality treatment such as aeration, filtration processes and disinfection depending on the characteristics of the water to meet WHO and other drinking water standards. Some of the samples, however, showed high iron content in the mine waters, which can be treated by aeration. The pH of the borehole water is low (i.e. high acidity) and can be treated by addition of hydrated lime. In conclusion the groundwaters from various sources within the study area conform to the WHO standards and are generally potable. They present no health hazards.

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