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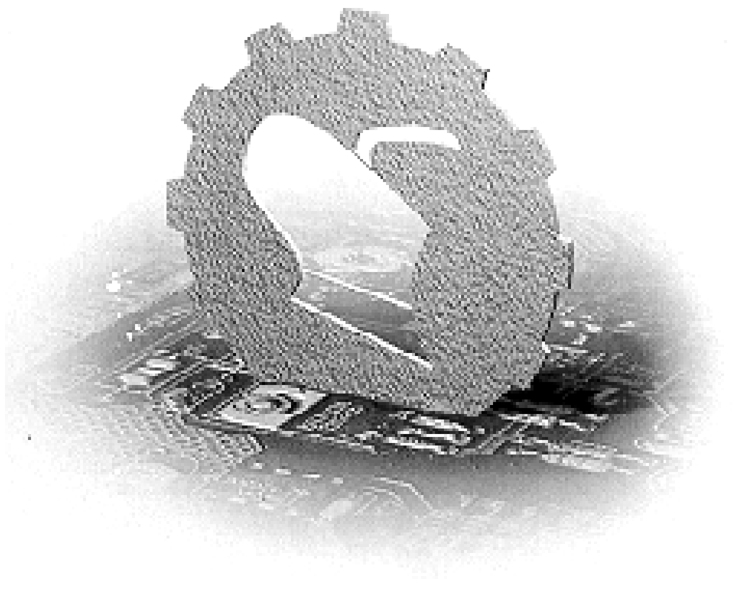

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ИНСТИТУТ ЗА ПОЉОПРИВРЕДНУ ТЕХНИКУ
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HIDRAULIČKI SIMBOLI - DEO V: “PRIBOR”

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Sažetak: Ovaj rad predstavlja peti deo serije u kome su prikazane grafičke oznake (simboli) većine standardnih komponenata hidrauličkih sistema prema važećim međunarodnim tehničkim standardima (ISO). Prikaz je fokusiran na simbole kojima se na hidrauličkim šemama uprošćeno predstavljaju pripadajuće komponente namenjene skladištenju, prečišćavanju i kondicioniranju hidrauličkog ulja, te za skladištenje energije predate hidrauličkom ulju, kao radnoj tečnosti, od strane izvornih organa (hidrauličkih pumpi). Funkciju skladištenja ulja obavljaju hidraulički rezervoari, a hidraulička energija se skladišti pomoću uljno-hidrauličkih akumulatora. Simboli komponenata za održavanje radnih parametara hidrauličkog ulja u optimalnim granicama su takođe prikazani. Obuhvaćene su komponente namenjene: prečišćavanju (uljno-hidraulički filteri), grejanju (predgrejači/grejači) i hlađenju (uljno-hidraulički hladnjaci).

Ključne reči*: hidraulika, simboli, rezervoar, akumulator, prečistač, predgrejac, hladnjak*

UVOD

Klasifikacija komponenata sistema uljne hidraulike se najčešće vrši prema njihovoj funkciji. Pri tome, najgrublja podela podrazumeva samo dve grupe [4]:

- osnovne uljno-hidrailičke komponente i
- pribor

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[*]Kontakt autor. E-mail adresa: epetrodr@agrif.bg.ac.rs. Rad je deo aktivnosti projekta “*Unapređenje biotehnoloških postupaka u funkciji racionalnog korišćenja energije, povećanja produktivnosti i kvaliteta poljoprivrednih proizvoda*“, broj TR 31051, Ministarstvo prosvete, nauke i tehnološkog razvoja Republike Srbije.

Ova klasifikacija je ipak previše gruba. Osnovni nedostatak se svodi na činjenicu da komponente druge grupe nikako nisu od sekundardnog značaja za pouzdan i dugotrajan rad sistema u celini. Stoga se u uljnoj hidraulici obično primenjuje preciznija i tačnija podela [4], [5], [10]:

1. izvorne komponente – pumpe;
2. regulacione komponente – ventili;
3. komponente za usmeravanje toka radne tečnosti (ulja) – razvodni ventili ili kraće hidraulički razvodnici;
4. izvršne komponente – radni cilindri i hidraulički motori;
5. vezivne komponente – cevovodi, crevovodi i priključci;
6. komponente za prečišćavanje radne tečnosti – filteri (prečistači);
7. komponente za skladištenje radne tečnosti – rezervoari;
8. komponente za održavanje temperature radne tečnosti – grejači/predgrejači, hladnjaci i kondicioneri;
9. komponente za akumuliranje hidrauličke energije radne tečnosti (ulja) – hidraulički akumulatori.

Komponente prve četiri grupe se svrstavaju u osnovne, a ostale pripadaju tzv. priboru.

Ovaj rad predstavlja nastavak prethodna četiri rada u istom časopisu [6], [7], [8], [9], u okviru kojih su prikazani grafički simboli osnovnih hidrauličkih komponenata definisanih međunarodnim standardima [1], [2], [3] i opšteprihvaćenim u svakodnevnoj tehničkoj praksi. U radu su prikazani simboli uljno-hidrauličkih komponenata iz 6., 7., 8. i 9. grupe, koje se grubo svrstavaju u tzv. “pribor”: filteri, rezervoari, hladnjaci, grejači/predgrejači, kondicioneri i hidraulički akumulatori.

SIMBOLIČKE OZNAKE HIDRAULIČKIH KOMPONENATA

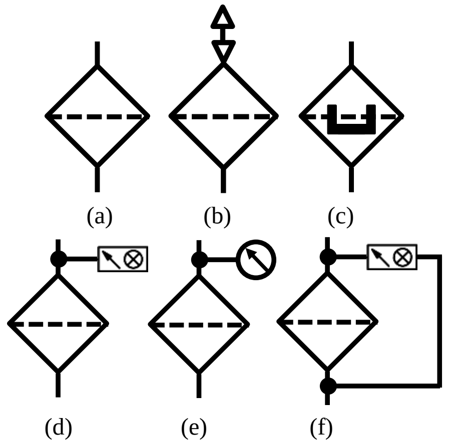
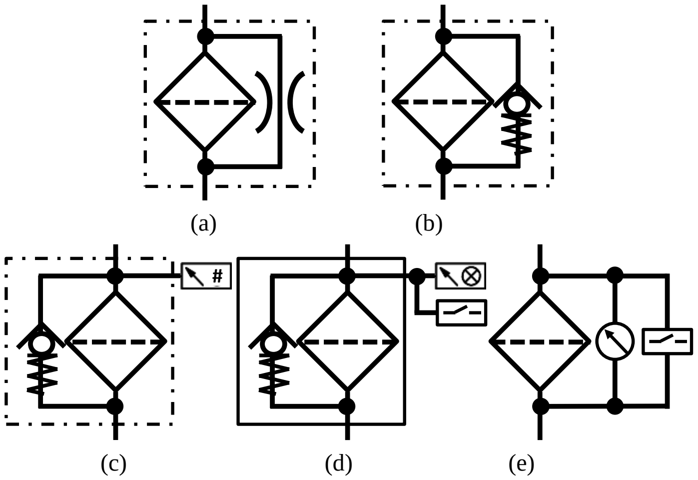
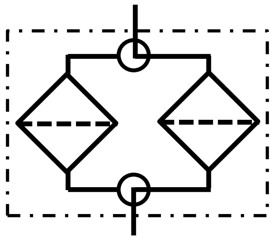
Prema nekim autorima (videti npr. [4]), čak 80% nepravilnosti u radu, kao i oštećenja sistema uljne hidraulike, prouzrokovani su prisustvom nečistoća u radnoj tečnosti unutar sistema. Među najopasnije neželjene čestice u sistemu sigurno spadaju metalni delići nastali habanjem elemenata sistema, ali i abrazivne čestice koje najčešće potiču iz spoljašnje sredine. To naravno ne umanjuje negativan uticaj i drugih čestica kada dospeju u sistem, odnosno radnu hidrauličku tečnost – ulje.

Standardni pristup za odstranjivanje nečistoća iz uljno-hidrauličkog sistema podrazumeva primenu prečistača ulja, tzv. filtera. Prema mestu ugradnje unutar sistema, filteri se dele u tri osnovne grupe:

1. usisni;
2. potisni i
3. povratni.

Usisni filter se postavlja na usisnom cevovodu pumpe sa zadatkom da spreči njegovo zapušavanje. Po pravilu, to su grubi filteri niskog pritiska sa sitom, otvora veličine od 0,5 mm do 2 mm. U cilju smanjenja pada pritiska ulja unutar filtera i produžavanja njegovog radnog veka, protočna površina ovih prečistača je obično nekoliko puta veća u poređenju sa protočnim presekom usisnog cevovoda. Kod većih pumpi, pored filtera u usisnom vodu pumpe, često se postavlja i gruba sitasta mrežica u rezervoar ulja na početku usisnog cevovoda.

Tabela 1. Uljni filteri i njihove konfiguracije sa pripadajućim pomoćnim uređajima.
Table 1. Oil filters and their configurations with appropriate auxiliary devices.

	Prečistači (filteri): (a) - obični; (b) - sa mogućnošću odzračivanja; (c) - sa magnetom za izdvajanje opiljaka; (d) - sa optičkim indikatorom zaprljanosti; (e) - sa manometrom; (f) - sa diferencijalnim optičkim indikatorom zaprljanosti na bazi pada pritiska.
	Prečistači (filteri) sa: (a) - prigušenim obilaznim vodom; (b) - obilaznim vodom sa nepovratnim ventilom; (c) - obilaznim vodom i digitalnim indikatorom zaprljanosti; (d) - obilaznim vodom optičkim indikatorom zaprljanosti i prekidačem; (e) - diferencijalnim manometrom i prekidačem.
	Dvostruki filter s ručnim prebacivanjem (izborom aktivnog filtera).

Potisni filter je prečistač visokog pritiska, koji se postavlja u potisnom cevovodu pumpe. Cena filtera ovoga tipa je visoka, te se primenjuju samo u posebnim slučajevima.

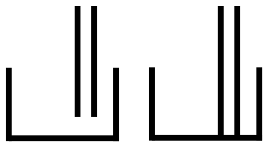
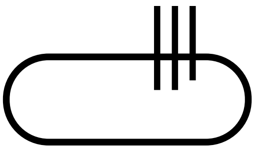
Ilustracije radi, može se navesti da su to uljni hidraulički sistemi letelica, atomskih centrala itd.

U praksi se najčešće koriste prečistači (filteri) u povratnom vodu hidrauličkog sistema, koji vraća ulje u rezervoar ili se postavljaju direktno u rezervoaru. Kod filtera ovoga tipa, radna tečnost prvo struji oko filtera, a potom kroz njega i kroz centralni kanal koji vodi ka izlazu iz kućišta. U slučaju prekoračenja protočnog kapaciteta filtera otvara se nepovratni ventil i propušta višak radne hidrauličke tečnosti iz filtera direktno u povratni vod ka rezervoaru. Po pravilu, filterski uložak se izrađuje od dva sloja papira, koji zadržavaju čestice veličine u opsegu od 8 do 100 μm.

Simboli prečistača hidrauličkog ulja i nekih njihovih konfiguracija u sadejstvu sa pripadajućim mernim pomoćnim uređajima prikazani su u tabeli 1.

Tabela 2. Rezervoari za ulje.

Table 2. Oil tanks.

 (a) (b)	Rezervoar povezan sa atmosferom. Vodovi tečnosti mogu biti proizvoljne dužine i postavljeni: (a) - iznad nivoa radne tečnosti i (b) - ispod nivoa radne tečnosti.
	Rezervoar povezan sa atmosferom, opremljen odvodom ka pumpi pod pritiskom.

Rezervoari hidrauličkih sistema obavljaju istovremeno više radnih funkcija. Najčešće su to:

1. skladištenje radne tečnosti – ulja;
2. prijem povratne radne tečnosti iz sistema;
3. punjenje sistema uljem – kroz odgovarajući otvor sa sitastim filterom za nalivanje;
4. merenje količine ulja u sistemu – pomoću ugrađenog merača;
5. prirodno hlađenje ulja predajom toplote okolini;
6. smeštanje prečistača – filtera;
7. ispuštanje ulja iz sistema pomoću čepa postavljenog na najnižem mestu i često opremljenim magnetom za prikupljanje metalnih opiljaka i
8. ispuštanje vazduha iz sistema pomoću postavljene oduške za vazduh.

Pored toga, nekada se hidraulička pumpa ugrađuje u rezervoar, a razvodni ventil/i montiraju na njega.

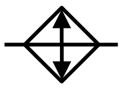
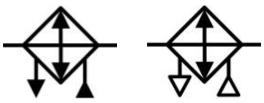
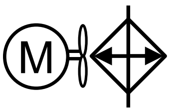
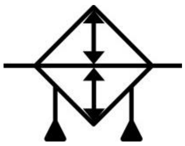
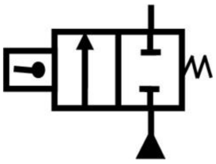
Zapremina, odnosno veličina, rezervoara zavisi od niza faktora: zapreminskog protoka pumpe, mesta ugradnje i očekivanih radnih uslova. Pri tome se mora voditi računa da izabrana (usvojena) zapremina rezervoara mora omogućiti zadovoljavajuće hlađenje hidrauličkog ulja.

Grafički simboli rezervoara hidrauličkog ulja prikazani su u tabeli 2.

Optimalna radna temperatura hidrauličke tečnosti (ulja) se u većini slučajeva kreće u granicama od 40 ^{o}C do 50 ^{o}C. U zavisnosti od radnih uslova, namene hidrauličkog sistema i vrste radne tečnosti, u posebnim relativno retkim situacijama, dozvoljavaju se i radne temperature hidrauličkog ulja do 80 ^{o}C.

Tabela 3. Izmenjivači toplote.

Table 3. Heat exchangers.

Grejač	
	Oznaka grejača hidrauličke radne tečnosti – ulja.
Hladnjaci	
	Opšta oznaka hladnjaka, bez opredeljivanja načina hlađenja.
 (a) (b)	Rashladni izmenjivač toplote, hlađen: (a) - vodom; (b) - vazduhom.
	Vazdušni hladnjak sa električnim ventilatorom.
Kondicioner temperature radnog fluida	
	Prema potrebama, radni fluid se greje parom ili hladi vodom. Moguće je umesto pare koristiti električni grejač. Unutrašnje strelice označavaju toplotu odvedenu ili dovedenu radnom fluidu. Spoljašnje strelice označavaju tok rashladne vode.
Temperaturski vođen (razvodni) ventil za kontrolu protoka vode	
Izlaz vode  Ulaz vode	U zavisnosti od temperature radnoog fluida, ovaj dvopoložajni ventil zatvara ili otvara protok rashladne vode od hladnjaka ka razmenjivaču toplote.

Međutim, zbog nedovoljno velikog prostora za ugradnju rezervoara ulja dovoljne zapremine, visoke temperature okoline itd., u nekim slučajevima se u uljno-hidraulički sistem ugrađuju hladnjaci ulja za održavanje njegove temperature u dozvoljenim granicama.

Nasuprot ovakvim slučajevima, kada se uljno-hidraulički sistem koristi u uslovima kada može biti izložen niskim temperaturama okoline, u sistem se ugrađuje predgrejač radi podizanja temperature ulja do potrebnih vrednosti. Hidraulički simboli predgrejača i hladnjaka ulja prikazani su u tabeli 3.

Najjednostavniji i investiciono najjeftiniji postupak hlađenja zasniva se na postavljanju ventilatora za hlađenje rezervoara. Učinak i efikasnost ovakvog pristupa su niski, te se koriste samo u sitruacijama kada je potrebno odvođenje male količine toplote od radne hidrauličke tečnosti, odnosno minimalno smanjenje njene radne temperature u pripadajućem uljno-hidrauličkom sistemu.

Pored navedenog, hlađenje ulja u rezervoaru može se ostvariti i postavljanjem (najčešće bakarnih zbog dobrog provođenja toplote i otpornosti na koroziju) cevnih zmija, kroz koje struji rashladna voda, u rezervoar ulja. Ovakav način hlađenja omogućava odvođenje veće količine toplote, ali zahteva velike protoke (potrošnju) vode i može imati negativan uticaj na ulje:

1. stvaranje kondenzata;
2. razgrađivanje ulja itd.

Primenu nalazi pri naknadno uočenoj potrebi za hlađenjem ulja kod već izvedenih hidrauličkih sistema, kao i za rashlađivanja ulja manjeg intenziteta.

Najveći rashladni efekat se postiže ugradnjom izmenjivača toplote (hladnjaka) u sistem, koji kao rashladni medjum koriste vodu.

Prethodna tri rashladna sistema koriste vodu za hlađenje hidrauličkog ulja. Stoga su, po pravilu, malih dimenzija, investiciono jeftini, ali skupi u eksploataciji zbog visokih troškova potrošene vode.

Zato se u nekim slučajevima koriste hladnjaci hlađeni vazduhom. Odlikuju ih niži eksploatacioni i viši investicioni troškovi. Pored toga, zahtevaju veće ugradbene prostore.

Neki autori [4] tvrde da su vodeni sistemi hlađenja tri puta skuplji u eksploataciji, ali zahtevaju oko pet puta manji ugradbeni proctor. Naravno, s obzirom na očekivani porast cena vode kao sve kritičnijeg resursa, može se očekivati dalji porast eksploatacionih troškova u slučaju primene vode kao rashladnog medijuma. Pored toga, sistemi hlađenja vazduhom po pravilu generišu viši nivo buke, u poređenju sa vodenim.

Pored hlađenja, u praksi se javljaju i slučajevi kada je potrebno zagrevati ulje u hidrauličkom sistemu. Najnepovoljniji uslovi u pogledu temperature nastaju posle dužih pauza u radu sistema. U zavisnosti od temperature okoline, to može rezultirati pothlađivanjem ulja ispod minimalne dozvoljene temperature. Da bi se obezbedila optimalna viskoznost i druge karakteristike hidrauličkog ulja, pre puštanja u pogon ulje se mora zagrejati. Tu funkciju obavljaju predgrejači ulja, koji se ugrađuju u sistem. Kod manjih hidrauličkih sistema, grejna tela se ugrađuju u rezervoare, a kod većih sistema i nižih temperature okoline ugrađuje se izmenjivač toplote koji se zagreva električnom energijom, toplom vodom, parom ili toplim vazduhom.

U nekim situacijama, primenjuju se i tzv. kondicioneri temperature radne tečnosti, koji se mogu grejati parom ili hladiti vodom, prema potrebi. Grafički simboli grejača i kondicionera radnog hidrauličkog ulja prikazani su, zajedno sa odgovarajućim simbolima hladnjaka, u tabeli 3.

Hidraulički akumulator je komponenta namenjena skladištenju (akumuliranju) energije radne tečnosti, izražene obično u formi povećanog pritiska.

Ova energija se vraća (odaje) sistemu kada je to potrebno. Osnovni razlozi ugradnje hidrauličkih akumulatora u odgovarajuće sisteme su:

1. obezbeđivanje stalne vrednosti pritiska u sistemu – kada izvršne komponente (cilindri i motori) miruju a pumpa i dalje radi, kao i za kompenzaciju gubitaka ulja kroz procepe;
2. obezbeđivanje privremenog rezervnog izvora energije za sistem u celini, a posebno za upravljački deo sistema, kada pumpa ne radi;
3. ublažavanje oscilacija pritiska i udara pri kritičnim radnim režimima hidrauličkog sistema;
4. ublažavanje oscilacija protoka i pritiska radne tečnosti prouzrokovanih radom pumpe itd.

U zavisnosti od funkcionalnog principa akumuliranja energije, uljno-hidraulički akumulatori se dele u tri osnovne grupe:

1. akumulatori sa tegovima;
2. akumulatori sa oprugom i
3. gasni akumulatori.

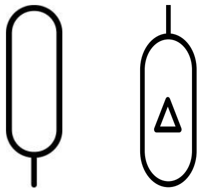
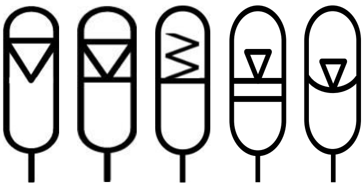
Akumulatori iz prve dve grupe se zajedničkim imenom nazivaju hidro-mehanički akumulatori energije. Retko se koriste u hidrauličkim sistemima.

Gasni akumulatori su ispunjeni nekim gasom ili vazduhom. Široko se koriste u hidraulici. U okviru hidrauličkih sistema iz ove grupe postoje dve osnovne podgrupe akumulatora:

1. klipni i
2. membranski.

Tabela 4. Hidraulički akumulatori i gasne posude.

Table 4. Hydraulic accumulators and gass vessels.

 (a) (b)	Opšte oznake: (a) - opšta oznaka hidrauličkog akumulatora; (b) - pomoćna gasna posuda.
 (a) (b) (c) (d) (e)	Izvedbe akumulatora: (a) - akumulator sa gasom u neposrednom kontaktu sa radnom tečnosti (levo); (b) - akumulator sa gasom, razdvojenim elastičnom membranom od radne tečnosti; (c) - akumulator sa oprogum; (d) - akumulator sa tegom i (e) - akumulator sa mehom (membranom).

ZAKLJUČAK

Po pravilu, hidraulički sistemi su sastavljeni od standardnih međusobno povezanih komponenata usklađenih operativnih karakteristika. Funkcionisanje hidrauličkih sistema zavisi od izbora ugrađenih komponenata u sistem i načina njihovog povezivanja. Zbog složenosti komponenata, a posebno celokupnog hidrauličkog sistema, pored radioničkih i sklopnih crteža za njihovo predstavljanje se koriste i odgovarajuće grafičke simboličke oznake. Njihova primena je posebno pogodna za funkcionalno predstavljanje hidrauličkih sistema i međusobne povezanosti njihovih komponenata.

Ovaj rad predstavlja peti nastavak serije radova o grafičkim simbolima standardnih komponenata uljno-hidrauličkih sistema. Posvećen je simboličkom predstavljanju prečistača (filtera), hladnjaka, grejača/predgrejača i kondicionera ulja kao radne tečnosti, ali i akumulatora energije. Simboli svih grupa prikazanih hidrauličkih komponenata, koje su u fokusu ovog rada, definisani su odgovarajućim ISO industrijskim standardima.

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HYDRAULIC SYMBOLS – PART FIVE: AUXILLIARY COMPONETS

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Abstract: This paper presents the fifth part of the serie, which presents the graphic designations, i.e. symbols, of the most of standard components of hydraulic systems according to current international standards (ISO). This work is focused to the symbols for simplified presentation on the hydraulic diagrams of the associated components intended for the storage and conditioning of hydraulic oil, and for the storage of energy delivered to the oil as working fluid by hydraulic pumps. The function of oil storage is provided by appropriate hydraulic tanks and the hydraulic energy is stored by means of oil-hydraulic accumulators. Symbols of components for maintaining hydraulic oil operating parameters within optimum limits are also shown. The components also included in this presentation are specified for: purification (oil-hydraulic filters), heating (preheaters/heaters) and cooling (oil-hydraulic coolers).

Key words: *hydraulics, symbol, reservoir, accumulator, filter, heater, cooler*

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ASSESSMENT OF SOIL SATURATED HYDRAULIC CONDUCTIVITY AT VFSTR CAMPUS USING DRI METHOD

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Abstract: Study of soil hydraulc conductivity is the most important parameter for fluid flow and molecules transportation phenomena through the soil profile. The water reaches in the land surface in the form of precipitation and irrigation can flow over the ground, which eventually reaches in surface water body and flows through soil surface, contributes groundwater recharge. Estimation and evaluation of soil saturated hydraulic conductivity (Ks) are soil hydraulic properties that effect fluid flow ability through the soil medium which help to understand transmission properties and water balance in soils. The Green-Ampt (GA) model is best suited for infiltration on homogeneous, initially dry, rough and rough soils. The study is conducted to estimate steady state infiltration rate by using in-situ method named Double Ring Infiltrometer (DRI) and finding the spatial variation of infiltration rate and to estimate saturated hydraulic conductivity by using the Green-Ampt (G-A) model for 6 plots, having area 15m x 15m each at Vadlamudi willage, Guntur district, Andhra Pradesh (India). The experiment conducted areas A1, A2, A6 is having more bulk density because of organic compounds in that area having comparatively less infiltration rate than A3, A4, A5. Point A1 having less moisture content with soil bulk density 1.95 g/cm^3 and having a maximum infiltration rate of 4.2 cm/h. The average estimated Ks was found 0.95 cm/h from the experiment plot.

Keywords*: Hydraulic conductivity, Infiltration rate, Precipitation, Green-Ampt (G-A), Double Ring Infiltrometer (DRI)*

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INTRODUCTION

Infiltration is the important component of the hydrological cycle. Water gets into the surface of the earth in the form of precipitation and irrigation can flow over the ground, which ultimately reaches the currents, lakes, rivers and oceans or flows through the surface of the soil, contributing to the regeneration of water underground. Estimating and assessing the hydraulic conductivity (Ks) of saturated soil is the hydraulic properties of the soil that affect the capacity of the fluid flow through the soil, which helps to understand the characteristics of the transmission and the water balance in the soil. Infiltration is the water source to support the growth of vegetation. Infiltration is filtered from the soil, which eliminates many pollutants and complements groundwater supply in wells and waterways. However, water infiltration data for different soils are essential for understanding the drainage process, soil macro porosity controls discharge and infiltration processes (Das, 2014). Determination of infiltration quantitatively is also useful for understanding water availability and estimating the need for water for irrigation in crop production.

Precise methods are needed to characterize infiltration to develop better hydrological models (Islam et al., 2019). Equations and infiltration patterns are widely used in the design of irrigation, drainage and wastewater systems, exploring the characteristics of the effluent and the restoration of groundwater, modeling the flow of fluid with soil and pesticides from agricultural soils to designing the irrigation system.

Hydrological leakage and groundwater supply estimates, water infiltration data for different soils are essential for understanding the drainage process (Sihag et al., 2017). Infiltration modeling approaches are often divided into 3 different categories, such as physical, approximate, and empirical models. The physical approach requires the Richards solution, which describes the flow of water in the soil, taking into account soil conduction and soil pressure, which depends on the soil water content in certain boundary conditions. Simplified approaches include empirical models such as Kostiakov, Horton and Holtan, as well as models based on a physical foundation such as Green and Ampt and Philip. The empirical models are less constrained by the soil surface and soil profile hypotheses but are limited by the conditions for which they are calibrated because their parameters are determined based on the measured infiltration data in the field. Equations based on physical approximation use model parameters derived from water and soil properties and do not require in situ infiltration data (Fashi et al., 2016, Islam et al., 2017). Hydraulic conductivity is very important for the infiltration rate as it expresses the water flowing through the ground. Hydraulic control of unsaturated soil is a function of the pressure head and water distribution in the soil matrix. Soil saturated hydraulic conductivity (Ks) is used as a parameter in many infiltration equations since it is easier to detect both unsaturated hydraulic conductivity and diffusion. In 1856, the French hydraulic engineer Darcy found that the special flow through the porous environment is directly proportional to the hydraulic gradient. The solution of the Richards equation requires many measurements to adequately describe changes in soil characteristics both vertically in the soil profile and at the point (Rooij, 2010), (Kostiakov,1932) and (Lewis, 1938) independently developed an empirical approach based on curve adaptation, adapting field data. Even Horton's approach has been criticized for not taking into account the importance of potential capillary slopes for reducing infiltration capacity and almost exclusively for controlling surface conditions (Bevin, 2004). The Philip's model is adapted to the constant rain intensity to determine the time of precipitation surplus and the resolution of the kinetic wave flow equation. These included storing depression between pond time and discharge time. In 1911, Green-Ampt (GA) developed a simple rough model that directly applies the Darcy Law. The initial infiltration equation was obtained on a surface covered with deeply homogeneous soil infiltration rate and find a spatial variation of infiltration rate and estimate saturated hydraulic conductivity using the Green-Ampt model.

MATERIAL AND METHODOLOGY

Study Area

The study area is located at Vignan's Foundation for Science, Technology and Research (VFSTR) campus, Vadlamudi, Guntur district, Andhra Pradesh (16.2334° N, 80.5509° E). The location has maximum and minimum temperature is 41°C and 27°C with average rainfall in the district is 830 mm, experienced mostly by both south-west monsoon and the retreating monsoon.

The study area consists of a green house, we have taken 6 plots with the 15m x 15m area and the infiltration test was conducted by using the DRI method at 10 cm depth from the surface with DRI method.

Double Ring Infiltrometer (DRI)

DRI consist of one metal cylindrical inner ring 30 cm diameter 29 cm height and outer ring 60 cm dia. Infiltration test has been conducted with the following steps.
Step 1: Cleared the sampling area of surface residues because it impedes to insert the ring when the surface was covered with vegetation.
Step 2: The cylinders were installed about 10 cm deep in the soil by taking care of the ring sides vertical and minimum soil disturbance.
Step 3: Measured the elevation difference with the help of sprit leveller.
Step 4: A polythene sheet was placed inside the inner ring and poured water to protect the soil surface from the disturbance.
Step 5: Add water inside the ring and the depth of water maintained up to depth 7-12 cm
Step 6: Measured water level in the inner ring with the field type point gauge attached.
Step 7: Calculate steady state infiltration rate.

Sample Collection

At each site, six soil samples were collected and determined the initial water content, soil bulk density.

Moisture Percentage And Bulk Density Of Soil

A gravimetric method was used to determine the initial water content of the soil. The wet specimens are weighed, dried in a hot air oven at 105 ° C for 24 hours, and then weighed again. The following equation used to determine water content.

$$\theta_m = \frac{\text{Mass wet soil} - \text{Mass dry soil}}{\text{Mass dry soil}} = \frac{m_w}{m_s} \tag{1}$$

Volumetric soil water content (V) was obtained by using the equation with the length (L) and diameter (d) of the soil rings

$$V = \frac{\pi d^2}{4} L \qquad (2)$$

Bulk density was of the soil

$$\rho_b = \frac{Mass\ of\ dry\ soil\ (m_s)}{The\ volume\ of\ soil\ (V_s)}$$

(3)

The volume of water content was then calculated by the equation:

$$\frac{V_w}{V_s} = \frac{m_w}{m_s} x \frac{m_s}{V_s} x \frac{V_w}{m_w} \qquad (4)$$

Where,

V_w= volume of water (cm^3)

V_s = Dry soil volume (cm^3)

m_w = Mass of the water (g)

m_s= Mass of the dry soil (g)

$$\theta_i = \theta_m \frac{\rho_b}{\rho_w} \qquad (5)$$

Where,

$\theta_i = \frac{V_w}{V_s}$ = *volumetric water content (cm^3 cm^{-3})*

$\theta_m = \frac{m_w}{m_s}$ = gravimetric water content (gg^{-1}),

$\rho_b = \frac{m_s}{V_s}$ = bulk density of soil (gcm^{-3})

$\rho_w = \frac{m_w}{V_w}$ = density of water (g cm^{-3})

Estimation of Saturated Hydraulic Conductivity

Saturated soil flow capacity is estimated using the DRI data Green-Ampt (GA) equation. DRI in situ data were used to generate data values f (infiltration rate) and F (cumulative infiltration) for different time values (t).

F values are displayed against 1 / F in Excel and the most appropriate straight line is drawn through the drawn points. The intersection of the best fit line is saturated hydraulic conductivity (Ks) (Nimmo et al., 2009).

$$f = \mathrm{Ks}(1 + \frac{\eta S_c}{F}) \quad (7)$$

Where,

F= Cumulative infiltration (L),
f= Infiltration capacity (L/T),
η = Soil porosity,
Sc= Capillary suction at the wetting front and
Ks= Saturated hydraulic conductivity of the field (L/T)

Arrange the Green-Ampt equitation in the form of a line

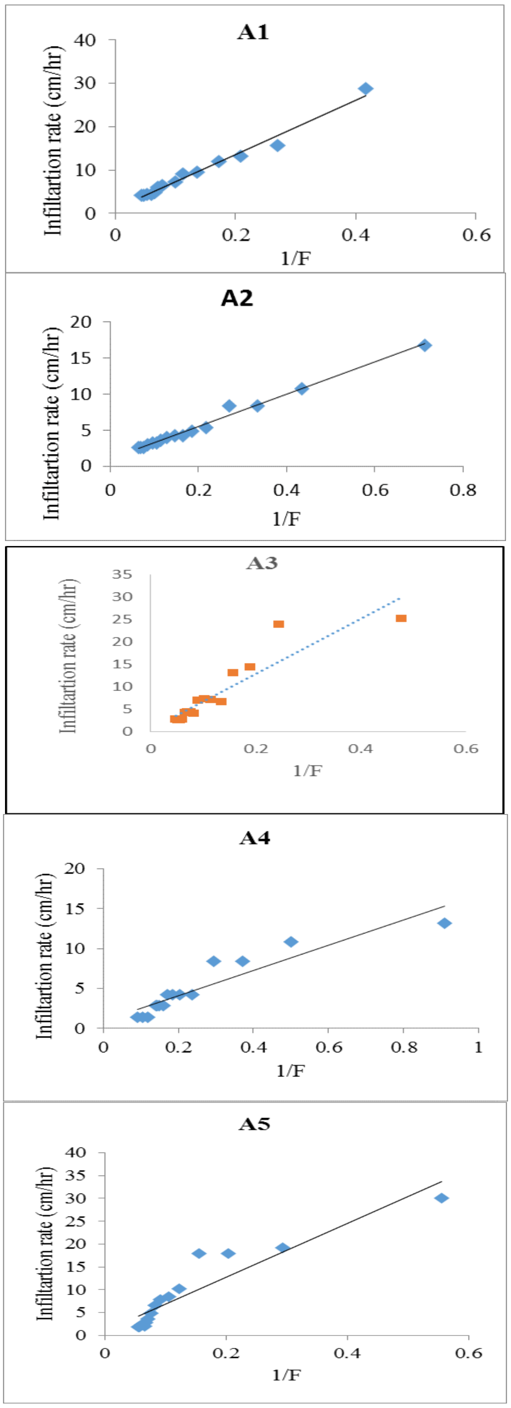
$$f = p + \frac{q}{F} \quad (8)$$

Where,

F= Cumulative infiltration [L]
f= Infiltration capacity [L/T]
p and q = Parameters of the infiltration model (Green-Ampt)

RESULTS AND DISCUSSION

The in-situ infiltration test was conducted in the field to find the spatial variability of infiltration rate. Based on the field tests at 6 plots at VFSTR campus, Vadlamudi, Guntur district, Andhra Pradesh and the results were analysed and individual infiltration curves have been produced. The in-situ infiltration rate reading was summarized in Fig. 1. The determined steady state infiltration rates for 6 plots were determined 4.2, 2.62, 2.72, 1.40, 1.80, 2.40 cm/h respectively. The graph is drawn between infiltration rate, cm/h and cumulative infiltration, 1/F. From the graph to plot A1, A2, A3, A4, A5, A6 the receptively intercept (Ks) is 1.05, 1.01, 0.63, 0.85, 1.04, 1.11 (cm/h). The determined/estimated Ks rates and moisture contents and bulk density of the soil samples of different locations shown in Table 1.


A1
Infiltartion rate (cm/hr)
1/F
A2
Infiltartion rate (cm/hr)
1/F
A3
Infiltartion rate (cm/hr)
1/F
A4
Infiltartion rate (cm/hr)
1/F
A5
Infiltartion rate (cm/hr)
1/F

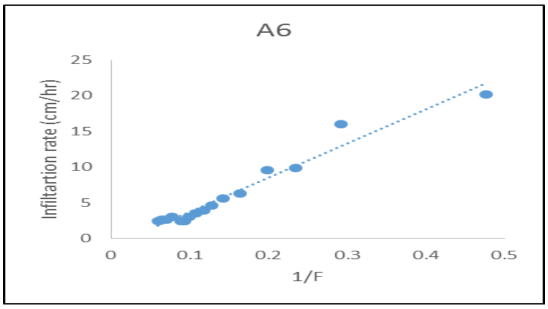


Fig.1. Curve fittings for estimation of saturate hydraulic conductivity for 6 different locations

Descriptive Statistics Of Soil Physical Parameters

The mean moisture content for the experimental site is found 7.47% with the maximum value of 11.3%. The mean bulk density for the experimental site is found 1.8 gm/cm3 with the maximum and minimum values are 1.69 and 2.10 gm/cm^3. The mean basic infiltration rate for all the 6 infiltration tests carried out in a systematic square grid pattern was found to be 2.44 cm/h with the maximum and minimum values of 4.2 cm/h and 1.4 cm/h, respectively.

Table 1. Descriptive statistics of soil physical parameters

Parameters	*Moisture content (%)*	*Bulk Density (g/cm^3)*	*Ks from Green Ampt (cm/h)*
Mean	*07.47*	*01.89*	*00.95*
Standard Error	*01.71*	*00.07*	*00.07*
Median	*07.88*	*01.87*	*01.02*
Standard Deviation	*04.19*	*0.187*	*00.17*
Sample Variance	*17.54*	*00.03*	*00.03*
Range	*11.30*	*00.41*	*00.47*
Minimum	*00.00*	*01.69*	*00.63*
Maximum	*11.30*	*02.10*	*01.11*
Sum	*44.84*	*11.35*	*05.70*
Count	*6*	*6*	*6*

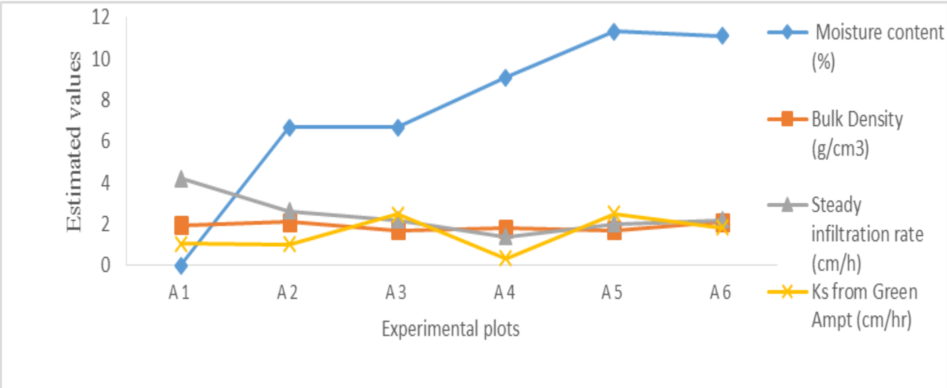


Fig. 2. Experimental plots Soil physical parameters

CONCLUSION

In this paper, we have tried to identify the spatial variability of infiltration characteristics and finding saturated hydraulic conductivity at 6 plots with 15m x 15m at VFSTR campus, Vadlamudi, Guntur district, Andhra Pradesh, India. The study reveals that infiltration rates vary throughout the plots. It was observed that the plot A1, A2, A6 having more bulk density because of organic compounds in that area having comparatively less infiltration rate than A3, A4, A5 and point A1 having less moisture content with soil bulk density 1.95 g/cm^3 and having maximum infiltration rate 4.2 cm/h. The estimated average saturated hydraulic conductivity (K_S) of the experimental plot is 0.95 cm/h. The knowledge of infiltration characteristics can be used to construct irrigation and drainage systems.

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PROCENA HIDRAULIČKE PROVODLJIVOSTI ZEMLJIŠTA NA VFSTR KAMPUSU UPOTREBOM METODE DRI

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Sažetak: Istraživanje hidraulične provodljivosti zemljišta najvažniji je parametar za protok tečnosti i transport molekula kroz profil zemljišta. Voda dospeva na površinu zemljišta u obliku padavina, navodnjavanjem i može prolaziti kroz profil zemljišta, i na kraju dospeva u veće dubine i formira različite forme podzemne vode. Procena hidrauličke provodljivosti zasićenog zemljišta (Ks) je hidraulička osobina zemljišta koja utiče na sposobnost prolaska kroz podzemnu sredinu i pomaže u razumievanju osobina prenosa i ravnoteže vode u zemljištima. Model Green-Ampt (G-A) je najprikladniji za infiltraciju na homogenim, u početku suvim i grubim zemljištima.

Studija je sprovedena za procenu procenta infiltracije kroz zemljište korišćenjem in-situ metode Double Ring Infiltrometer (DRI) i određivanjem prostorne varijacije brzine infiltracije i procenom hidrauličke provodljivosti pomoću modela Green-Ampt (GA) za 6 oglednih površine od 15m x15m, svaki kod mesta Vadlamudi, okrug Guntur, Andhra Pradesh (India).

Eksperiment obuhvata površine A1, A2, A6 koje imaju veću vrednost zapreminske težine zemljišta zbog sadržaja organskih jedinjenja u toj oblasti, i koja imaju relativno manji rang infiltracije od površine A3, A4, A5.

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Površina A1 sa manjim sadržajem vlage i vrednosti zapreminske težine zemljišta od 1,95 g/cm^3 imaju maksimalnu brzinu infiltracije od 4,2 cm/h. Prosečno određena vrednost Ks sa eksperimentalnog polja je 0,95 cm/h.

Ključne reči: *Hidraulička provodljivost, procenat infiltracije, padavine, model Green-Ampt. (G-A), dvostruki kružni infiltrometar (DRI)*

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DRYING CHARACTERISTICS OF YAM VARIETIES: A COMPARATIVE ANALYSIS

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Abstract.The drying characteristics of five yam varieties (white yam, purple yam, three leaves yam, water yam and yellow yam) were investigated under three drying methods, using electric oven, natural sun and solar dryer). The yam tubers were washed, hand-peeled, sliced to size of 10mm thickness and each variety was divided into three sets for use at the three different drying methods. They were dried to a constant weight at a temperature of 33°C.The drying was repeated 6 times and the average of the weights taken.

In all the drying methods the yam varieties had moisture ratio ranges of 0.21 – 0.08 % and the drying rates of 20%/hr – 10%/hr for solar dryer, 16%/hr – 10.1 %/hr for oven dryer and 23%/hr – 19.05%/hr for sun dryer while constant weight was attained at 180 to 300 minutes in oven- dried samples, 390 to 480 minutes for solar-dried samples and 780 to 960 minutes for sun-dried samples. In oven drying method purple yam dried faster (180 mins) followed by yellow yam (240 mins) and white yam (300 mins). Drying was accomplished in two days under sun drying method with three leave yam, purple yam and yellow yam having the same least time of drying while the white yam and water yam had the same highest drying period.

Key words: *Yam varieties, Drying, Drying methods, Solar, Sun, Oven.*

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INTRODUCTION

Yam is a tuberous crop with great economic value in the whole world, especially in the tropical regions of West Africa. It belongs to the family *Dioscoreaceae* and genus *Dioscorea* that produce tubers and bulbils or rhizomes.

Yams are widely distributed all over the world, but with greater circulation in the tropical regions where they form important crops and food sources for tropical countries in West Africa, West Indies, East African, America, China, Japan, Philippines, Madagascar, Southeast Asia, South Caribbean, Malaysia, South Pacific Island, Korea and Papua New Guinea (Agwu and Alu, 2005). In most of these countries, yam constitute good portion of the sources of dietary calories of their population, while in some countries like Japan and China, yams contribute significantly to their industrial raw materials, especially in the areas of pharmaceutical and brewery industries. In the recent past, the production of non grain ethanol as an alternative to fuel using yam, cassava and potato (Louis, 2008) has been embraced by technologically developed countries of Asia. According to FAO (2008), the trend of global yam production shows that Africa accounts for about 96% of world production of yam, with Nigeria alone being responsible for nearly three quarters of the world total production; 73.8% of African total production, 35.017million metric tons/year (IITA, 2013).

Most of the world and African yam production is concentrated in the "yam belt" starting from Cote d'Ivoire, through Ghana then Togo, Cameroon and Nigeria, where yam is not just a food security crop but an indigenous food crop that is harmonized into socio-cultural lives of the people (IITA 2008).

Yam tubers are among the major tuber crops making impact in the Nigeria economy, in terms of capacity and value. They are processed into flours for making livestock feed and in industrial starch production (Idumah et al., 2014; Agriculture Nigeria, 2014). Yams occupy significant position in the food combination of many homes, especially the middle and upper class family of the Nigerian society where consumption of pounded yam is considered classic.

The ancient process of making pounded yam which requires pounding with mortar and pestle is extremely tedious and sometimes unhealthy. The rise in population of middle class family and increase in health consciousness among the people is making the conventional method of making pounded yam in Nigeria outdated as people are now moving from the use of mortar and pestle to modern hygienically processed yam flour; which is easy to prepare and saves time (African - foodie, 2012). The critical stage in yam flour processing is the drying stage because the quality of flour depends to a large extent on the drying method and time. Longer time exposes the yam slides to extraneous contaminants such as microbial particles and particulate matters, while the drying method may have effects on the stability of the active nutrient components. The need to find the ideal drying methods that will minimize exposure to extraneous contaminants, conserve nutrients composition and produce yam flour of wide acceptability is the desire of food engineers, technologists and allied scientists. This study was designed to address this.

The aim of the study was to determine which of the three drying methods would provide the required data that would guide food manufacturers, processors and engineers in selection of engineering process design, instrumentation and storage stability of yam to meet the wider acceptability to the industrialists and consumers.

MATERIALS AND METHOD

2.1. Sample collection and preparation

Five varieties of yam tubers namely; white yam (*Dioscorea rutundata*), purple yam *(Dioscorea alata*), yellow yam (Dioscorea cayenensis), three leaves yam *(Dioscorea bulbifera*) and water yam *(Dioscorea alata)* were used for the study. They were obtained from Anambra State Agricultural Development Programme (ANADEP) farm in December 2016 at harvest moisture content range from 56.8 to 65 % wb. The yam tubers were washed, hand-peeled and sliced to range of 10 to 15 mm thickness.

2.2: Determination of the drying characteristics

Each sliced variety of the yam tubers were divided into three sets for use at three different drying methods (oven dryer, sun dryer and solar dryer). Equal weight (2g) of slice from each yam varieties was subjected to oven-drying using electric oven dryer (model LOA 1805, Munich Germany), solar-drying using solar dryer (locally fabricated with thermal efficiency of 46.77%, percentage energy loss of 16.73%) and open air-drying using natural sun dryer. A stable drying condition of 33^{o}C at air velocity of 1.85 m/s and relative humidity of 20.6%, for oven method was achieved in the oven before loading the first set of yam samples.

The drying temperature in solar dryer was controlled to 33^{o}C at 1.45 m/s air velocity and Sun drying was done between 30 to 35^{o}C (average 33^{o}C) at air velocity of 1.25m/s, and relative humidity of 30.6%. The microclimatic features (temperature, humidity and air speed were monitored using thermocouple for solar dryer, whirling hygrometer and vane anemometer for the relative humidity and speed of the air in sun dryer respectively and airflow meter for the air speed in the oven were determined according to standard methods. The same drying condition was maintained in all the drying methods for ease of comparison. The samples were removed and weighed every 30 minutes to record moisture loss data until constant weight was achieved in each case (Sinjh, 2001). The initial moisture content of the samples in (wb) was determined using moisture meter.

Moisture content at any time of drying was determined using equation:

$$\mathrm{MC}t = \frac{wt-(wi \times dm)}{wt} = \frac{wt-wd}{wt},$$

Where:
MC_t = moisture content (% wb) at time t;
wt = weight of sample at a time;
wi = initial moisture content (% wb);
d_m = dry matter ratio,
wd = Final moisture content.

As the drying progressed, the moisture contents of the samples were measured using gravimetric method (Association of Official Analytical Chemists, AOAC 2000). The experiment was done 6 times and average taken. The other drying characteristics were determined mathematically as derivatives from the moisture content.

Drying time

The drying rate was determined using the expression:
Drying rate, $hr^{-1} = \frac{dM}{d\theta}$, where M=Moisture content of grain at any time θ, θ= Time in hr.

Moisture ratio

The moisture ratio was calculated using equation:

MR = $\frac{M_t - M_e}{M_o - M_e}$, simplified to equation

MR = $\frac{Mt}{Mo}$,

Where:
MR = moisture ratio (-),
M_t = Moisture content at time, t (% wb)
M_e = equilibrium moisture content (% wb),
M_o = initial moisture content (% wb)

Equilibrium moisture content and equilibrium relative humidity

Equilibrium moisture content was determined according to Ndirika and Onwualu (2016) and the corresponding relative humidity was equilibrium relative humidity.

Me = $\frac{M - Moe^{-k\theta}}{1 - e^{-k\theta}}$,

Where:
Me = equilibrium moisture content, % (wb)
M = Moisture content at any time, % (wb), θ= Time, hr.
Mo = initial moisture content, % (wb),
K = drying constant (h^{-1}) = ln MR/t
t = time (h), MR = moisture ratio

The data acquired were subjected to descriptive statistics using statistical package SPPS version 7, Chicago and presented in tables and line graphs were drawn using Microsoft Excel 2007.

RESULTS AND DISCUSSION

The results are presented in tables 1-7 and figures 1-13. Drying characteristics at different heating methods at the same temperature are represented in tables 1-3, while the moisture ratios of the five yam varieties at the same temperature using oven method is represented in table 4. Comparative moisture behaviours are represented in figures 1 and 2,while the time effects on drying rates on moisture are represented in figures 3 to 9. Moisture ratios of the yam varieties are represented in figures 10-13.

Table 1 represents the drying characteristics of yam varieties dried using oven drying method at 33^{o}C. At about 100mins, the drying rate decreased as time progressed. The yellow yam had the highest average drying rate (0.91-0.01%/min with an average drying rate of 0.41%/min) followed by water yam (0.90-0.01%/min with an average drying rate of 0.39%/min), three leaves yam (0.88-0.01%/min and an average drying rate of 0.38%/min), purple yam (0.82 - 0.01%/min with an average drying rate of 0.36%/min) and least was the white yam (0.78-0.02%/min, with an average drying rate of 0.37%/mins). The standard deviation of the drying rate obtained for the yam varieties at 33^{o}C range from ±0.38 - ±0.46; which is an indication that the values obtained for the drying rate didn't deviate much from the mean values .The average drying rate obtained for the yam varieties fall within the range obtained by Shuaeb and Joshua (2013) for poundo yam. It took a total time range of 240- 300 mins to bring all the yam varieties to a constant weight level fit for milling.

Table 1: Drying characteristics of yam varieties dried using oven at 33^{o}C

Drying time (mins)	*White yam*		*Three leaves yam*		*Purple yam*		*Water yam*		*Yellow yam*	
	Drying rate, %/min	*M.C, % (wb)*	*Drying rate, %/min*	*M.C, % (wb)*	*Drying rate, %/min*	*M.C, % (wb)*	*Drying rate, %/min*	*M.C, % (wb)*	*Drying rate,%/min*	*M.C, % (wb)*
0.00	-	65.00	-	58.3	-	50.71	-	63.40	-	56.8
30	0.780	41.50	0.880	32.00	0.82	36.02	0.90	36.30	0.910	29.40
60	0.770	23.00	0.810	13.01	0.81	8.01	0.89	20.14	0.900	10.18
90	0.110	13.50	0.090	4.50	0.06	3.08	0.07	10.58	0.80	3.22
120	0.50	8.00	0.20	2.50	0.09	2.06	0.06	4.81	0.70	2.19
150	0.20	5.00	0.12	1.30	0.07	1.05	0.05	3.32	0.09	1.21
180	0.08	3.00	0.05	1.23	0.04	1.04	0.04	2.05	0.08	1.14
210	0.06	2.00	0.03	1.10	0.03	1.03	0.03	1.55	0.07	1.82
240	0.03	1.50	0.02	1.08	0.02	1.02	0.002	1.50	0.05	1.08
270	0.02	1.05	0.01	1.06	0.01	1.02	0.001	1.40	0.02	1.08
300	0.02	1.05	0.01	1.06	0.01	1.02	0.001	1.40	0.001	1.08
Mean± S.D	*0.37±0.38*		*0.38±0.44*		*0.36±0.41*		*0.39±0.45*		*0.41±0.46*	

S.D = Standard deviation.

Table 2 represents the drying characteristics of yam varieties dried using solar drying method at 33°C. White yam recorded a drying rate range of 0.42 – 0.01%/min while the three leaves yam had 0.53- 0.02%/min, purple yam 0.92 - 0.01%/min, water yam 0.51-0.01%/min and yellow yam 0.56 - 0.01%/min. The white yam, three leaves, purple yam, water yam and yellow yam recorded average drying rate of 0.21, 0.26, 0.46, 0.27 and 0.28%/min respectively.

Table 2. Drying characteristics of yam varieties dried at 33°C using solar drying method

Drying time (mins)	White yam		Three leaves yam		Purple yam		Water yam		Yellow yam	
	Drying rate %/min	M.C % (db)	Drying rate %/min	M.C % (db)	Drying rate %/min	M.C % (db)	Drying rate %/min	M.C % (db)	Drying rate %/min	M.C % (db)
0	-	65.00	-	58.30	-	50.70	-	63.4	-	56.80
30	0.42	52.50	0.523	42.60	0.920	23.10	0.513	48.01	0.560	40.00
60	0.400	41.70	0.520	31.03	0.900	20.00	0.510	37.10	0.550	27.50
90	0.108	32.00	0.071	24.60	0.088	12.09	0.079	30.00	0.083	20.05
120	0.042	27.00	0.034	20.50	0.034	8.04	0.058	23.00	0.049	14.20
150	0.021	24.30	0.025	16.80	0.013	6.30	0.026	19.06	0.028	10.00
180	0.018	20.60	0.021	13.09	0.012	4.07	0.023	15.00	0.011	8.00
210	0.015	19.95	0.015	10.00	0.09	3.30	0.020	13.09	0.010	6.00
240	0.09	18.01	0.08	8.03	0.08	2.00	0.018	11.08	0.09	5.01
270	0.08	16.30	0.07	7.01	0.07	1.54	0.09	9.01	0.07	4.00
300	0.06	12.00	0.05	6.00	0.06	1.03	0.05	8.00	0.06	3.00
330	0.05	9.01	0.04	5.04	0.05	0.99	0.04	6.51	0.05	2.01
360	0.04	7.06	0.03	4.56	0.04	0.53	0.03	5.17	0.04	1.08
390	0.03	5.04	0.02	2.31	0.03	0.08	0.02	3.53	0.03	0.93
420	0.02	3.08	0.01	1.03	0.02	0.04	0.02	1.50	0.02	0.32
450	0.001	1.07	0.01	0.90	0.001	0.04	0.01	0.73	0.01	0.32
Mean ±S.D	0.21±0.33		0.26±0.26		0.46±0.46		0.27±0.36		0.28±0.28	

Table 3 represents the drying characteristics of yam varieties dried at 33°C using sun drying method. It took 2 days to dry the yams to a constant weight. At day 1, white yam recorded a drying rate range of 0.22 - 0.11 %/min, three leaves recorded 0.19 - 0.06 %/min, purple yam 0.15-0.03 %/min, water yam 0.22 - 0.07 %/min and yellow yam had a drying rate range of 0.21 - 0.08 %/min. At day 2, the white yam, three leaves yam, purple yam, water yam and yellow yam recorded drying rate range of 0.17 - 0.01 %/min, 0.18-0.01%/min, 0.14-0.01%/min, 0.20-0.01%/min and 0.19-0.001%/min respectively. Their average drying rates were 0.11, 0.09, 0.08, 0.11 and 0.10%/min for white yam, three leaves yam, purple, water yam and yellow yam respectively. The standard deviation (±0.09 - ±0.16) obtained for the drying rate indicated that the values did not deviate much from the mean.

Table 4 represents the moisture ratio of yam varieties dried at 33°C using oven drying methods. For all the varieties the drying was completed within 300 mins at air velocity of 1.3 m/s. White yam had the highest moisture ratio (0.64 – 0.02) followed by water yam (0.60–0.08), three leaves yam (0.46 – 0.01), yellow yam (0.44 – 0.04) and least moisture ratio was observed with purple yam (0.38 – 0.02).

Table 4. Moisture ratio of yam varieties dried at 33^oC using oven drying methods.

Drying time (mins)	Moisture Ratio				
	White Yam	Three leaves yam	Purple yam	Water yam	Yellow yam
0.00	-	-	-	-	-
30	0.64	0.46	0.38	0.60	0.44
60	0.32	0.24	0.16	0.28	0.20
90	0.20	0.14	0.10	0.16	0.12
120	0.14	0.08	0.04	0.10	0.06
150	0.10	0.07	0.02	0.08	0.04
180	0.08	0.06	0.01	0.06	0.03
210	0.06	0.05	0.008	0.03	0.02
240	0.04	0.04	0.006	0.02	0.01
270	0.03	0.03	0.004	0.01	0.007
300	0.02	0.02	0.02	0.008	0.004
Mean	0.16	0.12	0.08	0.13	0.09

Table 5 represents the moisture ratio (M.R) of yam varieties dried at 33^oC using solar drying method. The white yam, three leaves yam, purple yam, water yam and yellow yam recorded moisture ratios of 0.80 – 0.04; 0.72 – 0.02, 0.68 – 0.02, 0.78 - 0.02 and 0.70 – 0.05 respectively, at an average air velocity of 1.45m/s and under a total drying time of 480 mins, This agrees with the findings of Jimoh et al. (2010).

Table 5: Moisture ratio of yam varieties dried at 33^oC using solar drying method

Dryingtime (mins)	Moisture Ratio				
	White Yam	Three leaves yam	Purple yam	Water yam	Yellow yam
0.0	-	-	-	-	-
30	0.80	0.72	0.68	0.78	0.70
60	0.70	0.58	0.48	0.66	0.48
90	0.60	0.45	0.26	0.52	0.34
120	0.51	0.34	0.16	0.42	0.22
180	0.36	0.18	0.07	0.26	0.10
240	0.30	0.11	0.06	0.18	0.09
300	0.14	0.06	0.05	0.10	0.08
360	0.08	0.04	0.04	0.04	0.07
420	0.06	0.03	0.03	0.03	0.06
480	0.04	0.02	0.02	0.02	0.05
Mean	0.36	0.25	0.19	0.30	0.22

Table 6. Moisture ratio of yam varieties dried at 33^oC using sun (open air) drying method (Day 1)

Drying time (mins)	Moisture Ratio				
	White Yam	Three leaves yam	Purple yam	Water yam	Yellow yam
Day 1	-	-	-	-	-
60	0.84	0.74	0.57	0.80	0.64
120	0.64	0.50	0.36	0.58	0.50
180	0.44	0.33	0.19	0.40	0.34
240	0.30	0.20	0.10	0.24	0.24
300	0.22	0.12	0.08	0.16	0.09
360	0.16	0.09	0.06	0.12	0.08
420	0.12	0.07	0.05	0.09	0.07
480	0.104	0.05	0.04	0.07	0.06
540	0.10	0.04	0.03	0.06	0.04
Mean	0.29	0.21	0.15	0.25	0.21

Fig 7.Moisture Ratio of five yam varieties dried at 33°C using sun (open air) drying method(Day2)

Drying time (mins)	Moisture Ratio				
	White Yam	Three leaves yam	Purple yam	Water yam	Yellow yam
Day 2	0.10	0.08	0.04	0.09	0.08
60	0.05	0.03	0.03	0.045	0.04
120	0.03	0.01	0.02	0.02	0.02
180	0.012	0.009	0.008	0.01	0.01
240	0.01	0.008	0.007	0.007	0.009
300	0.007	0.006	0.006	0.005	0.008
360	0.006	0.005	0.005	0.004	0.007
420	0.004	0.003	0.004	0.003	0.006
480	0.003	0.002	0.003	0.002	0.005
540	0.002	0.001	0.002	0.001	0.003
Mean	0.02	0.02	0.02	0.02	0.02

Tables 6 and 7 represent the moisture ratios of yam varieties dried at 33°C using sun (open air) drying method (day 1 and day 2). In day 1 (a) the M.R of the yam varieties varied from 0.84 to 0.10, 0.74 to 0.09; 0.57 to 0.02; 0.80 to 0.06 and 0.64 to 0.04 respectively for white yam, three leaves yam, purple yam, water yam and yellow yam, while in day 2 (b) in the same order, the yam varieties recorded moisture ratios of 0.10 to 0.002, 0.08 to 0.001, 0.04 to 0.002, 0.09 to 0.001 and 0.08 to 0.003 respectively.

The sun (open air) drying method took the highest drying time (540 mins each day) to reduce the moisture content levels of the yam varieties to acceptable limit for milling into flour as compared to oven and solar drying methods.

Figure 1 represents a plot of moisture content against drying time showing an inverse relationship. For every 10% increase in drying time, the moisture content of the yams dropped by14%. The yam varieties recorded their highest percentage of moisture removal within the time range of 30 - 90 minutes during which white yam had a moisture content level of 41.50 – 13.5 %(wb) while three leaves yam, purple yam, water yam, and yellow yam recorded moisture content levels of 32.00 – 4.50%, 36.02 - 3.08%, 36.30 – 10.58% and 29.40 – 3.22% (wb) respectively

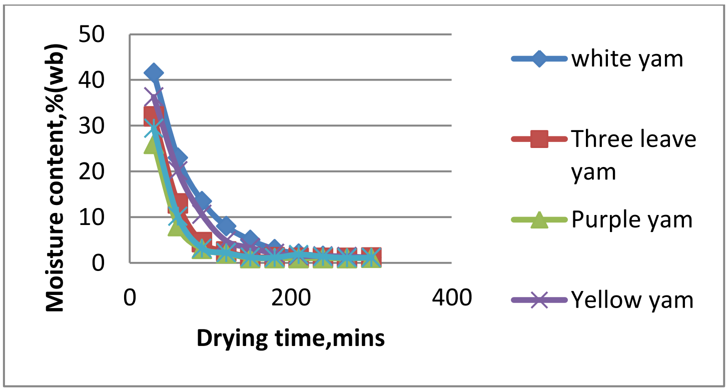

Figure 1: Drying curves of yam varieties at 33°C using oven drying method

Figure 2 represents the effect of drying rate on the moisture contents of the yam varieties. The drying rate showed an initial steep rise, followed by a constant rate, pronounced drop and then the drying rate became slow as time progressed. The curve displayed a short constant drying rate, at which the yam varieties had 0.88%/min, 0.85%/min, 0.82%/min, and 0.77%/min respectively for yellow yam, water yam, three leaves yam, purple yam and white yam. At these points the moisture content level of the yam varieties ranged from 20 - 40 %(wb). Furthermore, the yam varieties registered a falling rate within the moisture content level (12 - 20 %, wb) and corresponding drying rate (0.6 - 0.8%/min). Following a constant drying rate, the moisture levels of the yams dropped by 20% with corresponding fall of 17% in drying rate. This observation agreed favorably with the findings of Ibiyinka et al.(2011)

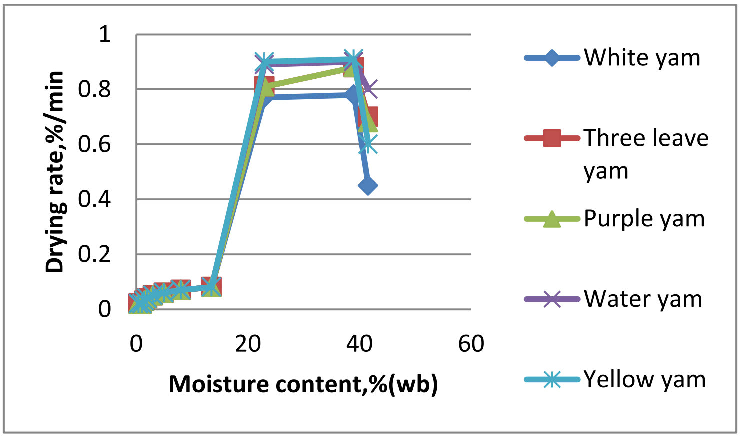

Figure 2: Effect of moisture content on drying rate of yam varieties at 33°C using oven drying method.

The effect of drying time on the drying rate of the yam varieties dried with oven drying method at 33°C.is represented in figure 3. The yams first displayed a short rise in drying rate and then maintained a constant drying rate at range of 0.78 to 0.91 %/mins with corresponding drying time of 30 - 70mins. Thereafter, there was a fall in the drying rate displayed by the various varieties from 70mins to about 100mins and slowly maintained drying rate ranging from 0.05 to 0.01%/min within the time range of 120 to 300 mins. After the constant rate, the drying rate of the yams decreased by 20% for every 25% increase in the drying time. During the constant rate, yellow yam recorded the highest drying rate of 0.91 %/min while the white yam recorded the lowest dying rate of 0.78 %/mins.

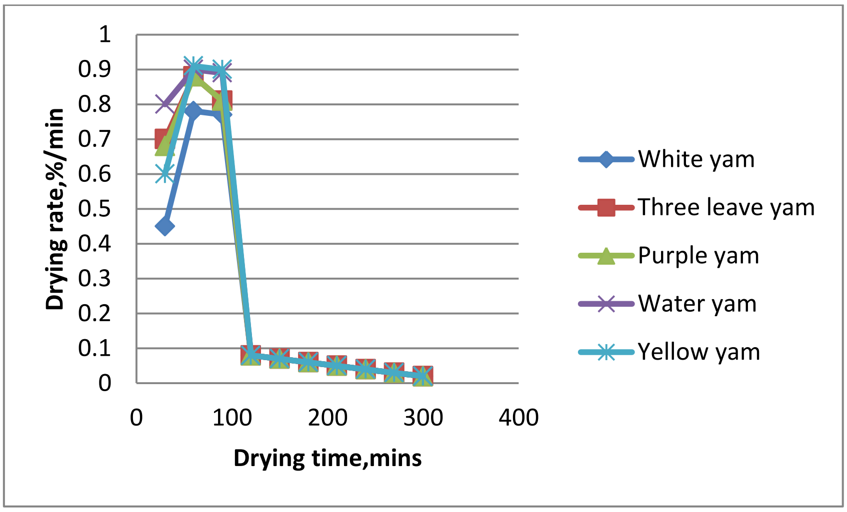

Figure 3. Effect of drying rate on drying time of yam varieties at 33°C using oven drying method

Figure 4 represents the drying curves of yam varieties dried at of 33°C using solar dryer. The yellow yam and the water yam attained a constant weight at time range of 390 – 420 mins while the white yam, purple and three leaves yam attained the constant weight moisture content at the range of 400 - 420mins. The standard deviation obtained at 33°C ranged from ±0.26 - ±0.46 indicating that values did not deviate much from the mean values of the drying rate.

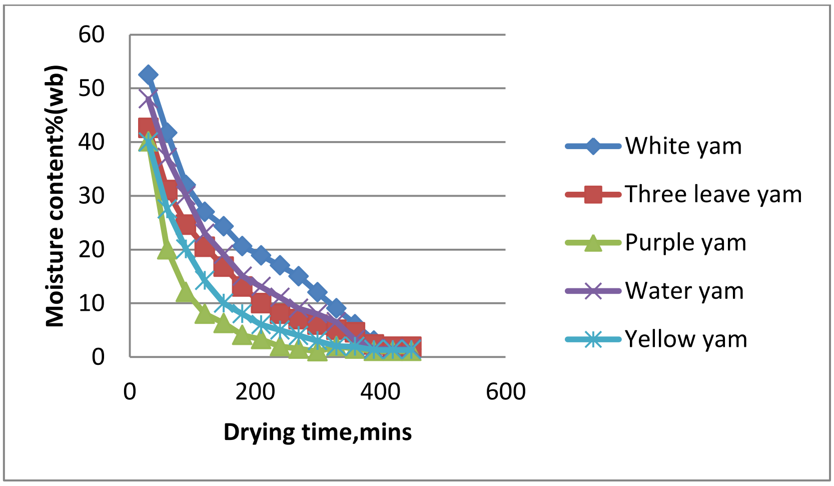

Figure 4. Drying curves of yam varieties dried at 33°C using solar dryer

Figure 5 represents the effect of moisture content on drying rate of yam varieties dried at 33°C using solar drying method. The constant drying rate of the yam varieties ranged from 0.4 - 0.9%/min and the moisture content level of 40 – 46 % (wb) with the purple yam having the highest drying rate (0.9%/min) at that period.

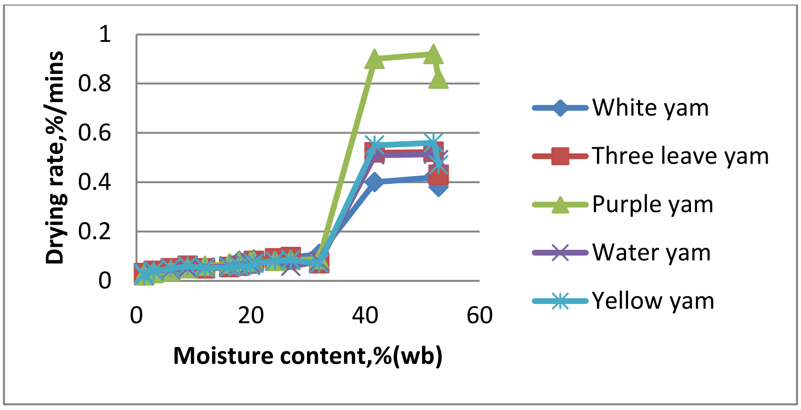

Figure 5. Effect of moisture content on drying rate of yam varieties dried at 33°C using solar dryer

Figure 6 represents the effect of drying rate on drying time of five yam varieties dried at 33°C using solar drying method. The yam varieties had short constant drying rate of 0.89%/min for purple yam, 0.57%/min for yellow yam, 0.46%/min for three leaves yam, 0.48%/min for water yam and 0.41%/min for white yam. The corresponding drying time to these drying rates observed for the yam varieties range from 40 - 70mins. The falling rate for the yam varieties was observed from 43 to 100 mins, and it gradually maintained a very slow drying rate from 0.06 - 0.01%/min within the drying time of 130 - 480mins.

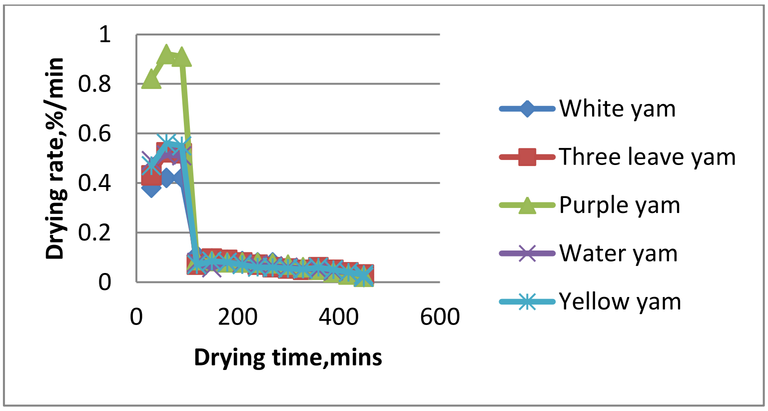

Figure 6. Effect of drying rate on drying time of five varieties of yam dried at temperature of 33°C using Solar drying method

Figure (7a and b) represents the drying curves of yam varieties dried at temperature of 33°C using sun dryer for day 1 and 2 at which the drying process was completed. At day 1 the drying stopped at 540mins leaving moisture content of 24.5% (wb) for white yam, 21 and 21.5%(wb) for water yam and three leaves yam respectively; 16% (wb) for yellow yam and 12% (wb) for purple yam. At day 2, (Fig 4.3b) the sun drying was completed; each variety attained a constant weight before milling into flour.

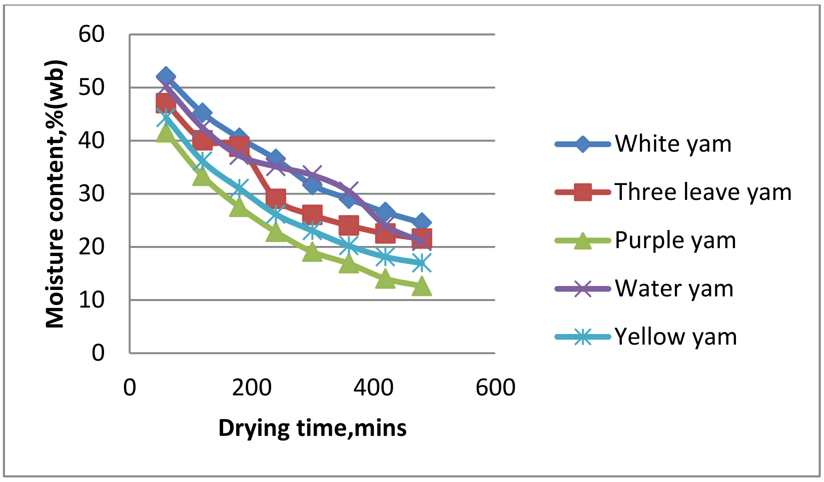

Figure 7a. Drying curves of yam varieties dried at temperature of 33°C using sun dryer. (Day 1)

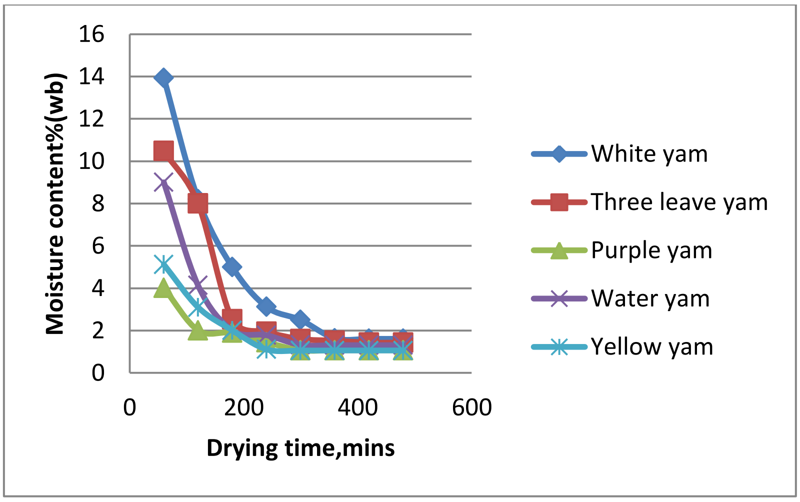

Figure 7b. Drying curves of yam varieties dried at 33°C using sun dryer (Day2)

The effect of moisture content on drying rate at 33°C using sun drying method for day 1 and 2 are represented in figure 8 (a and b). Like other drying methods the curve followed the same trend. However, the break up in the behaviour of the curve showed on the second day during which the drying process was completed. In day 1 a constant rate for the yam varieties was observed at moisture content range of 45 - 55%(wb) with the white yam having constant drying rate of 0.2%/min, three leaves yam had 0.18%/min, purple yam 0.15%/min, water yam 0.23%/min and yellow yam 0.21%/min. The drying was generally completed at day 2 with the yam varieties having a falling rate at 0.9 - 14% (wb) moisture content level.

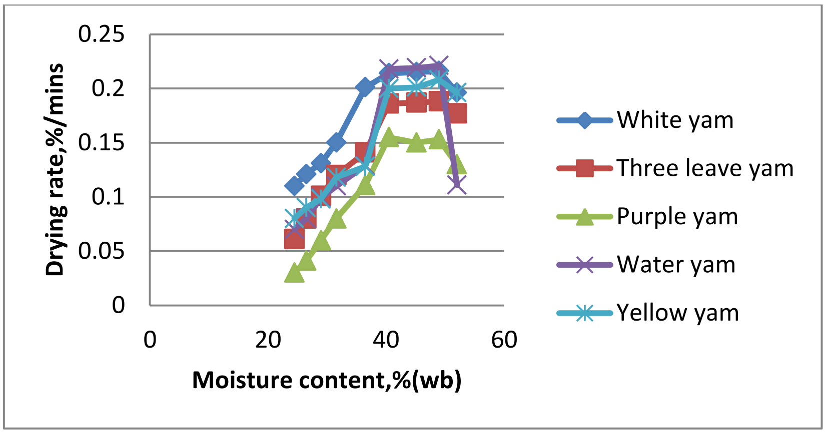

Figure 8a. Effect of moisture content on drying rate at 33°C using sun dryer Day 1

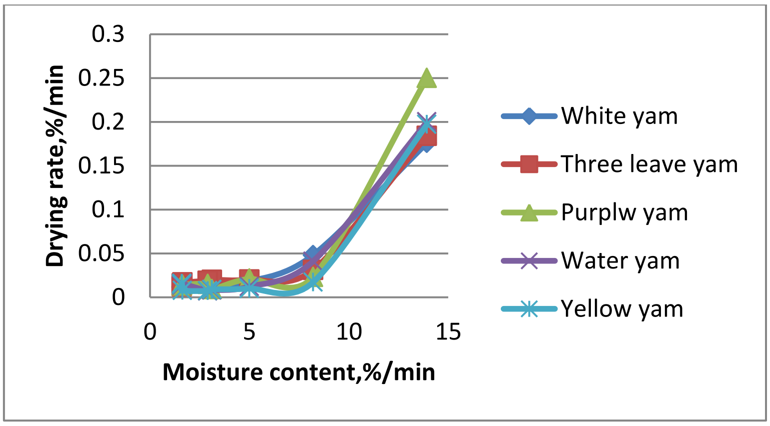

Figure 8b. Effect of moisture content on drying rate at 33°C using sun drying method Day 2

The effect of drying rate on drying time of five varieties of yam, dried at 33°C using Sun (open air) drying method for day 1 and day 2 is represented in Figure 9(a and b). The curves generally followed the same trend like other drying methods. Generally the sun or open air drying method took the highest drying time to attain a constant weight required for milling of the yams into flour.

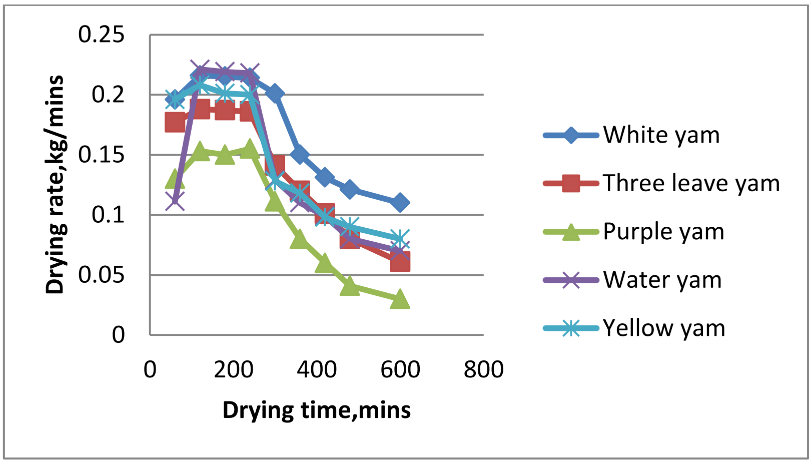

Figure 9a. Effect of drying rate on drying time of five yam varieties dried at 33°C using Sun (open air) drying method Day1

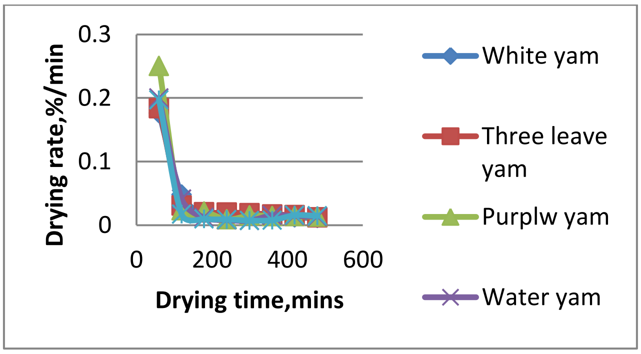

Figure 9b Effect of drying rate on drying time of five yam varieties dried at 33°C using Sun (open air) drying method Day2

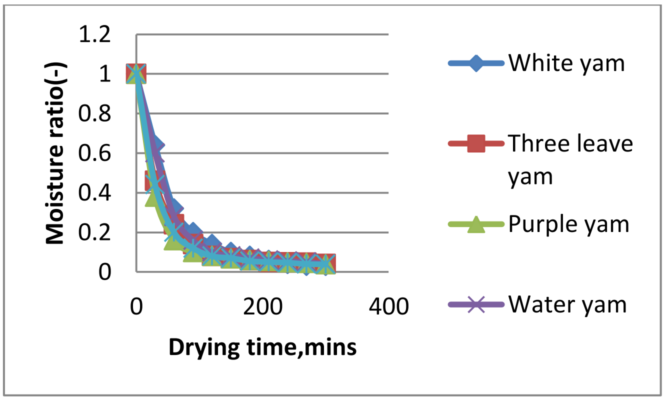

Figure 10: Moisture ratio of yam varieties dried at 33°C using oven dryer

Figure 11 represents the curves of moisture ratio of yam varieties against drying time. The curves also maintained inverse relationship with the drying time in the same manner with the oven drying method. As the drying time increased to 6% there was 17% decrease in M.R. The moisture ratio became very slow at about 360 mins of the drying time resulting to 6% increase in drying time with 5% decrease in moisture ratio.

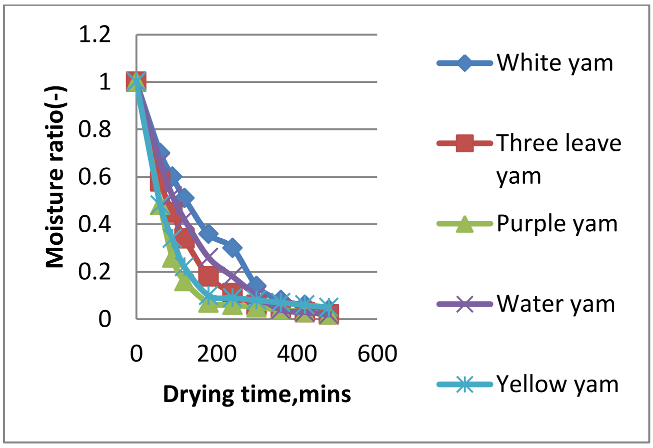

Figure 11. Moisture ratio of yam varieties dried at 33^{o}C using solar dryer

Figures 12 and 13 represent graphs of the moisture ratios of yam varieties dried at temperature of 33^{o}C using sun (open air) drying method for day 1 and day 2. It took a total drying time of 1008 mins (540mins each day). Like all other varieties, the curves displayed inverse relationship with the M.R; decreasing 2% with corresponding increase of 7% in drying time towards the end of the drying. At the beginning it was 7% increase in drying time resulting to 18% decrease in moisture ratio.

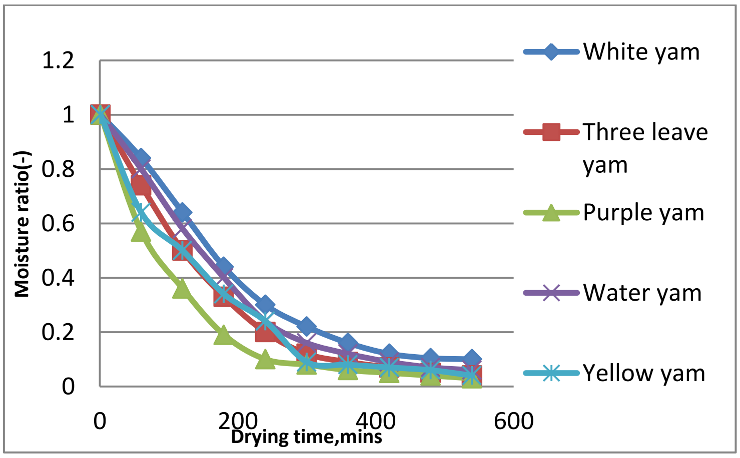

Figure 12. Moisture ratio of yam varieties dried at 33^{o}C using sun (open air) drying method (Day 1)

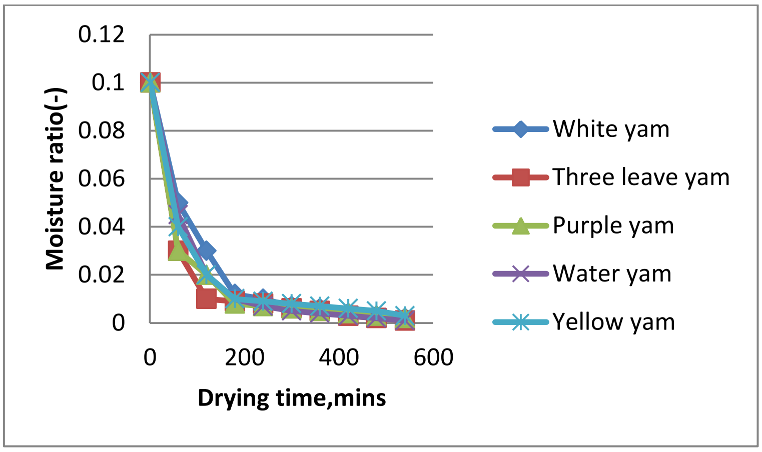

Figure13. Moisture ratio of five yam varieties dried 33°C using sun (open air)

CONCLUSIONS

1. The yam flour varieties attained their constant moisture contents level at different drying times. This variation in drying time may be attributed to the differences in molecular bond and initial moisture content of each of the yam flour varieties.
2. At any giving temperature, the drying rate and moisture content decreased as drying time progressed after the initial constant drying rate and the yam flour varieties showed different behaviours under diverse temperatures and drying methods; a notable point in yam flour drying and in design of yam flour drying equipments.
3. The yam flour varieties recorded drying rate of 0.001 – 0.95 kg/min; this can be useful in design of yam drying equipment.
4. The study compared the drying behaviours of different yam flour varieties under different drying methods which will guide engineers in design of yam drying equipment and in understanding of water activities during storage.

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KARAKTERISTIKE SUŠENJA JAM VARIJETA: KOMPARATIVNA ANALIZA

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Sažetak: Karakteristike sušenja pet Jam (familija *Dioscoreaceae*, rod *Dioscorea)* varijeteta: Beli jam, Ljubičasti jam, Trolisni jam, Vodeni jam i Žuti jam) ispitivane su u tri varijante sušenja: elektična sušara, prirodno sušenje na suncu i solarna sušare. Jam krtole (gomolji) su isprane, ručno oguljene, isečene na veličinu debljine od 10 mm. Svaki Jam varijetet je podeljen u tri seta za upotrebu i tri različita postupka sušenja. Sušeni uzorci imaju konstantnu težinu na temperaturi od 33°C. Sušenje je ponovljeno 6 puta zbog prosečnih rezultata merenja.

U svim metodama sušenja, odnos Jam varijeteta ima razliku vlage u rasponu od 0,21 do 0,08 %, a stope sušenja 20% /h - 10% /h za solarnu sušaru, 16%/h - 10,1% / h za sušenje u električnoj sušari 23% /h - 19,05% /h za sušenje na suncu. Konstantna težina uzoraka je postignuta od 180 do 300 minuta u uzorcima osušenim u električnoj sušari, 390 do 480 minuta za uzorke osušene u solarnoj sušari, i 780 do 960 minuta za uzorke osušene na suncu. Kod metode sušenja u električnoj sušari Ljubičasti jam se suši brzo (180 min), a zatim Žuti jam (240 min) i Beli jam (300 min).

Sušenje je završeno za dva dana metodom sušenja na suncu, za varijetet Trolisni jam, Ljubičasti i Žuti varijetet jam, koji imaju isto najmanje vreme sušenja, dok Beli i Vodeni Jam imaju isti najduži period sušenja.

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Ključne reči: *Jam varijeteti, Sušenje, Metode sušenja, Solarno sušenje, Sunce, Pećnica.*

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EFFECT OF MOISTURE CONTENT AND LOADING POSITIONS ON THE MECHANICAL PROPERTIES OF NEW RICE FOR AFRICA (NERICA)

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***Abstract**:* The mechanical properties of New Rice for Africa, (NERICA) were determined on different moisture content levels of 12.5, 17 and 21.5% (db), and loading positions of major, minor, and intermediate diameters using the Instron Universal Testing Machine (UTM). The mechanical properties studied were the maximum load at rupture, compressive extension at maximum load, load at bioyield point, toughness, stiffness, compressive strength, energy at maximum load, and the maximum slope. Results obtained indicated that, the loading pattern and moisture content affected the mechanical properties determined ($p < 0.05$). Results showed that, maximum load at rupture, compressive extension, load at bio yield point, ranged from 363.73 to 50.92 N; 0.50 to 2.79 mm; and 11.58 to 6.78 N/mm^2; respectively for NERICA Raw-Paddy major diameter loading; and from 18.46 to 5.44 N; 0.92 to 2.52 mm; 9.01 to 4.08 N/mm^2 respectively for NERICA Raw-Paddy minor diameter loading. For the NERICA Parboiled-Milled, results at both major diameter and minor diameter loading positions ranged as follows; maximum load at rupture (156.08 to 44.94 N; 94.90 to 22.05 N); compressive extension (0.59 to 1.61 mm; 0.46 to 2.67 mm). Regression analysis were carried out on the mechanical properties with moisture content, and there was positive correlation between the parameters. There were significant effects of moisture content ($p < 0.05$) on all parameters studied.

Keywords: *Moisture content, Mechanical properties, loading position, NERICA.*

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INTRODUCTION

The word NERICA means "New Rice for Africa" and this is used to represent inborn products developed from the effective crossing of two rice cultivars; the African rice, which is O.glaberrima steud, and the Asian rice, which is O. Sativa L., in order to generate offspring which brings together the first-class qualities of the two parentages, [1]. These involves high-level vintages from the Asian specie and the capability from the African specie to grow vigorously in an unpleasant and difficult environment. NERICA was developed by normal cross breeding and on that ground, they are not hereditarily improved rice, [1]. NERICA varieties are new class of highland varieties of rice which ideally accommodate to the rain-fed highland environment in the Sub-Saharan Africa (SSA), where poor farmers do not have access to irrigation, chemical fertilizers or pesticides. Reports from the Rice centre showed that, NERICA varieties also react positively than the local varieties to greater inputs. The NERICA varieties gives hope to multitudes of poverty-stricken rice farmers, and for numerous other farmers that works hard in a very bad and dirty conditions, spending majority of their little income on rice, [1]. Rice generally is a very important convenience food in Nigeria and much of Sub-Sahara Africa, and currently Nigeria is regarded as the largest rice producing country in Africa. This is as a result of steadily increasing incomes from rice and as well as continued population growth, [2]. However, the increasing demand for rice, both in quantity and quality, far overshadowed local production. Thus, the need to increase production and improve the locally produced rice to make it more competitive with imported rice led to the discovery of NERICA.

Moreover, intensifying cost-effective significance of agricultural food resources, in conjunction with the complications of contemporary technology for their processing, handling, storage and preservation, quality assessment, distribution, marketing and consumption, requires wide-ranging knowledge on engineering properties of these agricultural materials pertinent to their processing, handling, storage, and preservation. Information on the mechanical properties of agricultural materials are considered necessary in the designing and modification of machines and some parameters utilized during processing, and storage of agricultural products as well as in converting them into food, feed and fibre, [3].

These properties effect the designing and assessment of rice processing which includes; drying, shelling, blanching and shining as well as sorting equipment, storing and grain handling equipment, [4]. So, to obtain better quality-milled NERICA, packaging and further processing, the knowledge of mechanical properties of the grain are essential for modeling of dynamic abrasion in rice molding operations as well as for designing of appropriate polishing systems, [5]. Mechanical property of food is described as the discipline which investigates the agricultural product force-deformation and flow. Information from analysis of mechanical properties is needed in agricultural material evaluation quality, computation of engineering data, and process design.

The knowledge on force-deformation characteristics and behavior are very necessary to decide or establish actual parameters needed for process design, estimating other properties, characterizing foods, and quality determination and energy needed during processing of food.

Models obtained from the mechanical property parameters calculations from the measured experiments could be highly effective in the design of food process when applied concurrently through energy, force, and load proportions. There are several researches conducted on mechanical properties involved with rice and other agricultural products such as [6, 7, 8, 9, and 10], and others. Therefore, this study is aimed at determining the effect of moisture content and loading patterns on the mechanical properties of NERICA varieties relevant to their processing and handling.

MATERIALS AND METHOD

Source of Material and Sample Preparation

The research materials used in this study include five varieties of NERICA, and they are; FAROs 44, 52, 57, 60, and 61. These varieties of NERICA were collected from the Ebonyi State Agricultural Development Programme (EBADEP), Abakaliki, at storage moisture content of 12.5% (db). Some of the paddy from each variety were parboiled and dehulled using a rice dehulling machine to obtain parboiled-milled samples of the NERICA varieties thereby having ten samples of NERICA; viz: FAROs 44, 52, 57, 60, and 61 Raw-Paddy and FAROs 44, 52, 57, 60, and 61 Parboiled-Milled. The methods used in the parboiling and dehulling were in line with the rice parboiling and dehulling standard, and these processes are cleaning, soaking, steaming, drying and milling, [11]. The sample varieties were further hydrated to acquire more three different moisture content levels at which the tests were carried out. A total of 1000 grains were used for the experiments.

Methods

Determination of weight of the grains

The measurement of the weight of the sample grains were carried out using the Mettler Toledo analytical weighing machine of model XP 204 and 0.0001 g sensitivity. Measurements were replicated 20 times. Also, a thousand-grain weight of the sample seeds were carried out by picking 100 seed samples and weighing them using the analytical weighing machine, then multiplying them by 10 in order to get the 1000 grain mass of the sample materials. This was done using reported method by [12].

Determination of Moisture Content

The oven was used to dry the hydrated samples and the moisture content analytical machine was used in measuring the moisture content of the sample materials at room temperature, and these were further evaluated by using equation 1 as reported by [3].

$$\boldsymbol{Mc} = \frac{\boldsymbol{Ww - Dw}}{\boldsymbol{Dw}}\ \boldsymbol{x}\ \mathbf{100}\% \qquad 1$$

where; $\boldsymbol{Mc}$ = moisture content, %; $\boldsymbol{Ww}$ = wet samples; and $\boldsymbol{Dw}$ = dried samples.

Determination of the Mechanical Properties:

Force - deformation measurements of NERICA varieties were conducted at varying moisture contents using an Instron Universal Testing Machine (UTM) of model 3340 series single column, USA, controlled by a fully packed Dell computer with window 8 version and were installed with the latest Instron Blue Hill 3 Software. Three loading orientations namely; major, minor and intermediate diameters were used during the tests.

The NERICA samples were deformed at the crosshead speed of 10 mm per min. As deformation of the NERICA samples progresses and advances, a load - deformation curve was automatically plotted in relation towards the response of the NERICA sample to compressions. Randomly picked NERICA samples were tested at each sample's moisture content and loading pattern and the process was repeated three times and the obtained results were analyzed for; Maximum load (rupture point) (N); Compressive extension at maximum load (deformation) (mm); Load at bioyield point (N); Energy at maximum load (J); Maximum slope or (Automatic Young's modulus of deformability) (mm/mm). Toughness, which is the capability of an agricultural material to take up energy and plastically deform without rupturing, was computed using the equation 2 as reported by [13];

$$\boldsymbol{Toughness} = \frac{\boldsymbol{Rupture\ Energy}}{\boldsymbol{Volume\ of\ Material}}\ (\boldsymbol{N/mm^2}) \qquad 2$$

Stiffness modulus was also calculated from the equation 3 according to [7];

$$\boldsymbol{Stiffness\ modulus} = \frac{\boldsymbol{Max\ breaking\ force}}{\boldsymbol{Max\ deformation\ at\ breaking}}\ \left(\frac{\boldsymbol{N}}{\boldsymbol{mm}}\right) \qquad 3$$

RESULTS AND DISCUSSION

The results of the mechanical properties of the five varieties of NERICA (FAROs 44, 52, 57, 60, and 61) are presented in Tables 1 to 6. The moisture contents of 12.5%, 17% and 21.5% (db) were obtained and used to determine the mechanical properties under major diameter, minor diameter and intermediate diameter loading positions.

Table 1. Mechanical Properties of NERICA varieties (Raw-Paddy) at 12.5% (d.b) under different loading positions

Mechanical Properties	*NERICA Variety*	*Loading Positions*		
		Major Diameter	*Minor Diameter*	*Intermediate Diameter*
Maximum Load at Rupture [N]	*FARO 44*	*233.44 (1.03)*	*9.06 (0.09)*	*80.84 (1.56)*
	FARO 52	*336.90 (0.42)*	*10.36 (1.13)*	*115.75 (0.97)*
	FARO 57	*270.87 (2.09)*	*18.46 (0.07)*	*96.44 (2.03)*
	FARO 60	*363.73 (1.87)*	*12.31 (1.06)*	*125.35 (0.11)*
	FARO 61	*279.17 (0.67)*	*18.01 (0.43)*	*99.06 (0.57)*
	AVERAGE	*296.82 (1.22)*	*13.64 (0.56)*	*103.49 (1.05)*
Compressive Extension at Maximum Load [mm	*FARO 44*	*1.60 (0.23)*	*1.88 (0.98)*	*1.71 (0.09)*
	FARO 52	*1.53 (0.18)*	*1.51 (1.06)*	*1.48 (0.23)*
	FARO 57	*1.76 (1.53)*	*2.02 (1.83)*	*1.82 (1.07)*
	FARO 60	*1.40 (2.09)*	*1.24 (0.45)*	*1.29 (0.44)*
	FARO 61	*0.50 (0.18)*	*0.92 (1.09)*	*0.68 (0.99)*
	AVERAGE	*1.36 (0.84)*	*1.52 (1.08)*	*1.41 (0.56)*

Load at Bio yield Point [N]	*FARO 44*	*200.25 (0.65)*	*6.50 (0.87)*	*67.88 (1.66)*
	FARO 52	*250.19 (1.08)*	*7.92 (1.06)*	*91.45 (2.02)*
	FARO 57	*179.89 (2.02)*	*8.98 (0.98)*	*63.89 (0.56)*
	FARO 60	*321.56 (0.34)*	*7.87 (1.23)*	*88.76 (0.88)*
	FARO 61	*220.76 (0.08)*	*6.78 (0.89)*	*63.45 (1.44)*
	AVERAGE	*234.53 (0.83)*	*7.61 (1.01)*	*75.09 (1.31)*
Toughness (N/mm^2)	*FARO 44*	*11.58 (0.98)*	*9.01 (2.09)*	*10.12 (1.11)*
	FARO 52	*10.96 (0.56)*	*8.98 (1.07)*	*9.45 (0.97)*
	FARO 57	*8.89 (1.34)*	*6.06 (0.56)*	*7.32 (1.06)*
	FARO 60	*9.98 (0.94)*	*6.72 (0.74)*	*7.98 (0.99)*
	FARO 61	*8.67 (2.07)*	*7.08 (0.31)*	*7.23 (0.78)*
	AVERAGE	*10.02 (1.18)*	*7.57 (0.95)*	*8.42 (0.98)*
Stiffness (N/mm)	*FARO 44*	*36.89 (1.05)*	*34.70 (1.32)*	*35.12 (0.77)*
	FARO 52	*39.56 (0.97)*	*45.78 (2.09)*	*43.42 (2.07)*
	FARO 57	*48.98 (1.04)*	*46.98 (0.93)*	*47.27 (0.54)*
	FARO 60	*38.76 (2.05)*	*32.76 (1.04)*	*36.34 (1.97)*
	FARO 61	*43.72 (0.57)*	*40.07 (0.39)*	*42.97 (0.45)*
	AVERAGE	*41.58 (1.14)*	*40.06 (1.15)*	*41.02 (1.16)*
Compressive Strength (N/mm^2)	*FARO 44*	*6.91 (0.54)*	*5.21 (0.56)*	*6.01 (0.62)*
	FARO 52	*5.78 (0.88)*	*5.04 (1.67)*	*5.29 (2.03)*
	FARO 57	*5.21 (0.78)*	*4.32 (0.96)*	*4.61 (1.00)*
	FARO 60	*6.22 (0.65)*	*4.89 (2.03)*	*5.34 (0.31)*
	FARO 61	*5.38 (0.42)*	*5.09 (0.57)*	*5.11 (0.46)*
	AVERAGE	*5.90 (0.65)*	*4.91 (1.16)*	*5.27 (0.88)*
Energy at Maximum Load [J]	*FARO 44*	*0.06 (0.02)*	*0.05 (0.01)*	*0.05 (0.02)*
	FARO 52	*0.11 (0.08)*	*0.03 (0.10)*	*0.09 (0.10)*
	FARO 57	*0.05 (0.04)*	*0.04 (0.09)*	*0.05 (0.01)*
	FARO 60	*0.14 (0.10)*	*0.02 (0.01)*	*0.07 (0.02)*
	FARO 61	*0.08 (0.03)*	*0.04 (0.02)*	*0.06 (0.03)*
	AVERAGE	*0.08 (0.05)*	*0.04 (0.03)*	*0.06 (0.04)*
Maximum Slope (Automatic Young's) [mm/mm]	*FARO 44*	*1.51 (0.53)*	*1.32 (0.10)*	*1.46 (0.78)*
	FARO 52	*1.42 (1.09)*	*1.56 (0.72)*	*1.48 (1.11)*
	FARO 57	*1.67 (1.01)*	*1.43 (0.34)*	*1.57 (0.87)*
	FARO 60	*1.54 (0.65)*	*1.23 (0.32)*	*1.41 (1.05)*
	FARO 61	*1.34 (0.09)*	*1.45 (0.09)*	*1.38 (0.56)*
	AVERAGE	*1.50 (0.67)*	*1.34 (0.31)*	*1.46 (0.87)*

N.B: Data in parenthesis represents the standard deviation.

Table 2. Mechanical Properties of NERICA varieties (Raw-Paddy) at 17% (d.b) under different loading positions.

Mechanical Properties	*NERICA Variety*	*Loading Positions*		
		Major Diameter	*Minor Diameter*	*Intermediate Diameter*
Maximum Load at Rupture [N]	*FARO 44*	*212.45 (2.13)*	*8.47 (0.78)*	*87.64 (1.67)*
	FARO 52	*214.15 (1.88)*	*5.72 (0.55)*	*73.29 (2.08)*
	FARO 57	*215.66 (1.76)*	*15.51 (1.02)*	*79.07 (0.99)*
	FARO 60	*240.48 (2.09)*	*11.72 (0.89)*	*84.78 (1.21)*
	FARO 61	*260.83 (1.86)*	*11.50 (0.67)*	*96.78 (0.77)*
	AVERAGE	*228.71 (1.94)*	*10.58 (0.78)*	*84.31 (1.34)*
Compressive Extension at Maximum Load [mm	*FARO 44*	*1.86 (0.98)*	*1.19 (0.99)*	*1.63 (0.64)*
	FARO 52	*1.58 (0.66)*	*1.69 (0.89)*	*1.74 (0.32)*
	FARO 57	*1.96 (0.95)*	*2.19 (0.11)*	*1.99 (0.31)*
	FARO 60	*1.60 (0.56)*	*1.61 (0.34)*	*1.62 (0.64)*
	FARO 61	*1.11 (0.08)*	*1.49 (0.57)*	*1.38 (0.44)*
	AVERAGE	*1.62 (0.65)*	*1.64 (0.58)*	*1.67 (0.47)*
Load at Bioyield Point [N]	*FARO 44*	*180.78 (1.87)*	*7.96 (0.57)*	*55.34 (0.89)*
	FARO 52	*177.45 (1.07)*	*4.67 (0.45)*	*46.76 (1.08)*
	FARO 57	*181.93 (1.11)*	*11.17 (1.02)*	*51.39 (0.64)*
	FARO 60	*110.42 (0.87)*	*8.12 (0.88)*	*66.17 (2.08)*
	FARO 61	*215.54 (0.99)*	*7.89 (0.94)*	*73.35 (1.99)*
	AVERAGE	*173.22 (1.18)*	*7.96 (0.77)*	*58.61 (1.34)*
Toughness (N/mm^2)	*FARO 44*	*10.89 (0.75)*	*8.34 (0.09)*	*9.27 (0.67)*
	FARO 52	*9.01 (0.08)*	*6.78 (0.53)*	*8.01 (0.99)*

	FARO 57	8.06 (0.23)	7.29 (0.88)	7.67 (0.46)
	FARO 60	8.32 (0.89)	4.32 (0.42)	5.89 (0.57)
	FARO 61	7.67 (0.98)	6.96 (0.31)	7.98 (0.61)
	AVERAGE	8.79 (0.59)	6.74 (0.22)	7.76 (0.66)
Stiffness (N/mm)	FARO 44	39.32 (1.36)	36.73 (1.77)	37.93 (0.09)
	FARO 52	46.98 (0.69)	46.47 (0.51)	46.89 (1.01)
	FARO 57	54.56 (0.89)	48.87 (2.01)	50.43 (1.77)
	FARO 60	41.32 (0.34)	34.56 (1.04)	39.35 (0.76)
	FARO 61	45.21 (0.21)	41.97 (0.44)	43.78 (0.78)
	AVERAGE	45.48 (0.71)	41.72 (1.15)	43.68 (0.88)
Compressive Strength (N/mm^2)	FARO 44	6.27 (0.66)	5.02 (0.11)	5.98 (0.89)
	FARO 52	5.02 (0.41)	4.56 (0.17)	4.89 (0.65)
	FARO 57	4.88 (0.99)	3.99 (0.88)	4.01 (1.01)
	FARO 60	5.89 (0.57)	4.11 (0.43)	5.12 (0.88)
	FARO 61	4.47 (0.19)	4.95 (0.83)	4.78 (0.53)
	AVERAGE	5.31 (0.56)	4.53 (0.48)	4.96 (0.79)
Energy at Maximum Load [J]	FARO 44	0.05 (0.02)	0.03 (0.01)	0.04 (0.01)
	FARO 52	0.06 (0.02)	0.04 (0.01)	0.05 (0.02)
	FARO 57	0.13 (0.09)	0.02 (0.01)	0.11 (0.02)
	FARO 60	0.06 (0.03)	0.03 (0.02)	0.05 (0.01)
	FARO 61	0.08 (0.02)	0.02 (0.01)	0.06 (0.03)
	AVERAGE	0.08 (0.04)	0.03 (0.01)	0.06 (0.02)
Maximum Slope (Automatic Young's) [mm/mm]	FARO 44	1.56 (0.87)	1.56 (0.09)	1.56 (0.14)
	FARO 52	1.67 (0.11)	1.97 (0.33)	1.59 (0.18)
	FARO 57	1.98 (0.99)	1.46 (0.13)	1.93 (1.01)
	FARO 60	1.34 (0.46)	1.94 (0.77)	1.41 (0.77)
	FARO 61	1.72 (0.44)	1.48 (0.97)	1.86 (0.93)
	AVERAGE	8.27 (0.57)	1.68 (0.46)	1.67 (0.60)

N.B: Data in parenthesis represents the standard deviation.

Table 3. Mechanical Properties of NERICA varieties (Raw-Paddy) at 21.5% (d.b) under different loading positions.

Mechanical Properties	NERICA Variety	Loading Positions		
		Major Diameter	Minor Diameter	Intermediate Diameter
Maximum Load at Rupture [N]	FARO 44	97.90 (1.05)	6.12 (1.02)	54.67 (0.99)
	FARO 52	128.25 (2.19)	5.44 (0.98)	76.56 (2.01)
	FARO 57	72.24 (1.21)	7.86 (1.22)	51.05 (0.98)
	FARO 60	168.14 (2.08)	10.92 (0.45)	97.23 (1.89)
	FARO 61	50.92 (0.99)	5.92 (0.09)	30.34 (0.93)
	AVERAGE	103.49 (1.51)	7.25 (0.75)	61.97 (1.36)
Compressive Extension at Maximum Load [mm	FARO 44	1.95 (0.67)	1.57 (0.12)	1.78 (0.11)
	FARO 52	2.79 (0.34)	1.72 (0.87)	2.01 (1.01)
	FARO 57	1.98 (0.98)	2.52 (0.11)	1.91 (0.06)
	FARO 60	1.63 (0.09)	1.95 (0.91)	1.79 (0.78)
	FARO 61	1.95 (0.08)	1.36 (0.57)	1.56 (0.65)
	AVERAGE	2.06 (0.43)	1.83 (0.52)	1.81 (0.52)
Load at Bioyield Point [N]	FARO 44	77.43 (0.34)	5.42 (1.01)	23.45 (1.09)
	FARO 52	69.78 (1.09)	4.01 (0.67)	45.89 (0.88)
	FARO 57	53.23 (0.89)	5.81 (0.88)	33.78 (0.76)
	FARO 60	115.3 (2.04)	7.12 (0.98)	56.76 (1.11)
	FARO 61	23.13 (0.55)	4.73 (0.31)	21.67 (0.79)
	AVERAGE	67.77 (0.98)	5.42 (0.77)	36.31 (0.93)
Toughness (N/mm^2)	FARO 44	9.20 (0.31)	7.45 (0.67)	8.98 (1.01)
	FARO 52	8.32 (0.12)	6.21 (1.22)	7.82 (0.94)
	FARO 57	7.68 (0.33)	6.11 (0.34)	7.01 (0.89)
	FARO 60	7.04 (0.11)	4.08 (0.21)	5.87 (1.01)
	FARO 61	6.78 (0.13)	5.96 (0.76)	6.23 (0.49)
	AVERAGE	7.81 (0.21)	5.96 (0.64)	7.18 (0.87)
Stiffness (N/mm)	FARO 44	41.21 (1.91)	27.81 (1.33)	32.56 (0.46)
	FARO 52	47.82 (0.67)	47.87 (0.46)	45.76 (1.22)
	FARO 57	57.32 (1.91)	50.76 (1.01)	52.45 (1.97)
	FARO 60	43.21 (0.43)	37.39 (0.93)	39.56 (0.42)
	FARO 61	47.22 (0.59)	43.56 (0.48)	45.62 (0.49)

	AVERAGE	*47.36 (1.10)*	*41.48 (0.84)*	*43.19 (0.91)*
Compressive Strength (N/mm^2)	*FARO 44*	*5.98 (0.14)*	*4.23 (0.09)*	*4.98 (0.11)*
	FARO 52	*4.89 (0.46)*	*4.19 (0.14)*	*4.52 (1.02)*
	FARO 57	*4.06 (0.89)*	*3.22 (0.34)*	*3.78 (0.89)*
	FARO 60	*5.01 (0.56)*	*3.89 (0.13)*	*4.67 (0.67)*
	FARO 61	*4.13 (1.01)*	*4.07 (0.98)*	*4.11 (0.99)*
	AVERAGE	*4.82 (0.62)*	*3.92 (0.34)*	*4.41 (0.74)*
Energy at Maximum Load [J]	*FARO 44*	*0.11 (0.04)*	*0.04 (0.01)*	*0.09 (0.02)*
	FARO 52	*0.11 (0.04)*	*0.03 (0.01)*	*0.06 (0.03)*
	FARO 57	*0.04 (0.01)*	*0.06 (0.02)*	*0.05 (0.02)*
	FARO 60	*0.08 (0.04)*	*0.03 (0.01)*	*0.04 (0.01)*
	FARO 61	*0.09 (0.03)*	*0.02 (0.01)*	*0.06 (0.03)*
	AVERAGE	*0.09 (0.03)*	*0.04 (0.01)*	*0.06 (0.02)*
Maximum Slope (Automatic Young's) [mm/mm]	*FARO 44*	*1.67 (0.66)*	*1.52 (0.34)*	*1.61 (0.94)*
	FARO 52	*1.34 (0.19)*	*1.61 (0.08)*	*1.49 (0.99)*
	FARO 57	*1.36 (0.20)*	*1.12 (0.04)*	*1.26 (0.78)*
	FARO 60	*1.28 (0.99)*	*1.35 (0.11)*	*1.31 (1.02)*
	FARO 61	*1.57 (0.67)*	*1.71 (0.65)*	*1.62 (0.99)*
	AVERAGE	*1.44 (0.54)*	*1.46 (0.24)*	*1.46 (0.94)*

N.B: Data in parenthesis represents the standard deviation.

Table 4. Mechanical Properties of NERICA varieties (Parboiled-Milled) at 12.5% (d.b) under different loading positions.

Mechanical Properties	*NERICA Variety*	*Loading Positions*		
		Major Diameter	*Minor Diameter*	*Intermediate Diameter*
Maximum Load at Rupture [N]	*FARO 44*	*103.61 (2.05)*	*87.72 (1.09)*	*92.76 (1.23)*
	FARO 52	*110.10 (1.91)*	*64.28 (1.22)*	*102.19 (2.09)*
	FARO 57	*122.87 (0.76)*	*94.90 (0.99)*	*112.89 (2.11)*
	FARO 60	*156.08 (2.76)*	*51.85 (1.19)*	*133.96 (1.67)*
	FARO 61	*102.90 (1.95)*	*84.62 (1.96)*	*95.76 (0.89)*
	AVERAGE	*119.11 (1.89)*	*76.67 (1.29)*	*107.51 (1.61)*
Compressive Extension at Maximum Load [mm	*FARO 44*	*0.66 (0.12)*	*1.78 (0.89)*	*0.76 (0.17)*
	FARO 52	*1.61 (1.33)*	*1.77 (1.07)*	*1.72 (0.56)*
	FARO 57	*1.08 (0.54)*	*1.49 (0.41)*	*1.25 (0.43)*
	FARO 60	*1.17 (0.98)*	*0.53 (0.23)*	*0.98 (0.08)*
	FARO 61	*0.89 (0.34)*	*2.06 (0.34)*	*1.76 (0.56)*
	AVERAGE	*1.08 (0.66)*	*1.53 (0.59)*	*1.29 (0.36)*
Load at Bioyield Point [N]	*FARO 44*	*63.76 (0.99)*	*61.01 (1.09)*	*45.56 (2.91)*
	FARO 52	*85.23 (0.31)*	*45.22 (0.89)*	*67.89 (0.99)*
	FARO 57	*83.56 (0.96)*	*81.41 (2.11)*	*82.67 (1.22)*
	FARO 60	*101.34 (1.97)*	*35.12 (0.88)*	*83.18 (1.78)*
	FARO 61	*68.37 (1.01)*	*59.21 (0.32)*	*67.78 (0.49)*
	AVERAGE	*80.45 (1.05)*	*56.39 (1.06)*	*69.42 (1.48)*
Toughness (N/mm^2)	*FARO 44*	*10.23 (0.23)*	*8.88 (0.87)*	*9.78 (0.46)*
	FARO 52	*10.04 (0.56)*	*8.07 (1.01)*	*9.09 (1.01)*
	FARO 57	*7.98 (0.75)*	*5.98 (0.87)*	*6.98 (0.89)*
	FARO 60	*8.42 (0.99)*	*6.21 (1.01)*	*7.23 (1.03)*
	FARO 61	*8.06 (1.01)*	*6.77 (0.99)*	*7.11 (0.87)*
	AVERAGE	*8.946 (0.71)*	*7.18 (0.95)*	*8.04 (0.85)*
Stiffness (N/mm)	*FARO 44*	*34.99 (1.52)*	*31.88 (0.78)*	*32.67 (1.34)*
	FARO 52	*37.81 (0.97)*	*43.11 (0.87)*	*41.46 (0.84)*
	FARO 57	*45.87 (0.47)*	*44.75 (1.45)*	*44.21 (1.78)*
	FARO 60	*37.01 (1.01)*	*32.04 (0.67)*	*34.12 (2.02)*
	FARO 61	*40.22 (0.91)*	*38.22 (0.33)*	*39.01 (0.69)*
	AVERAGE	*39.18 (0.98)*	*38.01 (0.82)*	*38.29 (1.33)*
Compressive Strength (N/mm^2)	*FARO 44*	*6.44 (1.01)*	*5.13 (0.34)*	*5.98 (0.09)*
	FARO 52	*4.99 (0.97)*	*4.98 (0.11)*	*4.67 (0.57)*
	FARO 57	*5.11 (0.67)*	*4.49 (0.34)*	*5.56 (0.18)*
	FARO 60	*5.73 (0.89)*	*4.16 (0.88)*	*5.15 (1.71)*
	FARO 61	*4.97 (1.03)*	*4.44 (1.06)*	*4.19 (0.65)*
	AVERAGE	*5.45 (0.92)*	*4.64 (0.55)*	*5.11 (0.64)*

Energy at Maximum Load [J]	*FARO 44*	*0.09 (0.02)*	*0.08 (0.02)*	*0.08 (0.03)*
	FARO 52	*0.08 (0.03)*	*0.03 (0.03)*	*0.07 (0.04)*
	FARO 57	*0.11 (0.02)*	*0.04 (0.01)*	*0.10 (0.06)*
	FARO 60	*0.04 (0.01)*	*0.02 (0.01)*	*0.03 (0.01)*
	FARO 61	*0.06 (0.03)*	*0.08 (0.04)*	*0.07 (0.04)*
	AVERAGE	*0.08 (0.02)*	*0.05 (0.02)*	*0.07 (0.04)*
Maximum Slope (Automatic Young's) [mm/mm]	*FARO 44*	*1.46 (0.99)*	*1.43 (0.43)*	*1.37 (0.45)*
	FARO 52	*1.53 (0.21)*	*1.25 (0.91)*	*1.49 (0.87)*
	FARO 57	*1.23 (0.67)*	*1.43 (0.67)*	*1.32 (0.57)*
	FARO 60	*1.53 (0.09)*	*1.36 (0.45)*	*1.51 (0.89)*
	FARO 61	*1.75 (0.69)*	*1.31 (0.56)*	*1.69 (0.49)*
	AVERAGE	*1.50 (0.53)*	*1.36 (0.61)*	*1.48 (0.65)*

N.B: Data in parenthesis represents the standard deviation.

Table 5. Mechanical Properties of NERICA varieties (Parboiled-Milled) at 17% (d.b) under different loading positions.

Mechanical Properties	*NERICA Variety*	*Loading Positions*		
		Major Diameter	*Minor Diameter*	*Intermediate Diameter*
Maximum Load at Rupture [N]	*FARO 44*	*105.49 (2.31)*	*84.90 (1.94)*	*89.19 (0.56)*
	FARO 52	*111.10 (2.45)*	*28.41 (0.54)*	*93.76 (1.45)*
	FARO 57	*74.94 (1.88)*	*26.92 (1.02)*	*80.93 (2.71)*
	FARO 60	*128.87 (2.09)*	*71.78 (1.11)*	*110.33 (2.33)*
	FARO 61	*110.99 (1.88)*	*71.14 (0.66)*	*94.07 (0.94)*
	AVERAGE	*106.28 (2.12)*	*56.63 (1.05)*	*93.66 (1.61)*
Compressive Extension at Maximum Load [mm	*FARO 44*	*3.21 (0.78)*	*1.60 (0.98)*	*2.45 (0.67)*
	FARO 52	*0.86 (0.49)*	*0.46 (0.12)*	*0.67 (0.22)*
	FARO 57	*0.97 (0.98)*	*0.90 (0.65)*	*0.91 (0.43)*
	FARO 60	*1.46 (1.07)*	*1.64 (0.34)*	*1.52 (0.41)*
	FARO 61	*1.44 (0.66)*	*2.67 (1.01)*	*1.98 (0.85)*
	AVERAGE	*1.91 (0.96)*	*1.45 (0.62)*	*1.51 (2.58)*
Load at Bioyield Point [N]	*FARO 44*	*81.56 (0.95)*	*52.67 (2.05)*	*51.89 (1.55)*
	FARO 52	*65.17 (1.06)*	*6.78 (0.78)*	*67.75 (2.83)*
	FARO 57	*46.12 (0.76)*	*10.21 (0.55)*	*48.65 (1.08)*
	FARO 60	*61.79 (0.11)*	*51.34 (1.08)*	*64.76 (0.89)*
	FARO 61	*65.76 (1.15)*	*48.46 (0.89)*	*62.56 (0.67)*
	AVERAGE	*64.08 (0.81)*	*33.89 (1.07)*	*59.12 (1.40)*
Toughness (N/mm^2)	*FARO 44*	*10.46 (1.07)*	*8.12 (0.54)*	*9.23 (0.98)*
	FARO 52	*8.89 (0.08)*	*6.32 (0.11)*	*7.98 (1.09)*
	FARO 57	*7.77 (0.45)*	*7.12 (0.32)*	*7.56 (0.78)*
	FARO 60	*6.75 (0.34)*	*4.01 (0.08)*	*5.21 (0.71)*
	FARO 61	*7.32 (0.71)*	*6.11 (0.12)*	*6.89 (0.67)*
	AVERAGE	*8.24 (0.53)*	*20.94 (0.23)*	*7.38 (0.85)*
Stiffness (N/mm)	*FARO 44*	*36.49 (1.12)*	*32.12 (0.99)*	*35.17 (2.01)*
	FARO 52	*44.57 (1.21)*	*44.16 (1.76)*	*44.23 (1.90)*
	FARO 57	*51.39 (0.31)*	*47.81 (1.87)*	*48.91 (1.46)*
	FARO 60	*38.73 (1.01)*	*31.18 (0.91)*	*36.43 (0.99)*
	FARO 61	*44.15 (0.07)*	*38.79 (0.69)*	*41.12 (0.78)*
	AVERAGE	*43.07 (0.74)*	*38.82 (1.24)*	*41.17 (1.43)*
Compressive Strength (N/mm^2)	*FARO 44*	*6.32 (0.08)*	*4.76 (0.98)*	*5.09 (0.33)*
	FARO 52	*4.99 (0.42)*	*4.03 (1.01)*	*4.52 (0.78)*
	FARO 57	*4.15 (0.11)*	*3.23 (0.88)*	*4.09 (1.09)*
	FARO 60	*5.33 (0.43)*	*3.72 (0.98)*	*4.98 (0.98)*
	FARO 61	*4.12 (0.91)*	*4.34 (0.31)*	*4.23 (0.66)*
	AVERAGE	*4.98 (0.39)*	*4.12 (0.83)*	*4.58 (0.77)*
Energy at Maximum Load [J]	*FARO 44*	*0.20 (0.04)*	*0.02 (0.01)*	*0.18 (0.07)*
	FARO 52	*0.11 (0.13)*	*0.04 (0.02)*	*0.08 (0.05)*
	FARO 57	*0.09 (0.07)*	*0.04 (0.02)*	*0.04 (0.02)*
	FARO 60	*0.07 (0.02)*	*0.05 (0.03)*	*0.06 (0.01)*
	FARO 61	*0.08 (0.04)*	*0.08 (0.06)*	*0.05 (0.04)*
	AVERAGE	*0.11 (0.13)*	*0.05 (0.14)*	*0.08 (0.04)*

Maximum Slope (Automatic Young's) [mm/mm]	FARO 44	1.65 (0.23)	1.54 (0.03)	1.55 (0.19)
	FARO 52	1.45 (0.11)	1.57 (0.88)	1.48 (0.98)
	FARO 57	1.72 (0.07)	1.45 (0.93)	1.61 (0.87)
	FARO 60	1.58 (0.06)	1.52 (0.95)	1.53 (0.34)
	FARO 61	1.34 (0.04)	1.47 (0.87)	1.29 (0.56)
	AVERAGE	1.55 (0.10)	1.51 (0.73)	1.49 (0.59)

N.B: Data in parenthesis represents the standard deviation.

Table 6: Mechanical Properties of NERICA varieties (Parboiled-Milled) at 21.5% (d.b) under different loading positions.

Mechanical Properties	NERICA Variety	Loading Positions		
		Major Diameter	Minor Diameter	Intermediate Diameter
Maximum Load at Rupture [N]	FARO 44	44.94 (2.09)	38.88 (2.08)	40.78 (2.07)
	FARO 52	77.33 (2.11)	24.63 (1.97)	57.67 (2.77)
	FARO 57	78.16 (1.88)	22.05 (1.77)	61.13 (1.09)
	FARO 60	67.61 (0.87)	23.93 (2.04)	47.38 (1.67)
	FARO 61	49.74 (0.67)	34.29 (1.77)	38.89 (0.87)
	AVERAGE	63.56 (1.52)	28.76 (1.93)	49.17 (1.69)
Compressive Extension at Maximum Load [mm	FARO 44	0.71 (0.18)	0.65 (0.08)	0.68 (0.07)
	FARO 52	0.87 (0.05)	0.50 (0.02)	0.57 (0.12)
	FARO 57	0.95 (0.56)	1.31 (0.43)	1.22 (0.67)
	FARO 60	0.59 (0.12)	1.38 (0.54)	1.27 (0.68)
	FARO 61	1.49 (0.07)	1.45 (0.32)	1.47 (0.56)
	AVERAGE	0.92 (0.21)	1.06 (0.28)	1.04 (0.62)
Load at Bioyield Point [N]	FARO 44	18.38 (1.89)	10.98 (1.03)	17.86 (0.44)
	FARO 52	26.01 (1.01)	14.51 (1.08)	23.21 (1.22)
	FARO 57	31.21 (2.06)	13.34 (0.65)	25.68 (1.04)
	FARO 60	25.27 (0.87)	10.21 (0.67)	18.56 (0.67)
	FARO 61	17.67 (0.99)	17.91 (0.43)	16.43 (0.66)
	AVERAGE	23.71 (1.36)	13.39 (0.77)	20.35 (0.81)
Toughness (N/mm^2)	FARO 44	8.98 (0.99)	7.11 (0.11)	8.21 (0.88)
	FARO 52	7.18 (1.98)	5.99 (0.87)	6.37 (0.19)
	FARO 57	7.32 (0.89)	5.87 (0.56)	6.89 (0.98)
	FARO 60	6.19 (1.12)	3.97 (0.33)	4.74 (0.56)
	FARO 61	6.55 (1.87)	5.24 (0.67)	6.01 (0.17)
	AVERAGE	7.24 (1.37)	5.64 (2.54)	6.44 (0.56)
Stiffness (N/mm)	FARO 44	39.03 (2.03)	25.17 (2.05)	28.32 (1.01)
	FARO 52	45.11 (2.92)	45.22 (1.07)	45.15 (2.07)
	FARO 57	57.21 (2.33)	48.16 (2.09)	52.15 (2.87)
	FARO 60	40.14 (1.44)	35.22 (1.99)	38.76 (0.87)
	FARO 61	42.44 (0.99)	41.24 (0.49)	42.08 (0.97)
	AVERAGE	44.79 (1.94)	39.00 (1.54)	41.29 (1.56)
Compressive Strength (N/mm^2)	FARO 44	5.32 (0.98)	4.04 (0.92)	5.12 (0.06)
	FARO 52	4.11 (0.43)	3.22 (1.01)	4.09 (0.77)
	FARO 57	3.98 (0.87)	2.98 (0.88)	3.41 (0.42)
	FARO 60	4.34 (0.43)	3.45 (0.97)	3.98 (0.44)
	FARO 61	3.78 (0.09)	3.99 (0.67)	3.62 (0.76)
	AVERAGE	4.31 (0.56)	3.54 (0.98)	4.04 (0.49)
Energy at Maximum Load [J]	FARO 44	0.09 (0.02)	0.08 (0.02)	0.08 (0.02)
	FARO 52	0.11 (0.05)	0.04 (0.01)	0.10 (0.03)
	FARO 57	0.09 (0.04)	0.05 (0.02)	0.06 (0.01)
	FARO 60	0.08 (0.67)	0.03 (0.01)	0.07 (0.02)
	FARO 61	0.08 (0.03)	0.02 (0.01)	0.06 (0.02)
	AVERAGE	0.09 (0.16)	0.04 (0.01)	0.07 (1.00)
Maximum Slope (Automatic Young's) [mm/mm]	FARO 44	1.46 (0.98)	1.34 (0.34)	1.39 (0.54)
	FARO 52	1.64 (0.86)	1.54 (0.67)	1.45 (0.67)
	FARO 57	1.69 (0.67)	1.52 (0.55)	1.61 (0.09)
	FARO 60	1.23 (0.17)	1.19 (0.07)	1.21 (0.56)
	FARO 61	1.56 (0.53)	1.27 (0.32)	1.44 (0.87)
	AVERAGE	7.58 (0.64)	1.37 (0.39)	1.42 (0.55)

N.B: Data in parenthesis represents the standard deviation.

The values of the mechanical properties of the grain were found to be a function of moisture content (12.5 to 21.5 %) (db). The relationship between the moisture content and the mechanical properties was statistically significant ($p < 0.05$). The maximum load at rupture decreased with an increase in moisture content. The results ranged from 363.73 to 50.92 N, 125.35 to 51.05 N, and 18.46 to 5.44 N, at major, intermediate, and minor diameters loading positions respectively for NERICA Raw-Paddy.

And for NERICA Parboiled-Milled, the maximum load at rupture also ranged from 156.08 to 44.94 N, 133.96 to 38.89 N, and 94.90 to 22.05 N, at major, intermediate, and minor diameters loading positions respectively with an increase in moisture content, Tables 1 to 6. Rupture force is the total or maximum load required for an agricultural material to break or be deformed, [14]. Also, from Tables 1 to 6, compressive extension at maximum load (deformation) ranged from 0.50 to 2.79 mm, 0.68 to 2.01 mm, and 0.92 to 2.52 mm, at major, intermediate, and minor diameters loading positions respectively, with an increase in moisture content (12.5 to 21.5%) for NERICA Raw-Paddy, and 0.59 to 1.61 mm, 0.57 to 2.45 mm, and 0.46 to 2.67 mm, at major, intermediate, and minor diameters loading positions respectively, with an increase in moisture content (12.5 to 21.5 %) (db) for NERICA Parboiled-Milled. Load at bioyield point decreased as moisture content increases. Load at bioyield point is described as that point at which a rise in deformation is marked with a change of force in some agricultural products. Results indicated that load at bioyield point ranged from 321.56 to 23.13 N, 91.45 N to 21.67 N, and 11.17 to 4.01 N, at major, intermediate, and minor diameters loading positions respectively for NERICA Raw-Paddy. And for NERICA Parboiled-Milled, load at bioyield point ranged from 101.34 to 17.67 N, 83.18 to 16.43 N, and 81.41 to 6.78 N, at major, intermediate, and minor diameters loading positions respectively. Toughness also decreased with an increase in moisture content. Toughness is the ability of a material to absorb energy (or withstand shock) and plastically deform without fracturing (or rupturing), [14]. The result ranged from 11.58 to 6.78 N/mm^2, 10.12 to 5.87 N/mm^2, and 9.01 to 4.08 N/mm^2, at major, intermediate and minor diameters loading positions for NERICA Raw-Paddy, and 10.46 to 6.19 N/mm^2, 9.78 to 6.01 N/mm^2, and 8.12 to 4.01 N/mm^2 at major, intermediate, and minor diameters loading positions for NERICA Parboiled-Milled. Stiffness was the ability of NERICA varieties to resist deformation in response to the applied force. Increase in moisture content resulted to an increase in stiffness. The result ranged from 36.89 to 57.32 N/mm, 32.56 to 52.45 N/mm, and 27.81 to 50.76 N/mm at major, intermediate, and minor diameters loading positions respectively for NERICA Raw-Paddy. For NERICA Parboiled-Milled, stiffness ranged from 34.99 to 57.21 N/mm, 28.32 to 52.15 N/mm, and 25.17 to 48.16 N/mm at major, intermediate, and minor diameters loading positions respectively. The compressive strength of NERICA, which is the capacity of the material to withstand loads tending to reduce size, decreased with an increase in moisture content. The result obtained ranged from 6.91 to 4.06 N/mm^2, 6.01 to 3.78 N/mm^2, and 5.21 to 3.22 N/mm^2 at major, intermediate, and minor diameters loading positions respectively for NERICA Raw-Paddy, and from 6.44 to 3.78 N/mm^2, 5.98 to 3.41 N/mm^2, and 5.13 to 2.98 N/mm^2 at major, intermediate, and minor diameters loading positions respectively for NERICA Parboiled-Milled. Energy at maximum load for NERICA varieties decreased as moisture content increased. The result ranged from 0.14 to 002 J.

This is the amount of energy NERICA varieties can absorb at maximum load for both major, minor and intermediate diameters loading positions as moisture content increases from 12.5 to 21.5% (db).

Statistical analysis was carried out to study the effects of moisture content on the mechanical properties of NERICA varieties. Individual regressions, regressing mechanical properties with moisture contents were carried out on each variety. The values of the mechanical properties of the NERICA samples were found to be a function of moisture content.

All the mechanical properties showed similar pattern with increase in moisture content and decrease in load, at both major diameter, minor diameter and intermediate diameter loading positions, except the compressive extension at maximum load and the stiffness that increased with an increase in moisture content. This is as a result of the soft texture of the seeds at high moisture content levels. Similar relationships between moisture content and some mechanical properties, though, under horizontal and vertical loading orientations were reported by [7], for some NERICA varieties; [15], for locust bean; [10], for bush mango; [9], for mucuna flagellipes nut; [16], for brown rice; and [17] for Soybean grains.

CONCLUSION

The study proved the significance of the effect of moisture content of the mechanical properties of NERICA, and established the negligibility of variety factors and effects in the engineering processing of NERICA. There were significant effects of moisture content ($p < 0.05$) on all parameters studied. Results of the mechanical properties of NERICA generated will be highly needed in the design of dehullers, threshers and mills, and destoning machines for NERICA, especially in the determination of the power requirement of the equipment, and also, for the design of silos for storing of NERICA. These results obtained will serve as useful guides to farmers and processors of agro-products for proper harvesting and processing operations, such as size reduction or milling of the crop, and also assist in the design of wide range of handling and processing equipment of NERICA, such as transport facilities, storage facilities, cleaning, grading, and sizing equipment.

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UTICAJ SADRŽAJA VLAGE I POZICIJE ZA UTOVAR NA MEHANIČKE OSOBINE NOVE SORTE (NERICA) PIRINČA ZA AFRIKU

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Sažetak: Mehaničke osobine nove sorte pirinča za Afriku (NERICA) određene su kod različitih sadržaja vlage od 12,5, 17 i 21,5 % (db), i položaja punjenja glavnih, malih i srednjih prečnika otvora test uređaja Instron Universal Testing Machine (UTM). Ispitane mehaničke osobine zrna su: vrednost maksimalnog opterećenja i oštećenja kod pucanja i smicanja; vrednosti ekstenzije (istezanja) i pritiska zrna kao biološkog materijala; najveća energija opterećenja zrna, krutost i najveće klizanje zrna na nagibu. Dobijeni rezultati pokazuju da opterećenje i sadržaj vlage utiču na ispitivana mehanička svojstva determinisana sa ($p < 0{,}05$).

Rezultati ispitivanja su pokazali da je najveće opterećenje od 363,73 N do 50,92 N i oštećenje kod pucanja, kompresija u rasponu 0,50 mm do 2,79 mm; a opterećenje na preseku biološke izdržljivosti od 11,58 do 6,78 N/mm^2; respektivno za opterećenje najvećeg prečnika zrna NERICA Rav-Paddi; od 18.46 do 5.44 N; 0,92 do 2,52 mm; 9.01 do 4.08 N/mm^2 za NERICA Rav-Paddi opterećenje manjeg prečnika zrna.

Za NERICA Parboiled-Milled zrno pirinča rezultati na pozicijama punjenja glavnog prečnika i malog prečnika test uređaja su raspoređeni na sledeći način: maksimalno opterećenje pri pucanju (156,08 do 44,94 N; 94,90 do 22,05 N); kompresija zrna (0,59 do 1,61 mm; 0,46 do 2,67 mm). Regresijska analiza mehaničkih svojstava i sadržaja vlage u zrnu pokazuje pozitivna korelacija između ispitivanih parametara. Bilo je značajnih efekata uticaja sadržaja vlage (pozitivna korelacija $p < 0{,}05$) na sve ispitivane parametre.

Ključne reči: *Sadržaj vlage, mehaničke osobine, vrste/pozicija opterećenja, NERICA.*

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SIMPLE REGRESSION RELATIONSHIPS FOR ASSESSING THE PERFORMANCES OF SELECTED TILLAGE IMPLEMENTS IN SOUTH-EAST, NIGERIA

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***Abstract*:** Research was conducted on the three dominant agricultural soils of south-east Nigeria to develop some empirical regression relationships for predicting the performances of some selected tractor-hitched tillage implements from the experimental results obtained in the field. Results of the experiments revealed that the optimum speed of plough in clay-loam and loamy – sandy soil was 6km/h with corresponding field efficiencies of 88.11% and 87.55% respectively, while in sandy – clay soil, the plough recorded its optimum speed of 7km/h with field efficiency of 87.78%.The optimum speed of harrow in clay-loam soil was 8km/h with field efficiency of 87.98%. In loamy – sandy soil, its optimum speed was 8km/h with field efficiency of 87.19%; while in sandy – clay soil; it recorded optimum speed of 9km/h with field efficiency of 98.54%. The optimum speed of ridger was 9km/h for all the soils with corresponding field efficiencies of 87.96%, 87.95%, and 89.09% respectively, for clay-loam, loamy-sandy and sandy – clay soil.

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The optimum speed of rotovator was also 9km/hr in all the soils with corresponding field efficiencies of 89.81%, 87.11%, and 89.40% in clay-loam, loamy-sandy and sandy –clay soil, respectively.

These field efficiencies experimentally obtained in the field were compared with the efficiencies obtained from the regression equations using percentage error and the accuracy of the predictions were tested using error root mean square.

The comparison of the predicted results with the experimental results revealed that the regression equations broadly did not over or under- predict the experimental results, thus, the prediction errors were within allowable range of ±5%. The coefficient of determination, R^2 for the regression equations developed for predicting the various performance indicators of the tractor – hitched implements vary from 0.7 to 0.9 which show that the variables tested were highly correlated and also an indication that the regression equations were adequate for predicting the performance of the implements.

Key words: *Empirical, equation, performance, regression, tillage implement*.

INTRODUCTION

Performance efficiencies/capabilities of farm machinery can generally be evaluated by the rate at which they carry out their field operations and the quality and quantity of production. [1] state that machine field capacity is the rate at which the machine can cover a given field operation within the limit of time. [2] noted that effective capacity is evaluated by the rate of working of implement measured in hectares per hour, and that the indicators involved are the implement operation width and the working speed with the allowance for time loss, in turning at the end of the field, adjustment and servicing of the machines. The efficiency of machines/implements indicates how good the machine can perform its functions. According to [3], an experienced farmer is usually conscious of the effective and efficient operation of his/her farm machinery because poor operation or improper utilization of the equipment may lead to great operating loss and minimizes production or result to total loss of money/productivity.

Differences exist among various agro ecological areas; and performance data from various tractor - hitched implements are essential document that guides farm machinery users and managers in proper selection of machinery for a given field operation under different soil types/conditions. Selection and utilization of farm machinery are better done with the aid of detailed performance information of such machinery taking into account the variations in agro ecological soil types/conditions. [4] noted that, due to some differences in the agro-ecological soil conditions, performance data of the field capacities of machines under varying soil type/conditions is very essential for machinery selection; the performance data are the essential parameters for assessing the performances of farm machinery. But regrettably this information are not provided to farmers or farm managers in Nigeria by the producers of the machines to guide the farmers in assessing and making proper selection of the machine/implement before buying them. [5] studied the performance efficiencies of chisel and disc plough and the impact they have on some physical properties of soil in Sudan. They came out with the performance data of these implements. However, their study was only on plough tested on only one soil type, other tillage implements and their power requirements were not considered in their study; thereafter, they recommended that more investigations are needed to verify the impact of the ploughs under study on the physical properties of different types of soils in the area.

[6] evaluated the performance of some selected tillage implements in Samaru, Zaria. The study only considered one soil type; and because of variations among soil types in an ecological area, results of such study cannot provide enough information that may guide farmers in selecting machines for their agricultural field operations.

[7] investigated the performance efficiency of tractor – hitched tillage tools in clay soil in Urmia, Iran. This study was also based on only one soil type and because of the same reason, the results may not guide farmers properly in machine selection to be used in other soil types; furthermore, Iran and South-east Nigeria may not have the same soil type with same properties/conditions; there must be differences; in which case, farmers in Nigeria may not use data from such study area to select their farm machinery.

[8] evaluated disc plough performance on sandy- loam soil at different moisture levels in Ilorin. In this study, he used dimensional analysis to develop model expressions relating the cutting depth, disc plough weight and draught force on sandy-loam soil. Despite the detailed study, did not consider the energy requirements of the implement for operation; and the study was conducted on only one soil type with only one tillage implement. These may not be enough to guide machine users in implement selection because of variations in soil type and conditions as emphasized earlier.

Development of empirical model is an essential and simple way of assisting the farmers, farm managers and other users of agricultural machinery both at subsistence and commercial level in assessing and predicting the possible performance capabilities of farm machinery in order to make proper selection of the equipment based on soil type/conditions and season of operation before purchasing and/or engaging any machine to work. This will go a long way to reduce failures, unnecessary break down, mismatching of implement to prime movers, minimize fuel consumption (energy loss), reduce cost and generally maximize production and profit [9]. The objective of this work is to develop empirical regression equations/relationships that will be used to predict the field performances of tractor hitched tillage implement in South-east agro- ecological region of Nigeria.

MATERIALS AND METHOD

Description of the experimental site

The experimental sites have average area of 8100 m^2 (0.81ha) each. The land area was divided into four units of 45 x 45m^2 each for random observations. Each unit was separated by a distance of 2.5m from the other to avoid interaction between the plot borders and to be equally used as head lands for the commencement of the experimental operations.

The tests were conducted in May, through June, July, August, September and October, 2016. These months coincide with planting season of the year; and will also offer the tractor and the hitched implements an exposure to wide range of soil conditions.

Description of Machine used and its operation

A Massey Ferguson tractor with 3- point hitch systems and age of 5months from date of first hand purchase was hired with the hitched implements and used for the study. The same operator was used to operate the machine throughout the test to ensure minimal variation in the operation skill and style throughout the study.

Each field operation (test) starts in the morning (9 am) and lasts for 2,5 h to ensure that the operator did not get weary during the operation and the machines are properly checked for faults before being engaged to work. This is to minimize delays or unnecessary failures and to ensure optimum production time during operation.

Determination of soil physical properties

Some soil physical and mechanical properties such as moisture contents, bulk density, soil structure, texture, porosity, cone index, penetration resistance and shear resistance which affect implement performances were examined before conducting the test, using the method adopted by [9].

Field Performance Characteristics Test

The field operations were generally performed longitudinally at selected forward speeds, the distance travelled and the corresponding time taken to complete the working distance were noted; and the total productive and delay time were evaluated and recorded [10]. The speed selections were made within the speed range recommended by [11] for tillage. The implement performance indicators such as field efficiency, effective field capacity, theoretical field capacity and material efficiency were evaluated.

Measurement of Productive and Delay (Idle) Time

The total time spent on the entire row length operation and the delay or idle time encountered in the operation which include, time for refilling the tank, time for repair of breakdown/adjustments, turning time, and any other idle time observed was noted and the actual time (productive time) used in the operation was evaluated from the relationship [3];

$$T_e=T_t-T_d \tag{1}$$

Where:
T_e = actual (productive) time, (h)
T_t = total time spent on the entire row length operation, (h)
T_d = delay (idle) time, (h)

Measurement of turning time commences immediately the implement is raised on the completion of a row length, to initiate a turn until it turns completely to continue the operation.

Determination Field Efficiency

The field efficiency was determined from the expression suggested by [12]

$$Ɛ=\frac{100Te}{Tt} \tag{2}$$

Where:
Ɛ = field efficiency, %
T_e = actual working (productive) time, (h)
T_t = total working time = (T_e +T_d), (h)
T_d = delay or idle time

Determination of the Effective Field Capacity

The effective field capacity was determined by noting the speed of operation, implements working width and the field efficiency of the machine; and then was evaluated from the expression suggested by [11]

$$Ce = \frac{Swe}{c} \tag{3}$$

Where:
Ce = effective field capacity, ha/h [a/h]
S = speed, km/h, [mi/h]
W = rated width of implement, m [ft]
e = field efficiency as a decimal
c = constant, 10 [8.25]

Determination of Theoretical Field Capacity

The Theoretical Field Capacity was determined by rearranging the expression suggested by [1] for field efficiency as follows

$$Ɛ = \frac{Ce}{Ct} \tag{4}$$

By rearrangement,

$$C_t = \frac{Ce}{Ɛ} \tag{5}$$

Where:
C_t = theoretical field capacity, ha/h
Ce = effective field capacity, ha/h
Ɛ = field efficiency, decimal

Determination of the Material Capacity

The machine material capacity was determined by noting the speed of operation, implement working width, the field efficiency of the machine and the weight of soil scooped (for tillage implements), but for the planter, the quantity/weight of seeds loaded in the hopper; and then was obtained from the expression.

$$M = \frac{Swey}{c} \qquad (6)\ [11]$$

Where:
M = material capacity, kg/h
y = yield/mass of material handled, kg/m^2
s = implement/machine speed, km/h
w = implement working width, cm
e = implement field efficiency, %
c = constant = 10

Development of Empirical Regression Equation

The data obtained from the study were subjected to regression analysis and empirical regression equations for predicting the implement performances at different operation speeds were developed.

Determination of the adequacy of the equations

The adequacy of the equations developed from the study were determined by comparing the results obtained from the experiment with the regression results using percentage error (eqn. 7) suggested by [13]

$$\text{Error} = \frac{Regression\ Result - Experimental\ Result}{Experimental\ Result} \times 100 \qquad (7)$$

Thereafter, the root mean square (RMS) of the error where evaluated to determine the accuracy of the predicted results. The predictions are considered accurate if the RMS errors of the prediction are within the tolerable limit of ±5%.
More so, the coefficient of determination, R^2 will also indicate the adequacy of the model if it is within limit of 0 and 1 [14].

RESULTS AND DISCUSSION

Results of this research work are presented in Table 1-9

Table 1. Optimum speeds and efficiencies of tractor-hitched implements under different soil type/conditions

Soil type/M.C, %(wb)	Speed range, km/h	Range and optimum values of field efficiency, (%)			
		Plough	Harrow	Ridger	Rotovator
Clay-loam M.c,% (wb)	5-10 Optimum speed	85.74- 88.11 6 km/h (15.5- 17.2)	82.59 – 87.98 8 km/h (14.8 – 16.2)	83.65– 87.96 9 km/h (14.0-14.4)	85.81– 89.81 9km/h (13.0 -14.2)
Loamy-sandy M.c, % (wb)	5-10 Optimum speed	85.31- 87.55 6 km/h (15.2-16.2)	83.41 – 87.19 8 km/h (13.3 – 15.4)	85.54 – 87.95 9 km/h (13.2 -14.5)	81.10 - 87.11 9 km/h (13.1-13.6)
Sandy-clay M.c, % (wb)	5-10 Optimum speed	85.90- 87.98 7 km/h (14.8-18.6)	87.05-98.54 9 km/h (13.0-19.3)	86.26-89.09 9 km/h (13.0-17.1)	87.05-89.40 9 km/h (13.3-16.3)

Table 2. Regression equations for predicting ploughing efficiencies of the implement in different soil types in south-east Nigeria

Soil type	Efficiences (performance indicators)	Regression equations	Coefficient of determination, R^2
Clay-loam	Field efficiency (Ɛ)	$Y = 0.067x^2 – 0.7733x + 89.283$	0.9838
	Effective capacity (Ce)	$Y = 0.0864x^2 – 1.4406x +6.8173$	0.8081
	Theoretical field capacity(Te)	$Y = 0.0026x^2 – 0.0877x +1.7641$	0.909
	Material efficiency (Me)	$Y = 0.0888x^2 – 1.6513x + 49.11$	0.71
Loamy-sand	Field efficiency (Ɛ)	$Y = - 0.089x^2 + 0.8208x +85.801$	0.9615
	Effective capacity (Ce)	$Y = - 0.0036x^2 + 0.0318x +0.9189$	0.9524
	Theoretical field capacity(Te)	$Y = 0.0019x^2 – 0.033x + 1.2483$	0.8473
	Material efficiency (Me)	$Y = - 0.2184x^2 + 2.911x + 32.207$	0.9501
Sandy – clay	Field efficiency (Ɛ)	$Y= 0.0198x^2 + 0.0847x + 84.957$	0.9258
	Effective capacity (Ce)	$Y = 0.0672x^2 – 1.1748x + 6.0411$	0.8427
	Theoretical field capacity(Te)	$Y = - 0.0209x^2 + 0.3103x + 0.1481$	0.9625
	Material efficiency (Me)	$Y = - 0.9018x^2 +13.699x – 4.9457$	0.9515

Note: Y = Performance indicators; X = Operational speeds

Table 3. Regression equations for predicting the harrowing efficiencies of the implementin different types in south-east zone.

Soil type	Efficiencies (performance indicators)	Regression Equations	Coefficient of determination, R^2
Clay-loam	Field efficiency (Ɛ)	$Y = - 0.3745x^2 + 7.4659x + 50.757$	0.9149
	Effective capacity (Ce)	$Y = - 0.0056x^2 + 0.1486x + 0.3631$	0.9007
	Theoretical field capacity(Te)	$Y = 0.0041x^2 + 0.0885x + 0.9156$	0.8894
	Material efficiency (Me)	$Y = 0.1952x^2 – 0.6095x + 84.343$	0.9144
Loamy-sand	Field efficiency (Ɛ)	$Y = - 0.3423x^2 + 5.2326x + 67.303$	0.9549
	Effective capacity (Ce)	$Y = - 0.0301x^2 + 0.550x – 1.0181$	0.9752
	Theoretical field capacity(Te)	$Y = 0.0085x^2 + 0.186x +0.6977$	0.9475
	Material efficiency (Me)	$Y = - 1.512x^2 + 30.058x – 26.412$	0.9443
Sandy – clay	Field efficiency (Ɛ)	$Y = 0.3945x^2 – 4.2087x + 97.777$	0.8652
	Effective capacity (Ce)	$Y = - 0.0044x^2 +0.1375x + 0.4436$	0.9105
	Theoretical field capacity(Te)	$Y = - 0.01x^2 + 0.194x + 0.5459$	0.9607
	Material efficiency (Me)	$Y = - 0.3586x^2 + 11.229x + 36.297$	0.9105

Note: Y = Performance indicators; X = Operational speeds

Table 4. Regression equations for predicting the ridging efficiencies of the implement in different soil types in south-east zone.

Soil type	Efficiencies (performance indicators)	Regression equations	Coefficient of determination, R^2
Clay-loam	Field efficiency (Ɛ)	$Y = -0.1873x^2 + 3.9156x + 67.166$	0.933
	Effective capacity (Ce)	$Y = -0.0329x^2 + 0.9125x - 4.1054$	0.9112
	Theoretical field capacity (Te)	$Y = 0.027x^2 - 0.3873x + 2.5757$	0.8603
	Material efficiency (Me)	$Y = 1.3063x^2 - 17.514x + 115.46$	0.9276
Loamy-sand	Field efficiency (Ɛ)	$Y = -0.1861x^2 + 3.5461 + 70.901$	0.9637
	Effective capacity (Ce)	$Y = -0.0061x^2 + 0.114x + 0.6533$	0.859
	Theoretical field capacity (Te)	$Y = -0.0217x^2\ 0.3893x - 0.3754$	0.8117
	Material efficiency (Me)	$Y = -1.1914x^2 + 21.493x - 28.259$	0.899
Sandy-clay	Field efficiency (Ɛ)	$Y = 0.2082x^2 - 3.1954x + 98.731$	0.9425
	Effective capacity (Ce)	$Y = -0.0126x^2 + 0.1867x + 0.6991$	0.9591
	Theoretical field capacity (Te)	$Y = 0.0019x^2 + 0.0375x + 1.191$	0.9118
	Material efficiency (Me)	$Y = 0.8154x^2 - 11.968x + 109.01$	0.9233

Note: Y = Performance indicators; X = Operational speeds

Table 5. Regression equations for predicting the pulverizing efficiencies of the implement in different soil types in south-east zone.

Soil type	Efficiencies (performance indicators)	Regression equations	Coefficient of determination, R^2
Clay-loam	Field efficiency (Ɛ)	$Y = -0.1741x^2 + 4.531x + 59.272$	0.9672
	Effective capacity (Ce)	$Y = 0.0033x^2 - 0.0715x + 1.1462$	0.9501
	Theoretical field capacity (Te)	$Y = -0.0769x^2 + 2.0311x - 11.388$	0.8773
	Material efficiency (Me)	$Y = -0.2234x^2 + 5.8529x - 13.643$	0.9775
Loamy-sand	Field efficiency (Ɛ)	$Y = -0.7563x^2 + 18.097x - 19.798$	0.9122
	Effective capacity (Ce)	$Y = -0.0006x^2 + 0.0113x + 0.7612$	0.9614
	Theoretical field capacity (Te)	$Y = -0.0812x^2 + 1.668x - 6.5609$	0.9396
	Material efficiency (Me)	$Y = -0.868x^2 + 20.363x - 90.59$	0.8995
Sandy-clay	Field efficiency (Ɛ)	$Y = -0.0825x^2 + 1.9006x + 76.649$	0.9235
	Effective capacity (Ce)	$Y = -0.0053x^2 + 0.1441x - 0.1535$	0.9162
	Theoretical field capacity (Te)	$Y = -0.0426x^2 + 0.7346x - 1.1896$	0.7867
	Material efficiency (Me)	$Y = 0.0977x^2 - 2.0643x + 32.16$	0.8545

Note: Y = Performance indicators; X = Operational speeds

Table 6. Comparison of the field experiment and regression equation results for ploughing operation

Soil type	speed km/h	Field efficiency,%			Effective field capacity,ha/h			Theoretical field capacity,ha/h			Material efficiency, kg/h		
		Exp.	Regr.	Er %	Exp.	Regr	Er %	Exp.	Regr	Er %	Exp	Regr	Er %
Clay-loam	5	87.08	87.47	4.48	1.031	1.016	-1.45	1.844	1.162	-1.86	43.46	42.82	-1.46
	6	88.11	87.26	-0.96	0.99	1.002	1.21	1.123	1.147	2.14	41.73	42.18	1.08
	7	87.05	87.08	0.03	1.978	0.988	-0.01	1.124	1.132	0.71	41.22	40.53	-1.67
	8	86.45	86.84	-4.51	1.019	0.974	-4.42	1.179	1.117	-5.3	42.95	40.89	-4.8
	9	85.74	77.18	-9.77	0.847	0.960	13.5	0.981	0.912	-7.6	35.67	40.24	12.8
	10	87.24	86.42	-0.94	1.002	0.946	-5.6	1.149	1.059	-7.83	42.23	38.35	-9.19
	RMS			4.48			6.32			5.01			6.81
Loamy-sandy	5	86.79	88.99	2.52	0.981	0.976	-0.51	1.130	1.120	-0.88	41.35	40.76	-1.42
	6	88.55	88.79	1.40	0.991	0.958	-3.33	1.119	1.104	-1.34	41.77	40.50	-3.04
	7	87.07	88.59	1.75	0.875	0.955	9.14	1.005	1.088	8.26	36.88	40.24	9.11
	8	85.13	88.40	3.84	0.932	0.922	-1.07	1.102	1.072	-2.72	40.30	39.26	-2.58
	9	86.02	88.21	2.55	0.911	0.904	-0.77	1.111	1.056	-4.95	41.09	39.73	-3.31
	10	82.31	88.02	6.94	0.885	0.886	0.11	1.003	1.040	3.69	39.32	39.47	-0.38
	RMS			3.71			4.00			4.42			4.31
Sandy-clay	5	85.90	84.71	-1.39	0.974	1.061	8.93	1.134	1.199	5.73	41.05	45.20	9.21
	6	83.23	85.72	2.69	1.062	1.045	-1.60	1.275	1.171	-8.16	44.76	44.53	-0.51
	7	86.23	86.22	-0.13	1.113	1.029	-7.55	1.282	1.143	-10.8	46.91	43.86	-6.50
	8	88.23	86.97	-1,43	1.143	1.013	-11.4	1.296	1.115	-14.0	48.18	43.19	-10.4
	9	88.22	87.73	-0.56	0.848	0.997	17.6	0.961	1.087	13.1	35.74	42.52	19.0
	10	87.78	88.48	0.80	0.985	0.981	-0.41	1.122	1.059	-5.61	41.52	41.85	0.79
	RMS.			1.42			4.75			5.08			4.99

Table 7. Comparison of the field experiment and regression equation results for harrowing operation

Soil type	Speed km/h	Field efficiency,%			Effective field capacity,ha/h			Theoretical field capacity,ha/h			Material efficiency, kg/h		
		Exp.	Regr	Er %	Exp.	Regr	Er %	Exp.	Regr	Er %	Exp	Regr	Er %
Clay-loam	5	82.59	83.68	1.32	1.063	1.076	1.22	1.287	1.329	3.26	86.8992.04	88.01	1.29
	6	83.42	85.04	1.94	1.126	1.113	-1.15	1.350	1.347	-0.22	89.67	91.01	-1.12
	7	80.17	86.40	7.77	1.097	1.150	4.83	1.368	1.365	-0.22	105.8	94.00	4.83
	8	87.98	87.76	-0.25	1.289	1.187	-7.91	1.465	1.387	-5.60	97.76	97.00	-8.28
	9	86.70	89.12	2.79	1.196	1.224	2.34	1.379	1.401	1.60	101.3	99.99	2.28
	10	88.56	90.48	2.17	1.239	1.261	2.73	1.399	1.419	1.43		102.9	1.68
	RMS			3.60			4.10			2.81			4.11
Loamy-sandy	5	83.58	85.68	2.51	1.192	1.302	9.23	1.426	1.517	6.38	97.43	108.7	11.5
	6	86.82	85.41	-1.62	1.389	1.327	-4.46	1.600	1.542	-3.63	113.5	106.6	-6.14
	7	87.08	85.17	-2.19	1.436	1.352	-5.85	1.649	1.567	-4.97	117.4	104.5	-11.0
	8	84.19	84.92	0.87	1.399	1.377	-1.57	1.589	1.592	-0.19	98.32	102.4	4.13
	9	55.22	84.24	-1.15	1.386	1.402	1.15	1.603	1.617	0.89	97.18	100.3	3.20
	10	83.41	84.44	1.23	1.394	1.427	2.37	1.611	1.642	1.92	96.74	98.20	1.51
	RMS			4.23			5.03			3.72			6.19
Sandy-clay	5	87.55	87.15	-0.46	1.095	1.116	-1.92	1.251	1.291	3.20	89.51	92.09	2.88
	6	86.05	87.48	1.66	1.204	1.182	-1.83	1.400	1.357	-3.07	98.41	97.17	-1.26
	7	86.95	87.82	-0.99	1.281	1.248	-2.58	1.473	1.423	-3.39	104.7	102.3	-2.35
	8	91.38	88.15	-3.53	1.343	1.314	-2.16	1.470	1.489	1.29	1o9.8	107.3	-2.23
	9	88.54	88.49	-0.11	1.311	1.380	5.26	1.480	1.555	5.07	107.2	112.4	4.90
	10	87.45	88.82	1.57	1.458	1.446	-0.82	1.667	1.621	-2.76	119.2	117.5	-1.41
	RMS			1.82			2.83			3.35			2.84

Table 8. Comparison of the field experiment and regression equation results for ridging operation

Soil type	Speed, km/h	Field efficiency,%			Effective field capacity,ha/h			Theoretical field capacity,ha/h			Material efficiency, kg/h		
		Exp.	Regr	Er %	Exp.	Regr	Er %	Exp.	Regr	Er%	Exp	Regr	Er %
Clay-loam	5	83.65	83.68	0.04	1.065	1.117	4.88	1.273	1.152	-9.51	59.85	62.57	4.55
	6	85.68	84.56	-1.31	0.932	1.113	19.4	1.088	1.200	10.3	52.38	62.12	18.6
	7	83.90	85.43	1.83	1.457	1.109	-23.9	1.260	1.248	-0.95	79.40	61.67	-22.3
	8	86.00	86.31	0.36	1.152	1.105	-4.08	1.340	1.296	-3.28	64.74	61.22	-5.44
	9	88.06	87.18	-0.10	0.945	1.101	16.5	1.073	1.344	25.3	53.11	60.77	14.4
	10	87.92	88.05	0.15	1.089	1.100	0.73	1.603	1.392	-13.2	59.19	60.32	1.91
	RMS			0.91			5.81			4.63			4.33
Loamy-sandy	5	87.54	87.59	5.37	1.007	1.087	7.94	1.150	1.249	8.61	56.59	61.07	7.92
	6	87.45	87.50	0.06	1.175	1.109	-5.62	1.344	1.265	-5.88	66.04	61.20	-6.12
	7	87.54	87.42	-1.37	1.166	1.131	-3.00	1.332	1.281	-3.83	65.55	62.92	-4.01
	8	87.48	87.39	-0.10	1.170	1.153	-1.45	1.290	1.297	0.54	63.18	63.85	1.05
	9	86.95	87.26	0.36	1.165	1.175	0.86	1.318	1.313	-0.38	64.39	64.77	0.59
	10	87.32	87.17	-12.8	1.169	1.195	3.27	1.301	1.329	2.15	64.52	65.69	1.82
	RMS			2.61			3.42			2.71			2.52
Sandy-clay	5	87.07	86.63	-0.51	1.170	1.175	0.44	1.344	1.359	1.12	65.75	64.43	-2.00
	6	86.60	86.91	0.36	1.182	1.168	-1.18	1.365	1.345	-1.47	66.43	65.25	-1.78
	7	86.26	87.20	1.08	1.165	1.162	-0.26	1.351	1.331	-1.48	65.47	66.06	0.90
	8	89.19	87.48	-1.92	1.206	1.155	-4.23	1.352	1.317	-2.59	67.78	66.87	-1.34
	9	86.09	87.77	1.95	1.009	1.148	13.8	1.164	1.303	11.9	56.31	67.69	20.2
	10	88.82	88.05	-0.87	1.218	1.141	-6.32	1.371	1.289	5.98	77.05	68.50	-11.1
	RMS			0.64			3.12			4.12			4.22

Table 9. Comparison of the field experiment and regression equation results for pulverizing operation

Soil type	Speed km/h	Field efficiency,%			Effective field capacity,ha/h			Theoretical field capacity,ha/h			Material efficiency, kg/hr		
		Exp.	Regr	Er%	Exp.	Regr	Er%	Exp.	Regr	Er%	Exp	Regr	Er%
Clay-loam	5												
	6	85.81	85.81	0.00	0.775	0.789	2.97	0.903	0.916	1.39	20.93	18.20	-13.0
	7	87.38	85.55	-0.95	0.759	0.797	5.01	0.869	0.911	4.83	20.49	19.17	-6.42
	8	88.20	87.30	-1.02	0.962	0.795	-17.4	1.091	0.906	-17.0	25.97	20.15	-22.4
	9	88.24	88.05	-0.22	0.669	0.794	18.7	0.758	0.902	19.0	18.06	21.12	16.9
	10	89.81	88.89	-1.13	0.811	0.793	-2.22	0.903	0.898	-0.55	21.90	22.09	0.89
	RMS	86.63	89.54	3.36	0.795	0.792	-0.38	0.918	0.893	-2.72	21.47	23.06	7.41
				1.22			3.16			5.02			4.18
Loamy -sandy	5	81.10	83.80	3.33	0.804	0.804	0.00	0.913	0.917	0.48	21.71	22.51	3.70
	6	86.76	84.45	-2.67	0.803	0.805	0.21	0.925	0.924	-0.14	21.68	23.19	6.95
	7	86.83	85.09	-2.00	0.812	0.805	-0.86	0.935	0.930	-0.53	27.94	23.86	-14.6
	8	84.92	85.74	0.97	0.800	0.805	0.63	0.911	0.936	2.78	22.61	24.53	8.89
	9	87.11	86.39	-0.83	0.811	0.806	-0.65	1.002	0.943	-5.92	26.81	25.21	-6.36
	10	85.81	87.04	1.43	0.804	0.806	0.26	0.916	0.949	3.61	24.41	25.89	6.01
	RMS			2.24			0.51			2.21			3.60
Sandy-clay	5	87.05	87.81	0.87	0.800	0.763	-4.61	0.919	0.900	-2.05	21.60	20.75	-3.95
	6	89.40	87.91	-1.67	0.778	0.776	-0.23	0.933	0.910	-2.42	21.01	21.10	0.45
	7	86.88	88.02	1.31	0.685	0.789	15.2	0.788	0.921	15.7	18.50	21.46	16.0
	8	87.51	88.12	0.70	0.902	1.274	41.2	1.031	0.931	-9.72	24.35	21.82	-10.4
	9	88.36	88.23	-0.15	0.812	0.816	0.44	0.919	0.941	2.39	21.92	22.18	11.6
	10	87.43	88.33	1.03	0.825	0.829	0.32	0.950	0.951	0.11	22.36	22.53	0.77
	RMS			1.66			6.14			3.18			4.96

DISCUSSION

Table 1. presents the optimum performances of the implements under different soil types/ conditions. Results of this table revealed that the optimum speed of plough in clay-loam soil was 6km/h. At this speed, the plough recorded the highest field efficiency of 88.11% at a cutting depth of 25cm within soil moisture content range of 15.3 – 17.2% (w.b). In loamy – sandy soil, the optimum speed of the plough was also 6km/hr with corresponding field efficiency of 87.55% at moisture content range of 15.2 – 16.2% (w.b); while in sandy – clay soil, the plough recorded its optimum speed of 7km/hr with field efficiency of 87.78% at moisture content range of 14.8 – 18.6% (w.b).

Furthermore, the optimum speed of operation of harrow in clay-loam soil was 8km/hr with highest field efficiency of 87.98% within soil moisture content range of 14.2 – 16.2% (w.b). In loamy – sandy soil, the optimum speed of the harrow was 8km/hr with highest field efficiency of 87.19% at moisture content range of 13.3 – 15.4% (w.b); while in sandy – clay soil; it recorded its optimum speed of 9km/hr with the field efficiency of 98.54% at moisture content range of 13.0 – 19.3% (w.b). Results of this table also revealed that for all the soils studied, the optimum speed of ridger was 9km/hr with corresponding field efficiencies of 87.96%, 87.95% and 89.09% respectively in clay-loam, loamy-sandy and sandy clay soil at soil moisture content range of 14.0 – 14.4% (w.b) , 13.2 – 14.5% (w.b) and 13.0 – 17.1% (w.b) respectively. More so, the rotovator in recorded the same optimum speed with the ridger (9km/h) for all the soils with field efficiency of 89.81% at soil moisture content range of 13.0 – 14.2% (w.b) in clay-loam soil; 87.11% at moisture content range of 13.1 – 13.6% (w.b) loamy-sandy soil; and 89.40% at moisture content range of 13.3 – 16.3% (w.b) in sandy-clay soil.

Table 2 to 5 showed the regression equations developed from the experimental results obtained during the performance evaluation of the implements under study.

The developed regression equations were validated by comparing its results with the experimental results using percentage error (Table 6 - 9). The comparison of the predicted results with the experimental results of this study revealed that the regression equations broadly did not over or under- predict the experimental results, thus, the prediction errors were within allowable range. More so, from the root mean square error analysis, the errors are within acceptable limit of ±5%. However, the little deviations in the prediction of some performance indicators in some operations were attributed to variations in soil conditions/characteristics. The coefficient of determination R^2 for the regression equations developed for predicting the various performance indicators of the tractor – hitched implements vary from 0.7 to 0.9 which indicate that the equations are adequate for predicting the performances of the implements.

CONCLUSION

1. The optimum speed of plough in clay-loam and loamy – sandy soil was 6km/h with corresponding field efficiencies of 88.11% and 87.55% respectively, while in sandy – clay soil, the plough recorded its optimum speed of 7km/h with field efficiency of 87.78%.
2. The optimum speed of harrow in clay-loam soil was 8km/hr with field efficiency of 87.98%. In loamy – sandy soil, its optimum speed was 8km/hr with field efficiency of 87.19%; while in sandy – clay soil; it recorded optimum speed of 9km/hr with field efficiency of 98.54%.
3. The optimum speed of ridger was 9km/hr for all the soils with corresponding field efficiencies of 87.96%, 87.95%, and 89.09% respectively, for clay-loam, loamy-sandy and sandy –clay soil.
4. The optimum speed of rotovator was also 9km/hr in all the soils with corresponding field efficiencies of 89.81%, 87.11%, and 89.40% in clay-loam, loamy-sandy and sandy –clay soil, respectively.
5. The comparison of the predicted results with the experimental results (using percentage error and error root mean square) revealed that the regression equations broadly did not over or under- predict the experimental results, thus, the prediction errors were within allowable range of ±5%.
6. The coefficient of determination R^2 for the regression equations developed for predicting the various performance indicators of the tractor – hitched implements vary from 0.7 to 0.9 which indicate that the equations are adequate for predicting the performances of the implements.

RECOMMENDATIONS

Differences exist in soil conditions among different agricultural or ecological areas; it is therefore recommended that more studies should be conducted in every agricultural zone to provide data on machine/ implement performances based on soil conditions for increased production, minimization of production costs, reduce loss/wastage of energy, time and waste of agricultural products.

Finally, this study did not cover all the agricultural field machineries. Researchers are also recommended to make detailed time study in other machineries not covered in this work in other to provide database in their performances as to guide farmers here and other agricultural zones in machine/implement selections.

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JEDNOSTAVNE REGRESIJSKE VEZE ZA PROCENU PERFORMANSI IZABRANIH PRIKLJUČAKA OPREME U JUGOISTOČNOJ NIGERIJI

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Sažetak: Istraživanje je obavljeno na tri dominantna poljoprivredna zemljišta jugoistočne Nigerije da bi se razvio određeni empirijski regresijski odnos za predviđanje performansi nekih odabranih priključaka za obradu zemljišta agregatiranih na traktore na osnovu eksperimentalnih rezultata dobijenih na terenu. Rezultati eksperimenata pokazuju su da optimalna brzina oranja u glinovito -ilovastom i ilovasto - peskovitom zemljištu iznosi 6 km/h, sa odgovarajućom efikasnosti (učinkom) na polju od 88,11%, odnosno 87,55%, dok je u peskovito- glinovito zemljištu za plug registrovana optimalna brzina 7 km/h sa efikasnosti (učinkom) na polju od 87,78%. Optimalna brzina operacije obrade drljanjem na glinovito-ilovastom zemljištu bila je od 8 km/h, a učinak (efikasnost) je 87,98%. Kod ilovasto-peskovitog zemljišta, optimalna brzina bila je 8 km/h, a učinak (efikasnost) bila je 87,19%; dok je u kod peskovito - glinovitog zemljišta registrovana optimalna brzinu od 9 km/h sa učinakom (efikasnost) od 98,54%.

Optimalna brzina traktor–podrivač bila je 9 km/h za sva ispitivana zemljišta sa odgovarajućom efikasnosti (učinkom) na polju 87,96%, 87,95%, odnosno 89,09%, za glinovito-ilovasta, ilovasto-peskovita i peskovito-ilovasta zemljišta. Optimalna brzina rotatofreze bila je takođe 9 km/h na svim zemljištima u ispitivanju, sa odgovarajućom efikasnosti (učinkom) od 89,81%, 87,11%, odnosno 89,40%, u glinovito-ilovastom, ilovasto-peskovitom i peskovito–glinovitom tipu zemljišta.

Ove efikasnosti (učinci) na polju su eksperimentalno dobijene na terenu su upoređene sa efikasnosti dobijenom iz jednačina regresija, koristeći grešku od ±5%. , a tačnost predviđanja testirana je korišćenjem srednjeg kvadratnog odstupanja R^2. Upoređivanje predviđenih rezultata sa eksperimentalnim rezultatima otkrilo je da regresione jednačine u velikoj meri nisu premašile ili umanjile eksperimentalne rezultate, tako da su greške predviđanja bile u okviru dozvoljenog raspona od ± 5%.

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Koeficijent R_2 za regresione jednačine razvijen za predviđanje različitih pokazatelja performansi traktorskih priključaka varira od 0,7 do 0,9 što pokazuje da su testirane varijable bile visoko povezane, a takođe su pokazatelj da su regresione jednačine adekvatne za predviđanje performanse priključaka.

Ključne reči: *Empirijski, jednačine, performanse, regresija, primena obrade.*

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THE EFFECT OF ACTIVATED CARBON FILTRATION TREATMENT FOR WATER QUALITY ASSESSMENT

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***Abstract*:** Activated carbon has been identified as one of the major favoured water treatment technique because of its multifunctional nature without further detriment to the treated water. In this study, varying masses of the activated carbon from palm kernel (PK) shells were weighed at intervals to treat the water samples obtained at different locations. Location A is Otamiri River, in FUTO community while location B is Umuariagha River, in Ikwuano Local Government area of Abia state. The water samples collected were then analyzed using standard equipments. Results of the analyses revealed that the water quality parameters in the samples were highly reduced after treatment except for parameters like Nitrate ,with values 24.17 mg/L to 27.3 mg/L in location A; 4.73 mg/L to 7.9 mg/L in location B, Iron with values 1.0 mg/L to 0.42 mg/L in location A; 0.75 mg/L to 0.38mg/L in location B, and total bacteria coliform count with values 30 to 26 cfu/ml in location A; 28 to 24 cfu/ml in location B, showed little effect but confirm to standard for agricultural uses.
Furthermore, these values are within the ranges recommended by FAO for irrigation uses. In conclusion, these water samples should be subjected to further treatment processes such as boiling before being used for drinking.

Keywords: *filtration, activated carbon, water treatment, irrigation*

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INTRODUCTION

Water quality assessment is a very complex subject, in part because water is a complex medium intrinsically tied to the ecology of the planet Kolo *et al*., [1]. To determine water quality therefore, several parameters must be examined. The complexity of water quality assessment as a subject is reflected in the many types of measurements of water quality. Among the key parameters listed by (WHO, 2012) for the determination of water quality are Conductivity, dissolved oxygen (DO), pH, color of water, taste and odour, turbidity, total suspended solids (TSS), chemical oxygen demand (COD), biochemical oxygen demand (BOD), micro-organisms such as fecal coliform bacteria (*Escherichia coli*), cryptosporidium and *Giardia lamblia*; nutrients (fertilizers), dissolved metals and metalloids (lead, mercury, arsenic, etc.) and dissolved organics.

Water is an essential component of life on earth which contains minerals extremely important in human nutrition [2] and is very essential for sustaining life. As pointed out by Kofi Annan, "fresh water is precious: we cannot live without it. It is irreplaceable: there are no substitutes for it. And human activity has profound impact on the quantity and quality of fresh water available". The supply of safe drinking water is considered as having a significant impact on the prevention of transmissible water-borne diseases [3]. The dramatic increase in population has resulted in an enormous consumption of the world's water reserves Jain *et al.*, [4]. Unfortunately, about 2 billion people globally live in areas where there is chronic shortage of water. Similar studies carried out in different parts of Nigeria Yerima *et al*., [5]; Wazari and Ogugbuaja [6] and Muazu *et al*., [7] and other parts of Africa [8] and [9] reveal that various sources of drinking water have been contaminated at varying scales.

Lack of safe drinking water is considered a leading cause of many communicable diseases. Studies have estimated that the provision of clean water and basic sanitation alone would curtail the incidence of diarrhea by 50%, sleeping sickness by 80% and guinea worm infestation by 100% [10]. Consequently, access to safe water is recognized to be the foundation for sound health Kumar and Younger [11]; Rakesh [12]. Therefore, it is essential to constantly monitor water quality used for drinking purposes.

Filtration is one of the stages in water treatment. Under controlled condition in water purification/ treatment plant, it is an indispensable unit process. Filtration is a process in water treatment which removes suspended matter through the use of filters [13]. The removal of suspended solids by filtration plays an important role in both the naturally occurring purification of groundwater and artificial purification of surface water done in treatment plants. During filtration, the water to be treated is passed through a porous substance. The water quality improves by partial removal of suspended solids, colloidal matter and the reduction of number of bacteria, colour, odour etc. According to Baker and Taras [14], some of the various types of filter media used in filtration can be stable material like granular bed of sand, crushed stone, anthracite (hard coal), glass fibres, diatomaceous earth, activated carbon and coconut husk. In public and large private water supplies, granular beds of sand and activated carbons are almost exclusively used. It is cheap, inert, durable and readily available. Such bed allows penetration of impurities from the raw water without an immediate deterioration of the effluent quality.

Activated carbon is a black solid substance resembling granular or powdered charcoal. It is extremely porous with a very large surface area. Certain contaminants accumulate on the surface of the activated charcoal in a process called adsorption. The two main reasons that chemicals adsorb onto activated charcoal are a "dislike" of the water, and attraction to the activated charcoal. According to Kathy [15], many organic compounds, such as chlorinated and non- chlorinated solvents, gasoline, pesticides and tri-halo-methane can be adsorbed by activated charcoal. Activated charcoal is effective in removing chlorine and moderately effective in removing some heavy metals. Activated charcoal will also remove metals that are bound to organic molecules.

In general, activated carbon is a carbon that has been treated or processed with oxygen to make it extremely porous and thus to have a very large surface area available for chemical reaction. These tiny holes give the charcoal a surface area of 300 – 200 m^2/g allowing liquids or gases to pass through the charcoal and interact with the exposed carbon Ismail *et al.*, [16]; Frederick [17] and Eckenfelder [18]. According to Lartey *et al.*, [19] activated carbon is used in the gold mining industries to recover gold from cyanide while in the brewery and soft drink industries; activated carbon is used mainly to purify the water used in production. In oil palm processing, palm kernel shells (PKS) is usually regarded as waste even though it is commonly used as fuel for cooking and in boiler firing during palm oil processing. An alternative use of PKS which is economically viable is the manufacture of good quality activated carbon due to its high density, high carbon and low ash contents Arami-Niya *et al*., [20].
The aim of this study is to evaluate the effect of activated carbon filtration treatment for water quality assessment.

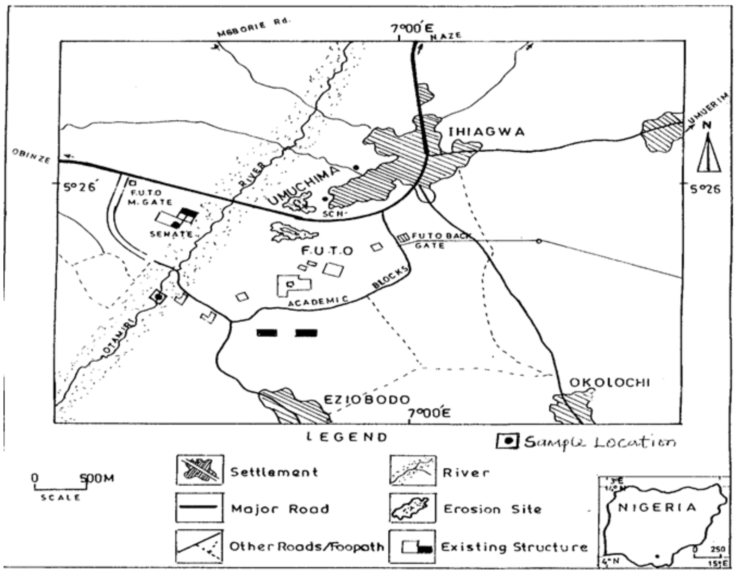

Fig: Location map of the study area.

Figure 1. Map of location A showing Otamiri River in FUTO Community, Imo State

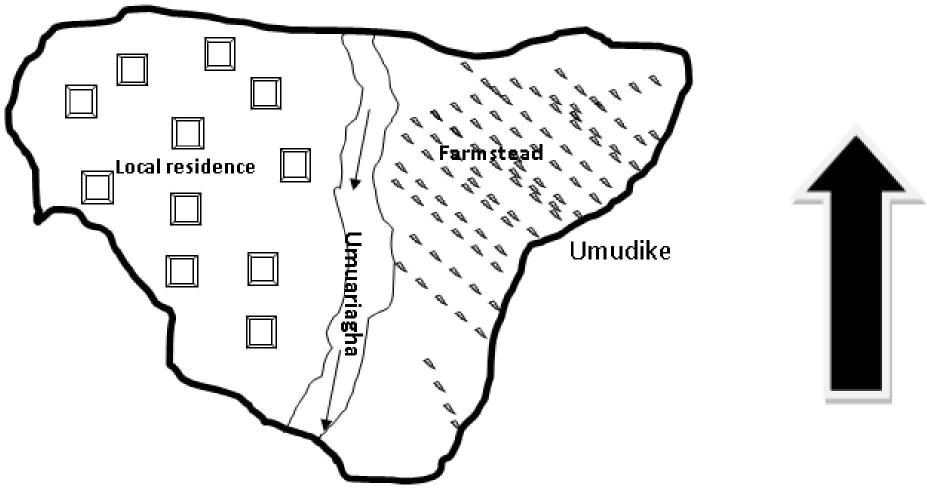

Figure 2. Map of location B showing Umuariagha River

Preparation Of Activated Carbon

The palm kernel shell was washed thoroughly, dried and grinded. The raw material was impregnated with 0.5M of orthophosphoric acid to submerge the sample and placed in the oven at 105^0C to dry. The initial weight of the grinded palm kernel shells was measured and placed in a 100ml beaker. The PKs was left for 48 hours and then heated in a muffle furnace at a temperature of 500^0C for two to three hours. The produced activated carbon was then allowed to cool, and washed with distilled water until a neutral pH was obtained. The sample was dried, further crushed, sieved using sieve shaker to size fractions between the ranges of 60µm to 100µm and stored in airtight plastic containers.

Moisture Content Determination

Moisture content of activated carbon was measured using oven drying method 5.0g of the activated carbon was dried in an oven for four hours at 105^0C, until a constant weight loss. The moisture content of the activated carbon was determined using equation 2 below.

$$X_0 = \frac{W_1 - W_2}{W_1} \, x \, 100 \quad (2)$$

Where

X_0 = Moisture content in weight percentage basis

W_1 = Initial weight of sample in grams

W_2 = Final weight of sample after drying in grams

This process is repeated for various masses of the activated carbon used in this study.

Ash Content Determination

5.0g of activated carbon produced was weighed, placed in a crucible and then heated in a muffle furnace at 900^0C for 180minutes. The weight of the sample was recorded after cooling at room temperature. The ash content for this sample was determined by dividing the mass differences obtained over the initial mass of sample used.

$$\text{Ash content (\%)} = \frac{M_1 - M_2}{M_1} \times 100 \qquad (3)$$

Where

M_1 = initial weight of sample in grams

M_2 = final weight of sample after cooling

Pore Volume

The increase in mass of the sample divided by the density of water gives the pore volume for the sample.
See equation 4 below.

$$\text{Pore volume in cm}^3 = \frac{\text{Increase in Mass in grams}}{\text{Densityof Water in g/cm3}} \qquad (4)$$

Table 1. Physical characteristics of the activated carbon from palm kernel shells

		Varying Masses of Activated Carbon from Palm Kernel Shells			
S/N	*Property*	*5g*	*10g*	*15g*	*20g*
1	*Ash content (%)*	*10.20*	*8.00*	*6.80*	*5.30*
2	*Pore volume (cm^3)*	*5.30*	*0.60*	*0.82*	*0.96*
3	*Bulk density (kg/m^3)*	*250*	*400*	*536*	*667*
4	*Water content (%)*	*1.60*	*1.10*	*0.67*	*0.40*

Design Procedure for the Water Treatment

The tanks used for the analysis is made up of PVC material, cylindrical in shape. The diameter of the two tanks is 220mm and 200mm deep to the outlet of the main pipe respectively. The two tanks have plastic lid for the prevention of micro-organisms. ½ inch (127mm) pipes serves as connection for water delivery from the primary tank down through the activated carbon filter and finally to the secondary tank. The length of the main pipe (primary) is 180mm; the height of the main pipe from the first chamber (elbow joint) is 110mm.The height of the secondary pipe is 50mm while the length of the secondary pipe to the sedimentation tank is 10mm. The activated carbon filter which is the treatment medium has a height of 170mm and a diameter of 80mm. The stand supporting the water treatment tank is made up of iron steel with the following dimensions: 900mm by 300mm; this serves as a base for the treatment tank. The thickness of the stand is 150 mm by 150 mm.

Mechanism of Operation

100ml of the water sample was poured into the primary tank for water treatment. A control valve located on the main pipe regulates the amount of water flowing through the pipe to the filter chamber for the purpose of this experiment. Varying masses of activated carbon was used to treat the water sample. It took 5 hours for the water passing through the activated carbon to be treated. The treated water collected in the secondary chamber was taken to the laboratory for water quality experiment. The results obtained after analysis were compared with the World Health Organization (W.H.O) standard for drinking water.

Table 2. Physico-chemical parameters of the sample locations before treatment

		Location A			Location B			Mean	Mean
S/N	Parameters	1	2	3	1	2	3	(A)	(B)
1	Turbidity (NTU)	11.00	10.00	11.0	4.50	5.00	4.70	10.67	4.73
2	Nitrate (mg/l)	24.20	23.80	24.50	5.00	4.60	4.60	24.17	4.73
3	Iron (mg/l)	1.10	1.20	0.70	1.00	0.70	0.66	1.00	0.75
4	BOD_5 (mg/l)	0.72	0.80	0.75	0.30	0.20	0.30	0.76	0.27
5	COD (mg/l)	42.00	41.0	40.00	20	19	18	41.30	19.00
6	Conductivity (µs/cm)	99.00	98.00	99.00	25	24	25	98.67	24.67
7	TSS (mg/l)	6.70	7.00	6.80	4.4	4.3	4.5	6.80	4.40
8	Total coliform count (cfu/ml)	30.00	29.00	31.00	24	28	32	30.00	28.00
9	Sodium (mg/l)	12.00	12.00	12.00	10	10.5	9.5	12.00	10.00
10	pH	6.50	6.50	6.40	5.8	5.9	6.0	6.50	5.90

NTU=Nepherometric Turbidity Unit; Mg/l=Milligram per litre; µs/cm=microsiemen/cm;
TSS =Total suspended Solids

Table 3. Physico-chemical parameters of the sample location A after treatment

S/N	Parameters	Location B (Mean)	Varying Masses of Activated Carbon from Palm Kernel Shells				WHO Guidelines
			5g	10g	15g		
1	Turbidity (NTU)	10.67	10.60	5NTU	7.3	5.6	5NTU
2	Nitrate (mg/l)	24.17	24.16	50	26.3	27.3	50
3	Iron (mg/l)	1.00	0.9	0.5	0.62	0.42	0.5
4	BOD_5 (mg/l)	0.76	0.75	5-7	0.68	0.62	5-7
5	COD (mg/l)	41.30	41	25-30	27	22	25-30
6	Conductivity (µs/cm)	98.67	98.62	400	97.6	91.4	400
7	TSS (mg/l)	6.80	6.5	50-150	3.0	1.8	50-150
8	Total coliform count (cfu/ml)	30.00	29	10-100	26	26	10-100
9	Sodium (mg/l)	12.00	11.8	200	10.7	10.5	200
10	pH	6.50	6.5	6.5-8.5	6.9	7.2	6.5-8.5

Table 4: Physic-chemical parameters of the sample location B after treatment

S/N	Parameters	Location B (Mean)	Varying Masses of Activated Carbon from Palm Kernel Shells				WHO Guidelines
			5g	10g	15g	20g	
1	Turbidity (NTU)	4.73	4.70	4.10	3.60	2.50	5NTU
2	Nitrate (mg/l)	4.73	4.72	5.20	6.80	7.90	50
3	Iron (mg/l)	0.75	0.60	0.51	0.57	0.38	0.5
4	BOD_5 (mg/l)	0.27	0.27	0.25	0.18	0.09	5-7
5	COD (mg/l)	45.30	43.20	37.60	22.00	17.5	25-30
6	Conductivity (μs/cm)	24.67	23.62	22.82	20.60	20.10	400
7	TSS (mg/l)	4.40	4.10	3.50	2.60	0.88	50-150
8	Total coliform count (cfu/ml)	28.00	27	26	25	24	10-100
9	Sodium (mg/l)	10.00	9.60	9.10	8.50	8.10	200
10	pH	5.90	5.90	5.93	6.30	6.80	6.5-8.5

RESULTS AND DISCUSSION

The results of the physical properties of the produced activated carbon are shown in Table 1. From the table it could be observed that carbonization period (two to three hours from 500^0C - 900^0C) reduced the ash content of the samples. This is true as further heating, in the temperature regime used, will lead to devolatilization of lignin content of carbonaceous biomass material.

The ash content was highest in the mass sample of 5grams. This is an indication of the level of impurity present in it and must have contributed to its poor performance in terms of water purification. Similarly, carbonization period increased the pore volume of the test samples. The values are within the accepted range of 0.4 to 1.1 for standard commercial activated carbon. The higher the pore volume of the activated carbon, its absorption capacity increases [21]. The pore volume is an indication of adsorbility of activated carbon. The reduction in bulk density due to increase in carbonization period resulted from further release of volatiles thereby reducing the unit weight of the samples.

However, the values are within the standard range of 240 to 780 kg/m^3 for standard activated carbon.

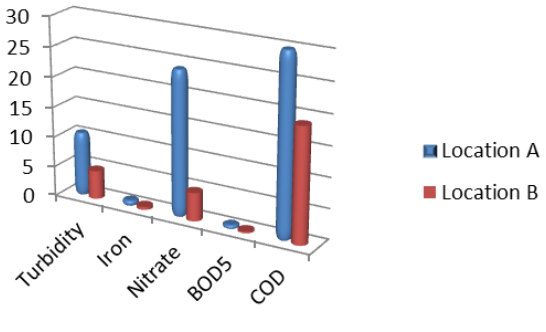

Fig. 1. Physico-chemical parameters before treatment

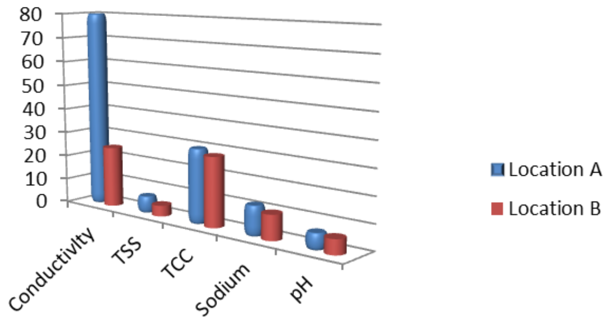

Fig. 2. Physico-chemical parameters before treatment

pH is an important water quality parameter in recirculation systems because various processes such as nitrification and optimum health of human and aquatic lives are related to the optimum pH in the water. The pH value of location A ranges from 6.4-6.5 and 5.9-6.5 in location B before treatment. After treatment, there was a slight change from acidic value to a neutral level in location A, from 6.5-7.2. Similarly, location B after treatment increased from 5.9-6.8.

This indicates a reduction in the amount of acidic contents in the river samples and a good balance in the amount of water level intake advised by water regulatory bodies. The initial values of the total suspended solids in the water samples for both locations where small see Table 2. This was properly filtered by the activated carbon as the values reduced from 6.8 – 1.8 mg/l for location A and 4.4-0.88 mg/l for location B. These values are within the acceptable standard of the World Health Organization [22].

Figure 1 and 2 shows the graphical relationship of the some physico-chemical parameters carried out before treatment. For location A, it was observed that Turbidity, Nitrate, Chemical Oxygen Demand (COD) and water conductivity were high as a result of the many activities on going within and around the location. The Otamiri River naturally contained very large amount of Coliform bacteria because of its exposure to community activities and natural deposits due to weathering activities.

Similarly, location B has increase in Nitrate, COD, Conductivity, Total Coliform Counts and traces of suspended solids. Farming activities are predominant here with other cultural activities within these community are reasons for some of the contamination/pollution of the River.

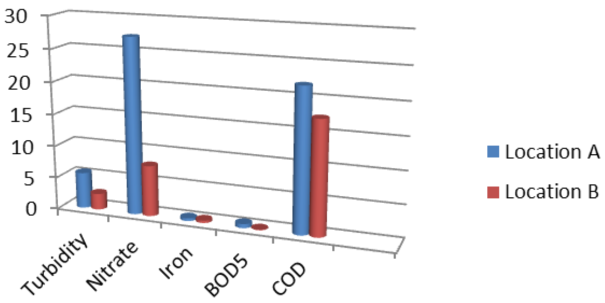

Fig. 3. Graphical relationship between location A and B after treatment

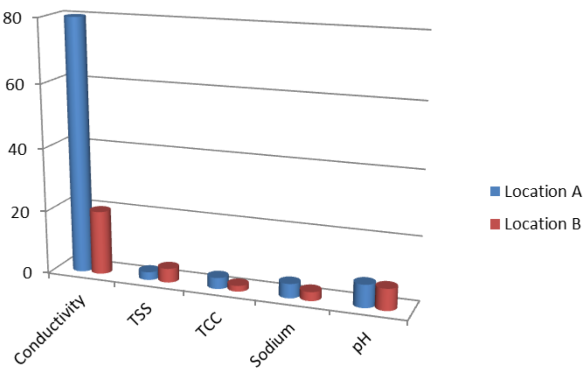

Fig. 4. Graphical relationship between location A and B after treatment

After treatment, Location A, recorded a drastic reduction in Iron content, BOD_5, TSS, TCC, salt etc. It was observed that when river water was passed through layers of activated carbon there was evident reduction in iron which was 80%. BOD was reduced to almost 66% from raw water and COD came down to 50%. There was increase in nitrate value from 24.16 to 27.3 mg/l for these parameters but turbidity came down to 2.5 NTU from initial value of 4.73 NTU. Location B showed a similarly trend in Iron content reduction to about 65% and from 4.44-0.88 mg/l for total coliform counts (TCC). The comparison between the two Rivers shows that the activated carbon filter gives similar trend in treatment but with different values in parameters recorded see Table 3 and 4.

CONCLUSION

From the study, it was observed that the varying masses of the activated carbon have a different rate of removal of some of the contaminants in the raw water samples.

It was observed that the pH, of the filtrate was increased especially by the activated charcoal. I will recommend for future treatment of water in removing suspended solids, iron and total organic carbon using different masses of activated carbon from palm kernel shell.

This technique is highly advantageous, inexpensive and cost-effective and in turn there will be utilization of a waste which would be otherwise simply dumped. However, on the basis of a comprehensive evaluation of the available data material, it is obvious that the water quality is improved and subsequent treatment steps may be supported and simplified leading to decreased water treatment costs.

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EFEKTI AKTIVNE FILTRACIJE TRETMANOM SA UGLJEM NA PROCENU KVALITETA VODE

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Sažetak: Aktivni ugalj je identifikovan kao jedna od glavnih tehnika prečišćavanja vode zbog svoje multifunkcionalne prirode bez daljnjeg oštećenja tretirane vode. U ovoj studiji su izmerene mase aktivnog uglja dobijenog od ljuski palminog ploda (PK) u intervalima da bi se tretirali uzorci vode dobijeni na različitim lokacijama. Lokacija A je reka Otamiri, u zajednici FUTO, dok je lokacija B reka Umuariagha, u oblasti lokalne samouprave IKVUANO u državi Abia, Nigerija. Uzorci vode su analizirani standardnom opremom. Rezultati analiza pokazuju da su parametri kvaliteta vode u uzorcima posle tretmana visoko smanjeni, osim za parametre poput nitrata, sa vrednostima od 24,17 mg/L do 27,3 mg/L na lokaciji A; 4,73 mg/L do 7,9 mg/L na mestu B, i sadržaj gvožđa ima vrednosti od 1,0 mg/L do 0,42 mg/L na lokaciji A; 0,75 mg / L do 0,38 mg / L na mestu B. Ukupan broj koliformnih bakterija sa vrednostima 30 do 26 cfu/ml na lokaciji A; 28 do 24 cfu / ml na lokaciji B, pokazuje male efekte filtracije, ali potvrđuje kao standard za poljoprivrednu upotrebu. Pored toga, ove vrednosti su u granicama koje preporučuje FAO za upotrebu za potrebe korišćenja kod navodnjavanja.

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Zaključno je, da ove uzorke vode, treba podvrgnuti daljim postupcima obrade filtracije, i zagrevanja (ključanja), pre upotrebe za piće.

Ključne reči: *ljuske palminog jezgra, filtracija, aktivni ugalj, obrada vode i navodnjavanje*

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BENEFIT COST ANALYSIS OF ADOPTING A MODIFIED CASSAVA ATTRITION PEELING MACHINE IN MECHANIZED CASSAVA PROCESSING

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Abstract. This paper assessed the benefits of adopting a modified cassava attrition peeling machine in mechanised Cassava (*Manihot Esculenta*) processing. The parameters evaluated and compared between the modified cassava attrition peeling machine, existing attrition peeler and manual peeling technique include the specific energy consumption, peeling efficiency, flesh loss, throughput capacity, payback period and benefit cost ratio. The results showed that the improved machine has a payback period of one year and four months with Benefit Cost Ratio, BCR of 2.56. Significant improvements on its performance parameters was evident with 43% increase in peeling efficiency, 74.8% increase in throughput, 67% tuber flesh recovery, 12 % energy cost savings and 10.6% reduction in specific energy consumption over the existing attrition peeler.

Keywords*: Modified Cassava attrition peeling machine, payback period, benefit cost ratio, energy cost savings, performance parameter.*

INTRODUCTION

Cassava, *Manihot Esculenta,* is an annual crop cultivated in the tropical and subtropical regions for its roots high carbohydrate content as a major source of edible starchy food.

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It is utilized extensively for human and livestock consumption as well as for other industrial products such as starch and alcohol production (El-Sharkawy and Cock, 1987). Its roots in addition to being rich in starch contain calcium, phosphorus and vitamin C in significant traces of 16 mg /100 g, 27 mg/100 g and 20.6 mg /100 g respectively (Ravindran, 1992). Though poor in protein and other nutrients they are generally composed of 70 % moisture, 24 % starch, 2 % fibre, 1 % protein and 3 % other nutrient (CSIR 2017).

The commercial potential of cassava is currently under utilized in Nigeria, even though she is one of the largest producer in the world with approximately 45 million tones of tubers produced annually, accounting for 19 % of world production (Adekanye *et al*., 2013).

This is attributed to inadequate mechanization of the processing operation. Egbeocha *et al.* (2016) posited that the best form of cassava tuber preservation and the reduction of post-harvest losses has been its immediate processing into various shelf stable products. Several operations are involved in the cassava processing into various desired products, and these include peeling, washing, grating, boiling, parboiling, drying, milling, pressing, sieving, extrusion and frying. Before the cassava tuber is processed into any of its food and some of its non-food products, it must be peeled.

Peeling removes the cortex and the outer periderm layer adhering to it basically for product quality and reduction of cyanide content. For a root composed of 15 % peel with a total cyanide content of 950 mg/kg (weight basis) and 35 mg/kg in the flesh, 83 % of the total cyanide is removed by peeling (Bencini, 1991) which is acceptable and safe for consumption. Ideally, and especially in the food industry, the peel must be completely removed without removing the useful tuber flesh for safe consumption and better quality of the end products. This justifies the need for improvement in mechanisation of cassava processing with special interest in the peeling process.

However, cassava peeling operations which obviously is the first post harvest processing operation in an attempt to commercially mechanise it has been faced with the challenges of preoperational treatment, geometric and morphological disparities in addition to other varying tuber properties. Thus, it is difficult to design an economically viable cassava peeling machine that is capable of peeling all roots from various varieties and sources with minimal useful tuber flesh wastage. To bridge the gap created by inefficient and low output of manual peeling process, mechanical peeling broadly achieved by either knife peeling principle (use of knife-like parts as peeling tools) or abrasive/attrition principle (use of frictional surfaces to cause wear) became inevitable

Numerous attempts made in development of peeling technology (Ezekwe, 1979; Nwokedi, 1984; Odigboh, 1983a; IITA, 2011; Akintunde *et al*., 2005, Olukunle, 2005; Oluwole, 2013), have been adversely characterised by drudgery of pre- operational activities of trimming, sorting, soaking and grading of tubers prior to peeling operation to mitigate for the afore mentioned design challenges and this consequently increases the processing cost and time Abrasive/attrition peeling concept exploited in cassava peeling model developed by Projects Development Institute (PRODA) though erroneously criticised and under rated by some researchers (Adetan, 2002 and Olukunle, 2013) possesses great prospects in eliminating these preoperational activities.

Their perceived inefficiencies could be attributed to some obvious design shortcomings and inappropriate design conception adopted.

In order to address the issues associated with the mechanised cassava attrition peeling process, Edeh (2017) designed and developed a modified cassava attrition peeling machine (Figure 1.0) based on the attrition peeling concept with the introduction of breaker baffles, enhancement of inner peeling drum surface, introduction of egg shaped peeling balls which improved cassava peeling in quality and quantity, eliminated the drudgery of pre-operational treatment of trimming, slicing, sorting and grading of cassava tubers prior to peeling thereby reducing processing time and cost. Performance optimization of the developed modified cassava attrition peeling machine confirmed that the machine performs optimally with an efficiency of 88.7 %, throughput of 180kg/hr, flesh loss of 5.49 % and specific energy consumption of 58.4 kJ/kg at an optimal peeling drum speed, cassava moisture content, mass of loaded cassava, number of peeling balls, geometric mean diameter and peel thickness of 45 rpm, 85 % Wb, 82 kg, 110, 48 mm and 4.13 mm respectively (Edeh, 2017). The machine showed improved peeling time resulting in reduced cost of processing hence suitable for further economic analysis.

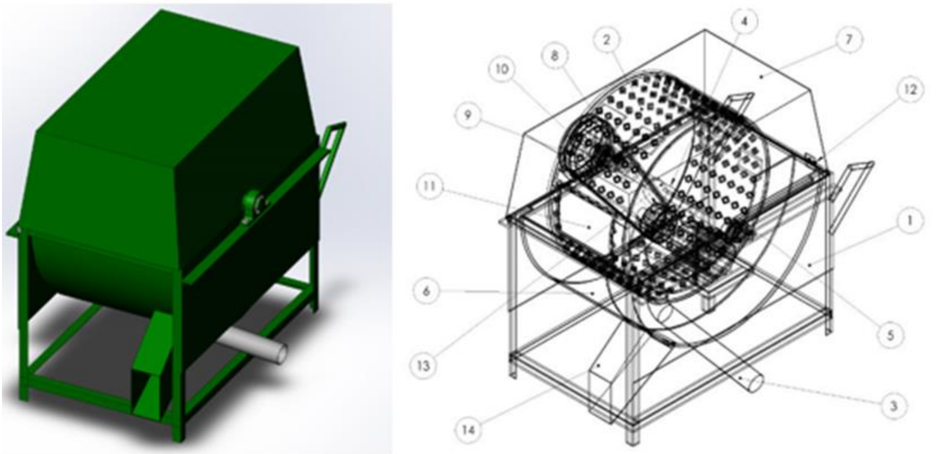

Figure 1. Modified Cassava Attrition Peeling Machine:1.Structural Frame, 2. Peeling drum, 3. Discharge pipe, 4. Shaft, 5. Bearing, 6. Water bath(trough) , 7. Covering hood, 8. Electric motor, 9.pulley, 10. Motor shaft, 11. Loading cover, 12. Hinges, 13.Bolt, 14. Discharge slit.

Despite the considerable improvement in the performance of the modified cassava attrition peeling machine, cassava processors and investors have remained sceptical in adopting this technology because most processors use initial capital (procurement) cost as the primary (and sometimes only) criteria for equipment selection (Oti and Lewachi, 2017) while most of the processors still rely on the manual peeling technique. Application of a benefit cost analysis will determine if an investment in this new peeling technology is profitable as well as provide a cost evaluation basis for comparing the modified cassava attrition peeling machine with existing peeling technology. Hence, in this study, the benefit cost analysis is used to explore the cost effectiveness and economic viability of adopting this modified cassava attrition peeling machine.

MATERIALS AND METHODS

Machine Description and Evaluation Parameters

The detailed diagram and photograph of the modified cassava attrition peeling machine with egg. shaped peeling balls designed and developed by Edeh, *2017* are shown in Figure 1 and Plate 1 respectively. The principle of operation of the modified cassava attrition peeling machine is achieved by attrition which constitute the use of metal surfaces of roughened inner peeling drum and egg shaped peeling balls to cause abrasion with consequent removal of softer cassava tuber surface (the peel). In operation, a known mass of cassava for which other relevant properties are determined and estimated numbers of peeling balls are loaded through the gate into the peeling drum. The machine is energized through the prime mover causing a rotational motion of the drum.

The egg. shaped peeling balls together with the embossed inner surface of the drum causes the wearing of the cassava peel. Being a batch process operation, the cylindrical peeling drums impacts rotational motion on the balls freely mixed with the cassava and consequently creating tumbling effect in the drum that gives random relative motion hence effecting peeling. Material removed from the surface of the cassava by abrasion, which has the form of flake and also tiny particles in pulpy matter, sinks through the perforations of the drum to the bottom of the housing trough serving as water bath and also prevents the clogging of the balls.

Plate 1: (a) Modified cassava attrition peeling machine *(b) Peeling Balls*

Performance test indicators which aid in the analysis of the economic viability of the modified machine include the peeling efficiency, flesh loss, throughput, and specific energy consumption. Flesh loss is the amount of starchy flesh removed alongside the peels during peeling. Peeling efficiency is the ratio of the total mass of peel by the machine to mass of manual peel (theoretical mass of peel) while its throughput is the total mass of cassava peeled and discharged by the machine per unit time.

Specific energy consumption of the machine is quantity of energy it used to peel a unit mass of cassava fed into it. The mathematical relationship used for computing the test indicators are shown in equations 1 – 4 given by (Agrawal, 1987; Nwankwojike et al., 2016; Edeh, 2017).

$$F_l = M_{c-}(m_{cp} + m_{pt}) \tag{1}$$

$$\eta_p = \frac{M_{Pc}}{M_{pr}+M_{pc}} \times \frac{100}{1} \tag{2}$$

$$TP = \frac{M_c}{t} \tag{3}$$

$$SE = \frac{Pt}{M_c} \tag{4}$$

Where F_l=Tuber flesh loss (%), η_p=peeling efficiency (%), TP= throughput, (kg/h), and SE = specific energy consumption (kJ/kg).

m_{cp} = mass of the peeled cassava(kg), m_{pt} = theoretical mass of peel, M_c = mass of the loaded cassava, M_{pc} = mass of peel (kg) collected through the peel outlet of machine and M_{pr} = mass of peel removed by hand after machine peeling (kg), t = Time taken (s). P = Power consumed by the electric motor in kW.

The benefits in adopting the improved cassava attrition peeling machine was also evaluated using the time taken to complete batch peeling process, amount charged for peeling in the various techniques, the average price per kg for peeling batch cassava mass, throughput capacity for the various batch mass of cassava and the total energy cost. Energy cost savings is evaluated using Equation (5).

$$ECS = \frac{TEC_{proda/Manual} - TEC_{MCAPM}}{TEC_{proda/Manual}} \times 100 \tag{5}$$

Where:
ECS = Energy cost savings,
TEC = Total Energy cost.

The Benefit Cost Ratio, BCR of the modified machine was evaluated using Equation (6) by Gerald and Marta (2009).

$$BCR = \frac{PVB}{PVC} \tag{6}$$

Where the Present Value Cost,

$$PVC = \sum_{t=1}^{T} \frac{B_t}{(1+r_i)^t} \tag{7}$$

And the Present Value Benefit,

$$PVB = \sum_{t=1}^{T} \frac{C_t}{(1+r_i)^t} \tag{8}$$

B_t and C_t are the respective benefits and costs in time t and r_i is interest rate = 13% (Daniel and Elisha, 2015).

RESULTS AND DISCUSSION

The improved machine charged ₦500 per 80 kg batch mass of cassava while the existing and manual peeler charged ₦500 per 60 kg and 20 kg batch mass respectively. The modified cassava attrition peeling machine (MCAPM) designed and fabricated using locally sourced material with egg shaped ball accessories and improved peeling surface features eliminated pre-operational treatment with 42.8% savings in processing time, 43% increase in peeling efficiency, 74.8% increase in throughput, 67% tuber flesh recovery and 10.6% reduction in specific energy consumption over the existing machine as shown in the performance graphs in Figure 2.

Since the peeling machines are powered electrically, the cost of generated electricity is taken into consideration to determine the energy cost of using the machines. Electrical cost from the national grid used to power the machines is at the rate of ₦30.93 per kWh while energy cost for the manual peeler was considered as his wages per batch mass of cassava.

The analysis as shown in Table 1 reveals a decrease in the total energy cost in using the improved cassava attrition peeling machine as compared to the existing version and manual peeling process. In addition to its increased throughput capacity, the improved cassava attrition peeling machine performed optimally with a 12% and 69% energy cost savings than the existing and manual peeling process.

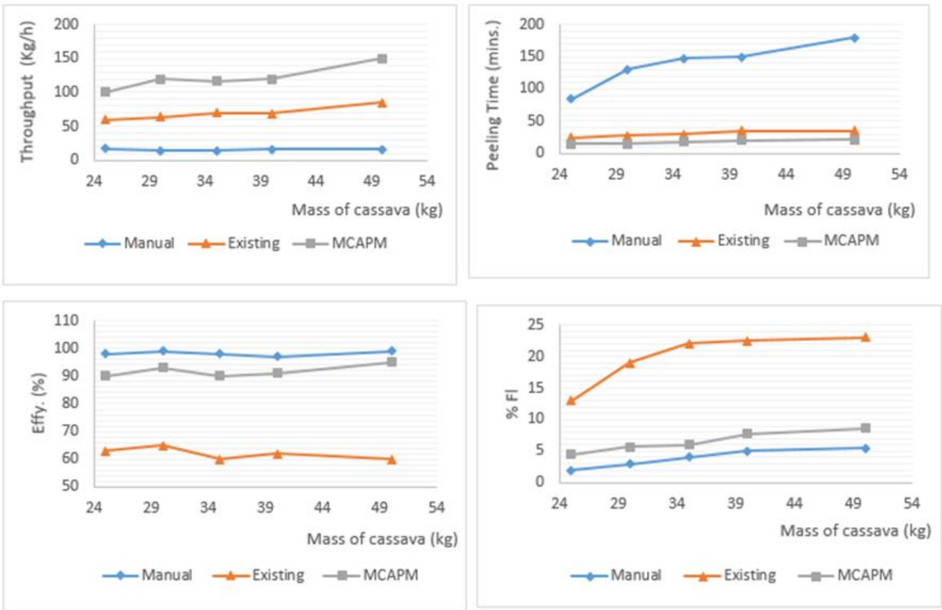

Figure 2. Performance Test Graphs

Table 1: Cost Evaluation

S/N	Manual peeling			Existing Machine			Improved Cassava Attrition Peeling Machine		
	Mass of cassava (kg)	Amount (₦)	Time taken (Mins.)	Mass of cassava (kg)	Amount (₦)	Time taken (Mins.)	Mass of cassava (kg)	Amount (₦)	Time taken (Mins.)
1	100	2500	300	100	833	45	100	625	25
2	200	5000	430	200	1666	65	200	1250	40
3	300	7500	560	300	2500	80	300	1875	65
4	400	10000	600	400	3333	120	400	2500	90
5	450	11250	750	450	3750	150	450	2812.5	110
6	500	12500	950	500	4166	185	500	3125	130
Average price (₦/kg)			25		8.33			6.25	
Average time taken (Min/kg)			1.84		0.33			0.23	
Throughput capacities (kg/h)			32.59		181.39			254.34	
Total energy cost (TEC)			8125		2795			2451	
Energy cost savings per kg (ECS)			69%		12%				

Payback and benefit cost ratio analysis

In the analysis of the payback period and cost benefit ratio of the existing (PRODA) and Modified cassava attrition peeling machines (Table 2), the following considerations were made.

1. The machines operate at 8 hours/day and 6 days/week, hence the machine operation time per year is 288 days/yr (2304 hrs/yr). If the maintenance time is taken as 24hrs/yr, thus the effective machine operation time is 2280 hrs/yr.
2. The existing PRODA machine utilizes a total of 3728.5W (≈ 3.73KW) for its operation. Thus energy consumed per year is 8504.4 KWh. while the modified cassava attrition peeling machine (MCAPM) utilizes a total of 2237.1W (≈ 2.23kW) for its operation. Thus its energy consumed per year is 5084 kWh and as stated earlier PHCN charges ₦30.93 per kWh.

This result reveal a payback period of one year and four months for the modified machine while the existing PRODA version has a payback period of three years and nine months. Thus, the amount invested in this project will be recovered within this length of time with an average yearly cash inflow of **₦** 414,420 from just peeling cassava tubers**.**

The Benefit Cost Ratio, BCR of the modified machine tabulated in Table 3 was evaluated as 2.56 using Equation (6). This implies that for every **₦**1 spent, a benefit of **₦**2.56 was realized. The investment is therefore acceptable.

Table 2: Payback period of the attrition machine.

NON Recurring costs and revenues	Modified machine		PRODA Version	
	Costs (₦)	Revenues(₦)	Costs (₦)	Revenues (₦)
1. Capital Investments				
Cost of machine	200,000.00		220,000.00	
Installation Cost	5,000.00		5,000.00	
2. Revenue				
Sales of equipment after useful period		68,000.00		80,000.00
Total	205,000.00	68,000.00	225,000.00	80,000.00
Recurring annual costs and revenues	Costs (₦)	Revenues (₦)	Costs (₦)	Revenues (₦)
1. Operational and Maintenance cost				
(a) Direct Costs				
Labour	120,000.00		120,000.00	
Material Cost	4,320.00		4,320.00	
(b) Indirect costs				
Maintenance	60,000.00		70,000.00	
Utilities (Power)	157,260.00		263,041.10	
Other cost	3,000.00		3,000.00	
2. Revenue				
Revenue		950,400.00		850,500.00
Total	344,580.00	950,400.00	460,361.10	850,500.00
Before Tax Net Cash Flow (BTCF) Analysis				
End of year	Modified Machine		PRODA Version	
0	205,000.00		225,000.00	
1	400,820.00		165,138.90	
2	400,820.00		165,138.90	
3	400,820.00		165,138.90	
4	400,820.00		165,138.90	
5	468,820.00	414,420.00	245,138.90	181,138.90
Payback period	Initial investment cost/average annual cash inflow			
		1.33		3.78

Table 3: Benefit-cost analysis of the modified cassava attrition peeling machine.

YR	Investment Cost (₦)	Operating Cost (₦)	Total Cost (₦)	Sales (₦)	Salvage value (₦)	Total Benefit (₦)	Present Value Benefit (₦)	Present Value Cost (₦)
0	135,000.00	344,580.00	479,580.00	950,400.00	-	950,400.00	950,400.00	479,580.00
1		344,580.00	344,580.00	950,400.00	-	950,400.00	841,061.95	304,938.05
2		344,580.00	344,580.00	950,400.00	-	950,400.00	744,302.61	269,856.68
3		344,580.00	344,580.00	950,400.00	-	950,400.00	658,674.87	238,811.22
4		344,580.00	344,580.00	950,400.00	-	950,400.00	582,898.12	211,337.37
5		344,580.00	344,580.00	950,400.00	68,000.00	1,018,400.00	552,746.72	187,024.22
	Total						4,330,084.27	1,691,547.55

CONCLUSION

The modified cassava attrition peeling machine eliminated pre-operational treatment with 42.8% savings in processing time, 12 % energy cost savings compared to the existing machine, 43% increase in peeling efficiency, 74.8% increase in throughput, 67% tuber flesh recovery and 10.6% reduction in specific energy consumption over existing machine.

Its benefit cost analysis showed that the improved machine has a payback period of one year and four months with Benefit Cost Ratio, BCR of 2.56 hence a worthwhile investment.

Since peeling constitutes the major bottle neck in the processing cassava, Government and other agencies should grant loan to farmer so that they can afford to adopt this important innovation immediately for mass processing of cassava products to meet the growing demand of the Nigeria industries and for export.

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ANALIZA TROŠKOVA PRIMENE MODIFIKOVANE MAŠINE ZA LJUŠTENJE KOD MEHANIZOVANE OBRADE CASAVE

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Sažetak: U ovom radu su ocenjene prednosti usvajanja primene modifikovane mašine za ljuštenje kod mehanizovane obrade kasave (*Manihot Esculenta*). Parametri koji se procenjuju i upoređuju između modifikovane mašine za piling -ljuštenje kasave, postojećeg alata za ljuštenje i tehnike ručnog ljuštenja uključuju: specifičnu potrošnju energije, efikasnost ljuštenja, gubitak mase, propusni kapacitet mašine, period otplate i procenu troškova koristi.

Rezultati pokazuju da poboljšana – modifikovana mašina ima rok vraćanja troškova od jedne godine i četiri meseca, a odnos koeficijenta koristi i troškova (BCR) od 2,56.

Značajna poboljšanja parametara performansi mašine bila su evidentna sa povećanjem efikasnosti ljuštenja do 43%, povećanje protoka zrna od 74,8%, protokom mase od 67%, sa uštedom troškova energije od 12% i smanjenja potrošnje specifične energije od 10,6% u odnosu na postojeći aparat-uređaj za ljuštenje

Ključne reči: Modifikovana mašina za piling-ljuštenje kasave, rok otplate, procena troškova I koristi, ušteda troškova energije, parametari performansi.

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EVALUATION OF MAXIMUM BIOGAS PRODUCTION CAPACITY FROM DIFFERENT FEEDSTOCKS: AN EXPERIMENTAL STUDY

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Abstract: This study reveals the maximum biogas production capacity of different biomass using plant and animal waste material as feedstock. A comparative experiment conducted under anaerobic condition showed that biogas yield from poultry litter (28 liters) was higher than that of rice husk (18 liters) in a 30day retention time. However, the yield of biogas was significantly influenced by the composition of the waste feedstock and the environmental conditions within the reactor. The poultry litter had already undergone some digestion process before it was excreted by the birds, which means their bonds were broken by digestive organisms which made the anaerobic digestion process to be easily accomplished. Similarly, the rice husk had a low gas production rate due to the presence of high lignin properties because rice is a lignin cellulose material. Therefore, for optimum gas production, the waste should be pretreated at lower temperate region to increase the digestion temperature since temperature exerts a major influence in biogas production.

Key words*: prediction, maximum biogas capacity, poultry litter, rice husk, anaerobic digestion.*

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INTRODUCTION

In Nigeria, energy is produced in low quantity and its consumption varies. As such there is need for an alternative source of energy to replace the fossil fuel energy source. However, the cost of energy (electricity, firewood and gasoline fuel) in Nigeria is of heavy charge, the bigger part corresponding to the cooking gas (Sioulas et al., 2008). The various challenges faced in reducing animal and plant wastes that causes environmental pollution and the various effects of using fossil fuel energy such as: (1) Non-Renewability:

As of today, fossil fuels are being extracted at an exorbitant rate to meet the gap between demand and supply and it is estimated that they will be finished in next 30-40 years Sioulas and Boukis, (2001). Since they are non-renewable, it is more likely that fuel expenses will face a steep hike in near future. It would take millions of years to replace coal, and oil, and this means that we will not be able to drive cars anymore unless we switch to electric cars that use energy from renewable energy sources or cars powered with biogas. This means once these non-renewable sources are completely used up, there is nothing more left (Petz, 2008). (2) Rising Prices of fossil fuel. Petroleum Exporting Countries (OPEC) which is a group of 13 countries including Nigeria, Iran, Iraq, Kuwait, Qatar, Saudi Arabia and UAE are responsible for 40 percent of the world's oil production and hold the majority of the world's oil reserves, according to the Energy Information Administration (EIA). OPEC constantly monitors the volume of oil consumed and then adjusts its own production to maintain its desired barrel price. This results in worldwide price fluctuations, according to the U.S. Department of Energy (Petz, 2008). (3) Effect on Human Health: Pollution related diseases range from mild to severe and can significantly affect quality of life. Air pollution can result in asthma, chronic obstructive pulmonary disorder and lung cancer. Long-term exposure may increase respiratory infections in general population (Petz, 2008).

Biogas production has long been a valuable technology, as the constant feed of organic raw materials such as energy crops, manure, and sewage sludge and plant residues help to produce energy. The ability to produce energy at a constant rate is a clear advantage over other renewable energy sources such as wind or solar energy, which depend on the wind or sun for production. The production and collection of biogas from a biological process was documented for the first time in United Kingdom in 1895. Since then, the process has been developed and broadly applied for wastewater treatment and sludge stabilization. The energy crisis in the early '70s brought new awareness about the use of renewable fuels, including biogas from anaerobic digestion. Nigeria as a nation with population of about 160 million people is blessed abundantly with different kinds of energy resources both renewable and non-renewable (Oyedebo, 2012). The interest in biogas has increased due to alternatives in fossil fuels used for energy production because of higher cost and the necessity of finding environmentally sustainable solutions for the treatment and recycling of animal manure and organic wastes. Biogas typically refers to a mixture of the different gases produced from the breakdown of organic matter in the absence of oxygen. Anaerobic digestion is a microbiological process of decomposition of organic matter, in the absence of oxygen, common to many natural environments and largely applied today to produce biogas in digesters (Kanokwan, 2006).

MATERIAL AND METHODS

Description of study location

The study was conducted in the Engineering workshop of Michael Okpara University of agriculture, Umudike.

Umudike is a semi-urban settlement in Ikwuano LGA, Abia State, Nigeria, about 11 kilometers Southeast of Umuahia, the state capital city.

Umudike lies between latitude 5.4801° N and longitude 7.5437° E in the rain forest area of South-East agricultural zone of Nigeria and 152 meters elevation above the sea level. The state is located east of Imo state and shares common boundaries with Anambra, Enugu and Ebonyi states, to the North-West, North and North-East, respectively**.**

Feedstock Procurement

The animal waste being poultry litter was collected from the National Research Institute Umudike Poultry farm. The poultry waste used was free from wood shavings since they were obtained from battery cage farming. The rice husks were gotten from Bende local government rice mill. The type of digester that was used in the course of this research was a batch-type digester. This type of digester was chosen because it allows feedstock to be digested in batch levels. Batch digesters are mostly used for experimental purposes and for research study.

Experimental design and Analysis

The animal waste being poultry litter was collected from the National Research Institute Umudike Poultry farm. The poultry waste used was free from wood shavings since they were obtained from battery cage farming. The rice husk where gotten from Bende local government rice mill. The type of digester that was used in the course of this research was a batch-type digester. This type of digester was chosen because it allows feedstock to be digested in batch levels. Batch digesters are mostly used for experimental purposes and for research study.

Experimental Procedure

The substrate was carefully weighed was added with water in a ratio of 1:1 and was transferred to be fed into the digester through the inlet chamber. Before the introduction of this substrate to the digester, the substrate pH level was checked also with the ambient and slurry temperature. Rice husk and poultry litter were mix with water to the digester at a ratio of 1:1. The total volume of the substrate in addition to water mixture in the digester where at 80% leaving 20% gas volume where the gas will be retained. since the digester was a 30 liter digester, so 80% of 30litter is 24liter and at a ratio of 1:1 means that the wastes to water volume was 12kg and 12 liters respectively according to substrate addition rate by Ojikutu and Osokoya, (2014). To achieve homogeneity of the slurry, it was continually stirred so that it will not form scum beneath the digester because once this happens it will slow down the rate of digestion and the micro-organisms responsible for the breakdown of the substrate will only be active at a particular spot, Using the built-in stirrer, the slurry was stirred regularly to distribute and maintain uniformity of temperature and thus, the thickening and caking of scum was prevented. Stirring did not only distribute temperature, it also ensured even distribution of bacteria and at the same time improved surface contact of the waste with the anaerobic bacteria, thereby speeding up biochemical reaction of fermentation.

Temperature Monitoring

In this study, ambient and slurry temperatures were monitored on daily basis. The pH level of the slurry was monitored daily using a pH meter.
According to Adelekan and Bamgboye (2009) that pH is one of the major factors that affects biogas production and that the micro-organisms that are involved in anaerobic reaction required a neutral or mildly alkaline environment for optimum performance.

Retention time

The poultry waste and rice husk were subjected to a 14 (days) retention time, during which the waste was allowed to stay in the bio-digester and their gas production rates were taken at intervals.

Pre-treatment process of feedstock

Prior to digestion the feedstock was partially fermented by soaking in water for fifteen days to help in softening and breaking down of the lignin matter because rice husk is a lignin-cellulose material by mechanical pretreatment method of crushing to fine particles. Crushing prepares the surfaces of the particles for biological decomposition and the subsequent methane production. As a general rule, the decomposition process is faster when the particle size is smaller. The following instruments were used in the study: (1) a weighing balance was used for taking the weight of test samples. (2) plastic measuring cylinder was used for measuring the volume of gas produced. (3) mercury-in-glass thermometer was used for monitoring the ambient and slurry temperatures. (4) a digital pH meter of range 0-14 was used for daily recording of test samples for their pH level.

Moisture content determination

The moisture content of the waste was determined by subjecting the feedstock to oven drying method. The crucibles to be used were washed and dried using an oven at 105^0 c for 30mins and then allowed to cool in desiccators. Pre-weighed samples were placed in the crucible and then inserted into the oven set at 105 degrees Celsius for 5hours.the samples were then removed from the oven after this period then cooled and weights were intermittently recorded until a uniform weight was achieved.

Determination of Total Solid, Organic dry matter content, Ash content

The oven dried samples that were used in determining moisture content gave us the total solid that were present in the test sample. To determine the ash content, a little quantity of the pre-dried test sample was burnt in a muffle-furnace at 650^{0}C for 6 hours according to Ojikutu and Osokoya (2014).

$$\text{Percentage organic matter content} = \frac{\%\text{ dry matter} - \text{ash content}}{\%\text{ dry matter}} \quad (1)$$

$$\text{Percentage ash content} = \frac{\text{weight of crucible} + \text{ash} - \text{crucible}}{\text{oven dry weight of sample}} \quad (2)$$

Determination of Percentage Volatile content and Fixed Carbon content

The percentage volatile content and fixed carbon for the waste were calculated using a mathematical equation as the weight of biomass substrate from the weight remaining after digestion over weight of biomass expressed as a percentage according to Ehiem and Adama (2014). The performance evaluation for the waste was evaluated according to Adelekan and Bamgboye (2009).

Table 1. Moisture Content of Rice husk and Poultry litter.

Waste Type	W_s *(kg)*	W_{ds} *(kg)*	*Moisture content (%)*	
Rice husk	*5.00*	*4.32*	*15.7^{db}*	*13.6^{wb}*
Poultry litters	*5.00*	*3.2*	*56.25*	*36.0*

wb – wet basis, db – dry basis

Table 2. Bioconversion Efficiency of Rice husk and Poultry litter.

Waste Type	W_1 *(kg)*	W_2 *(kg)*	*Conversion efficiency (%)*
Rice husk	*24.00*	*21.10*	*12.08*
Poultry litter	*24.00*	*19.30*	*19.58*

Table 3. Composition of substrates

Parameters (%)	*Rice husk*	*Poultry litter*
Moisture content	*15.7*	*56.25*
Ash	*4.16*	*7.81*
Total solid	*4.32*	*3.2*
Fixed carbon	*76.89*	*61.94*
Volatile solid	*3.25*	*4.0*

Table 4. Operating parameters for biogas production: poultry litter feedstock

Time (days)	Ambient Temp (degC)	Slurry Temp (degC)	pH	Gas vol. (L)
1	36	39	6.4	0.0
2	32	36.5	6.4	0.0
3	30	33.75	6.0	1.38
4	37	41.7	5.8	1.46
5	32	40	5.5	1.4
6	34	36	5.4	1.2
7	32	33.5	5.4	0.98
8	31	32	5.2	0.94
9	30	30	5.2	1.2
10	36	34	5.0	1.4
11	32	30	5.1	1.2
12	34	36	5.0	1.44
13	31	32	5.2	1.2
14	30	31	5.4	1.0
15	29	28	5.2	0.53
16	30	29	5.1	0.32
17	28	28	5.1	0.62
18	29	30	5.0	0.3
19	29	31	5.1	0.58
20	32	36	5.0	1.1
21	33	32	5.1	1.27
22	31	30	5.1	1.3
23	34	33	5.2	1.32
24	30	31	5.2	1.0
25	31	33	5.2	0.98
26	34	37	5.0	1.50
27	31	33	5.2	0.34
28	32	34	5.2	0.32
29	31	30	5.1	1.3
30	28	30	5.0	1.0795

Table 5. Operating parameters for biogas production: rice husk feedstock

Time (days)	Ambient Temp (degC)	Slurry Temp (degC)	pH	Gas vol . (L)
1	36	34	5.6	0.0
2	32	36	5.6	0.0
3	30	38	5.2	0.0
4	37	36	5.0	0.0
5	32	37	5.2	0.1
6	34	34	5.0	0.2
7	32	36	5.1	0.06
8	31	29	4.9	0.11
9	30	36	4.8	0.12
10	36	36	4.9	0.2
11	32	35	4.9	0.22
12	34	34	4.9	0.21
13	31	35	5.0	0.62
14	30	30	4.8	0.35
15	29	32	4.9	0.43
16	30	30	4.8	0.21
17	28	28	4.9	0.12
18	29	35	5.0	0.5
19	29	30	5.0	0.7
20	32	36	5.0	0.8

21	*33*	*31*	*5.0*	*0.6*
22	*31*	*33*	*4.9*	*1.1*
23	*34*	*34*	*4.9*	*1.2*
24	*30*	*30*	*4.8*	*1.5*
25	*31*	*33*	*4.8*	*1.7*
26	*34*	*32*	*4.9*	*2.0*
27	*31*	*33*	*4.9*	*1.6*
28	*32*	*31*	*4.8*	*2.1*
29	*31*	*32*	*4.7*	*1.6*
30	*28*	*30*	*4.8*	*1.2*

RESULTS AND DISCUSSION

The poultry litter had the highest bioconversion efficiency of 19.58%, this is expected, since the sample had the highest amount of gas production. While, the rice husk had a bioconversion efficiency of 12.08 (%). This is as a result of the micro-organism for bio-degradation acted more on the poultry litter because it is believed that the feed had been broken down through proper digestion, before excretion by the animal. As such most of the lignin bonds from the food particles that constitute the poultry were broken down for easy digestion.

Conversion efficiency

Poultry litter and rice husk had bioconversion efficiencies of 12.47 (%) and with 4.22 (%) respectively, which means that poultry litter had higher conversion efficiency compare to rice husk which indicates that is lower volume of gas production (see table 4.2). This is similar to the result obtained from the research work by Iwuchukwu (2016) where the sample that had the highest gas production rate had higher bioconversion efficiency. It shows that greater fraction of the poultry litter was converted to biogas as compared to the rice husk. Consequently, bioconversion efficiency will also be higher for substrate having the highest number of gas production rate. This variation in gas volume was as a result of their various physical properties. For the rice husk, the waste was not degraded when it was subjected to the digester but the animal litter was already partially bio-degraded through digestion and consequently enabled its speedy reaction.

The variation and low performance of the rice husk as compared to a similar research work done by Ezekoye (2009) where the rice husk was subjected to microbial pretreatment process by the addition of green algae to the rice husk hence, the high-performance rate which means the green algae had a significant effect on the rice husk. According to the researcher, the feedstock that was used in his research had the following features: (1) The sample feedstock did not consist of only rice husk, but a combination of rice husk and algae (2) The rise in the gas production rate was due to the high level of green algae (micro-organism which aids bio-degradation) present (3) A 45 day retention time employed in the work cited, may as well be believed to had encouraged the production of biogas, as compared to a 30 day retention time allocated in this study.

pH level

The pH level relationship between rice husk and the poultry litter. Since poultry litter had a higher gas yield compare to the rice husk, it could be denoted that the pH level of this feedstock had a significant effect in the production of biogas (see Tab 4.). The optimum pH interval for mesophilic digestion is between 6.5 and 8.0 and the process is severely inhibited if the pH value decreases below 6.0 or rises above 8.3. The solubility of carbon dioxide in water decreases at increasing temperature. The pH value in thermophilic digesters is therefore higher than in mesophilic type, as dissolved carbon dioxide forms carbonic acid by reaction with water by Omer and Ibrahim (2015).

Effect of Temperature

The relationship between ambient temperatures, slurry temperature and gas volume produce for poultry litters for a 10 day retention time. It was observed that the ambient temperature had a little variation with that of the slurry temperature. This result corresponds with the those obtained by Opraku et al. (2013), which indicated that when indigestion was carried out using a metallic digester the ambient temperature was a little lower than the slurry temperature. This concession is true because metal digester tends to trap in temperature and the heat generate inside the digester plus that of the surrounding will the greater than the ambient temperature. Also, comparing with a study by Omer and Ahmed (2015) on biogas production from poultry manure, it was observed that their research work was done in a high temperature region of Sudan. The researcher also cited the fact that the poultry birds that produced the manure which was used for their research work were subjected to environmental hazard, where the birds were left to roam about and also there was no proper cleaning of the birds pens which generated harmful bacteria, lice and aerobic bacteria, especially the methanogens, which are sensitive to the acid concentration within the digester and their growth can be inhibited by acidic condition.

The variation in temperature was as a result of the difference in study location. The poultry litters gotten for this research work were free from wood shavings and as such the micro-bacteria from the saw dust in addition to that of the digested waste was minimal. Micro-bacteria tend to act more when there is high temperature for gas to be produced. In conclusion, Sudan has a higher temperature which poses a significant effect with the reaction of the microbial activities in the digester that was used by the researchers.

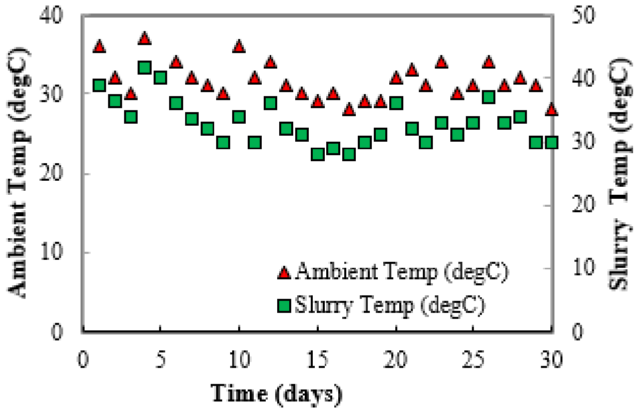

Figure 1. Variation in temperature of the different feedstock

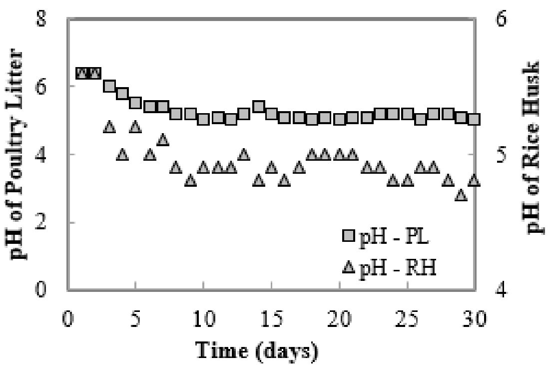

Figure 2. Variation in pH of the different feedstock

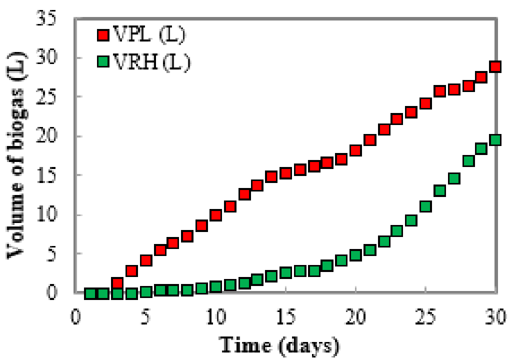

Figure 3. Variation in cumulative biogas volume

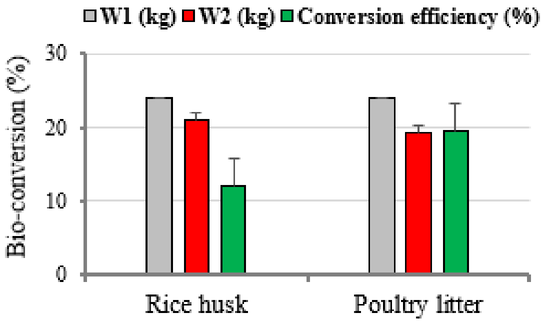

Figure 4. Bio-conversion efficiency

CONCLUSIONS

In anaerobic digestion, microorganisms digest the organic material producing biogas which can be collected and used as a valuable fuel. The yield of biogas depends on the composition of the waste feedstock and the environment conditions within the reactor. The poultry litter had already undergone some digestion process before it was passed out by the animals which mean their bonds were broken by digestive organism which makes the anaerobic digestion process easily. Similarly, the rice husk had a low gas production rate due to the presence of high lignin properties because rice is a lignin cellulose material. As such, the lignin in the rice husk took a longer period of time to break its bond due to inadequate digestive organisms that could easily digest and break the bonds to produce gas.

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PROCENA MAKSIMALNE PROIZVODNJE BIOGASA IZ RAZLIČITIH SIROVINA: EKSPERIMENTALNA STUDIJA

Ikechukwu Okosa[*1], Onyenwoke Chukwuka Austine[1], Horsfall Ibiba Taiwo[1], Umunna Muofunanya Francis[1].

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Sažetak: Ova studija prikazuje najveći kapacitet proizvodnje biogasa od različitih biomasa, kada se koristi kao početna sirovina biljni i životinjski otpadni materijal. Uporedni eksperiment u anaerobnim uslovima pokazuje da je količina biogasa od živine (28 litara) veći od ljuski pirinča (18 litara) u roku trajanja ciklusa u reaktoru od 30 dana.

Međutim, na prinos biogasa je značajno uticao sastav otpadne sirovine i uslovi životne sredine u reaktoru za gas. Prostirka za živinu već je bila podvrgnuta nekom procesu razgradnje pre nego što je živina (ptice) ostavila svoj deo, što omogućuje da se anaerobni proces lako izvrši. Slično tome, ljuska pirinča ima malu mogućnost proizvodnje gasa zbog prisustva visokih sadržaja celuloze (lignin.

Zbog toga, za optimalnu proizvodnju gasa, otpad treba prethodno predtretirati u oblasti nižih temperatura da bi se posle povećala temperatura razgradnje, jer temperatura digestije u bioreaktoru ima veliki uticaj na proizvodnju biogasa.

Ključne reči: *Predviđanje, najveći kapacitet za gas, ljuske pirinča , anaerobno razlaganje.*

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