TURKISH JOURNAL OF AGRICULTURAL ENGINEERING RESEARCH

VOLUME: 4
ISSUE: 2
YEAR: 2023

TURKAGER

2023

e-ISSN:2717 - 8420

https://dergipark.org.tr/tr/pub/turkager

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Volume 4,
Issue 2,
Year 2023

Indexing / Abstracting

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https://dergipark.org.tr/tr/pub/turkager

Turkish Journal of Agricultural Engineering Research

TURKAGER

PUBLISHER

Prof. Dr. Ebubekir ALTUNTAŞ

Tokat Gaziosmanpaşa University, TÜRKİYE

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Turkish Journal of Agricultural Engineering Research (Turk J Agr Eng Res, TURKAGER) is an international open-access online, and peer double-blind reviewed journal. TURKAGER publishes the original English and Turkish research articles and a very limited number of review articles. There are no page charges for manuscript publishing in this journal. TURKAGER has an open access system and online journal published twice a year in June and December.

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TURKISH JOURNAL OF AGRICULTURAL ENGINEERING RESEARCH
TURKAGER
e-ISSN: 2717 - 8420
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Turkish Journal of Agricultural Engineering Research
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TURKISH JOURNAL OF AGRICULTURAL ENGINEERING RESEARCH
TURKAGER
e-ISSN: 2717 - 8420
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Turkish Journal of Agricultural Engineering Research TURKAGER

Volume 4,
Issue 2,
December 31, 2023

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TURKISH JOURNAL OF AGRICULTURAL ENGINEERING RESEARCH
TURKAGER
e-ISSN: 2717 - 8420
https://dergipark.org.tr/tr/pub/turkager

Turkish Journal of Agricultural Engineering Research TURKAGER

Volume 4,
Issue 2,
December 31, 2023

Turkish Journal of Agricultural Engineering Research

https://dergipark.org.tr/en/pub/turkager
https://doi.org/10.46592/turkager.1260521

Turk J Agr Eng Res
(TURKAGER)

ISSN: 2717-8420
2023, 4(2), 151-177

Research Article

Development and Performance Evaluation of Double Shaft Plastic Bottle Crusher for Small Scale Industrial Application

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Article Info

Received: 09.03.2023 **Accepted:** 01.08.2023 **Published:** 31.12.2023

ABSTRACT

Plastic pollution is a problem that is affecting many aspects of human endeavour. Searches are being made for ecofriendly alternatives and waste management practices that can lessen the impact of plastic pollution. On the list are waste plastic reuse, use of bioplastics, reduction of reliance on plastic usage, and plastic waste recycling. In this technical brief, a plastic shredder was developed to recycle plastic waste in the value chain. Plastic shredder is a machine that turns used plastic bottles to smaller particle sizes to enhance portability, easiness and readiness for use into new products. While in operation, the prime mover drives the transmission shafts with low speed in the range of 25 to 65 rpm to give shredding torque that masticates materials fed in, into desired granular size. Bivariate Linear regression was the statistical model used to understand the relationship between the two variables of evaluation, the predictor x (speed) and the response variable y (shredding capacity). Since significance F (0.0216) is less than 0.05, there is 95% confidence that there is linear relationship between speed of rotation and shredding capacity of the machine. Model equation is therefore given as $Y = 0.952 X_1 - 11.725 \pm 2.53$*. The machine respectively gave highest shredding capacity for PET bottles, Tin can and wastepaper as 56.52 kg h^{-1}, 29.60 kg h^{-1} and 42.09 kg h^{-1} at optimum speed of 65 rpm. If operated for 8 hours in a day, it can favorably shred almost half a ton of plastic bottles (452.16 kg day^{-1}). The machine was developed at an affordable cost of $817.72. The paper shredded with the machine can be pulped and made into poultry egg crates and paper print used in building industry. The machine is less stressful to operate and economical to run and maintain. If the machine is widely adopted, the menace caused by nonbiodegradable materials like plastic will be ended.*

Keywords: *Shredder, Mastication, PET bottles, Shredding capacity*

To cite: Okusanya MA, Ogunlade CB and Oluwagbayide SD (2023). Development and Performance Evaluation of Double Shaft Plastic Bottle Crusher for Small Scale Industrial Application. *Turkish Journal of Agricultural Engineering Research (TURKAGER), 4(2): 151-177.*
https://doi.org/10.46592/turkager.1260521

INTRODUCTION

Nigeria has the highest Gross Domestic Product (GDP) and is the most populous country on the African continent. The sporadic rise in the country's population has made its citizens' consumption of plastics to surge from 578,000 tonnes in 2007 to approximately 1,250,000 tonnes in the recent time. As a result, the per capita usage of plastic has increased from 4.0 kg to 6.5 kg, or roughly 5% annually. Each resident is reportedly consuming 7.5 kilogram of plastic annually (Okorafor, 2022). Also, report by World Bank reveals that plastic trash makes about 12% of all municipal solid waste created globally. Out of the plastic waste generated, only 14% of that waste is collected for recycling and only 9% of the waste collected is eventually recycled (World Bank, 2018).

The overuse of plastic and improper management of the country's wastes represents a threat to human health and the environment because they leach harmful chemical contents into foods, drinks, and the environment, including endocrine disrupting chemicals that have been linked to infertility, diabetes, and prostate/breast cancer. In order to solve the problem of plastic menace that has put the nation's ecology and public health in peril, the government of Nigeria embraced a circular economy model in collaboration with United Nations Industrial Development Organization, UNIDO (Okorafor, 2022).

The ongoing circular economy initiatives in Nigeria include: National Plastic Waste Recycling Programme under which at least one plastic recycling plant is to be established in each of the 774 Local Government Areas in the country; Community Based Waste Management Programme that encourages the involvement of local communities in modern waste management practices such as waste sorting, segregation, composting and recycling as well as ownership of projects; The World Bank Assisted Pro-Blue Project for Lagos aimed at reducing marine plastic pollution and creating plastic recycling markets; Waste to wealth entrepreneurship programme for the empowerment of the most vulnerable group especially youth and women; Putting in place, legal and regulatory framework - National Policies on Solid waste, Plastic waste and Battery waste Management; Studies on the Alternative Packaging Material to Plastics in collaboration with UNIDO; Establishment of the Nigeria Circular Economy Working Group; etc. (Ikeah, 2018). The initiatives are hoped to address plastic waste menace constituting nuisance to our environment.

Plastic waste has become a global menace that threatens the environment and human health. The widespread use of single-use plastics, such as water bottles, bags and food packaging, has led to a massive accumulation of plastics waste in landfills and oceans. Plastic waste has also taken a toll on terrestrial ecosystems. It clogs drains and contributes to flooding in urban areas (see Figures 1a, 1b and 1c for more details on how plastic waste pollution impacts some urban areas of Lagos, Nigeria). The poorest members of society are frequently negatively impacted by poor waste management practices. Our resources need to be used and then reused continuously so that they do not end up in landfills or clog drains.

Efforts to tackling plastic waste menace have been implemented globally so as to promote sustainable development goal of 2030 (SDG 12, 14 and 15) through an absolute reduction in plastics. If efficient waste collection systems are implemented globally while also reducing the usage of plastics, there will be enormous positive

effects. Removing plastic from beaches and collecting it at sea are vital initiatives; they will not make much of a difference if the flow of plastic is not also decreased. Moreover, plastics and chemical additives pose a threat to ecosystems in the ocean and on land; they can suffocate animals, make them unable to consume enough food, making them easier prey for other animals, sicken coral reefs, and do much more; their significant reduction will hasten the restoration of ecosystems and biodiversity. (Plastic Soup Foundation, 2016).

Utilizing biodegradable plastic as a substitute for traditional plastic is another workable method of reducing plastic waste pollution. Regulations and financial incentives can be used to encourage firms to use biodegradable packaging materials this will lower the demand for traditional plastics and reduce plastic pollution. Other common methods of managing plastic garbage include landfilling and cremation. However, according to a paper by Okusanya and Ibrahim (2020), burning plastic produces toxic dioxin emissions, and if incinerators are inefficient, the chemicals seep into the environment, causing air pollution and creating photochemical haze that is dangerous to human health. Additionally, it was discovered that landfilling should be avoided at all costs because it has negative effects on people and puts plant and animal life in jeopardy.

Collaborative effort from people, industry, and government at all levels of governance is needed to find a sustainable solution to plastic pollution problem. Individuals can help reduce plastic trash by adopting proper disposal and consumption practices. This can involve recycling properly, utilizing reusable water bottles and shopping bags, avoiding single-use plastics whenever possible. Government should implement laws and regulations governing efficient methods of managing plastic waste and form alliances with groups dedicated to sustainable development.

Everything we consume becomes waste including plastic bottles. The process of treating waste materials to produce new products is termed recycling. Recycling significantly will reduce the amount of plastic waste generated annually. Energy consumption and air pollution coming from plastic waste combustion will also reduce significantly where plastic waste recycling is in practice (Degli and Marzetti, 2019). Recycling is therefore a good waste management practice of choice one can explore.
Shredding PET (Polyethylene terephthalate) plastic is an essential step in the recycling process. Once the bottles are shredded, they can be cleaned, washed, and separated from other materials such as caps, labels and residues. The PET flakes can then be melted and reprocessed to create new plastic products, including fibers for textiles, plastic strapping, and the production of new bottles. By reducing PET plastic to smaller pieces, they take up less space in recycling facilities, making transportation and storage more efficient. Shredded PET plastic can be used for various applications beyond recycling. It can be used in the manufacturing of construction materials, like carpets, insulation, or even as a raw material for the production of polyester fabrics.

The process of shredding PET bottles involves feeding the bottles into a shredder or granulator machine that contains sharp blades or rotating cutters. These blades or cutters tear the bottles into smaller pieces, typically ranging from a few millimeters to a few centimeters in size. The resulting PET flakes can then be further processed for recycling or used for other purposes. This technical brief is therefore

geared towards developing PET bottles shredder of 500 kg capacity in one hour for managing plastic waste at small scale level.

Figure 1a. *Plastic waste clogging drains in urban area of Lagos, Nigeria.*

Figure 1b. *Plastic waste dump at Idimu Area, Lagos, Nigeria (Okusanya and İbrahim, 2020).*

Figure 1c. *Plastic Waste Dump at Egbeda Area, Lagos, Nigeria (Okusanya and Ibrahim, 2020).*

MATERIALS and METHODS

Design Consideration

Some relevant factors were considered in the design and development of the plastic shredder; such factors include power requirement, ease of replacement of various components, ease of mobility, possibility of machine duplication, safety of operation of parts, cost of construction, types of load and stresses, machine kinematics, machine kinematics and cost of maintenance. A 12 mm thick mild steel plate was used for the construction to prevent shearing of part and ultimate machine failure.

Design Philosophy

The transmission shafts of the shredder work in an interwoven manner through the help of gear drive to deliver a strong abrasive force on the materials in the shredding chamber so as to achieve mastication into desired granular size.

Component Parts of the Machine

The designed shredder thus reduces the particle size of used plastic for easy movement and ease of conversion into another new product. The shredder is made up of the following parts:

i. Hopper: a section that takes in waste PET into the shredding chamber.

ii. Shredding chamber: where the waste pet bottle is reduced into smaller size. This chamber is made up of mild steel. The shredding chamber has two counter rotating shafts that are 500 mm long and 35 mm in diameter. On the shaft are 12mm mild steel plates attachment which are machined on the lathe.

iii. Transmission shafts: The shafts are two in number. One acts as driving shaft while the other acts as driven shaft. The counter rotation of the shafts is aided by set of gears at the peripheral of the transmission line.

iv. Cutter blade: This cuts the pet bottle into smaller grains with its sharp edge.

v. Bearing: it is a mechanical device that supports another part (like transmission shaft) set in motion to reduce friction.

vi. Chain drive: It is used to transfer power or motion from the shaft of the prime mover to the driving shaft of the shredder.

vii. Counterweight: This is a heavy mass of iron mechanically linked in opposition to a load. It supports the machine and maintains balancing.

viii. Member frame: it is a support on which other component parts rest to make the entire assembly stable. It is made from mild steel and has a dimension of 480 mm x 480 mm x 400 mm.

ix. Discharge outlet: The shredded plastic passes through an outlet provided at the peripheral of the machine. It is made from mild steel and has a dimension 279 mm × 131 mm x 102 mm.

x. Prime mover: is a machine that receives and modifies energy as supplied by some natural sources or fuel and transforms it into mechanical work. The machine fabricated is powered by a petrol engine with a reducer gear assembly.

xi. Channel: It is the platform that maintains the stability of the machine. It carries the load and weight of the machine. It is made up of angle iron.

Material Selection

Table 1 below shows the materials used for construction of various subcomponents of the shredder assembly. The dimensions, remarks and the criteria for selection of those components were also presented in the table.

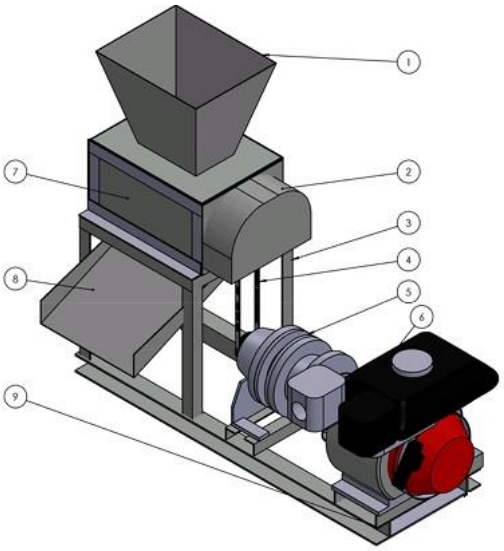
Table 1. Material selection.

Machine component	Criteria for material selection	Machine selected	Dimension	Remark
Hopper	Must be strong and able to acquire more material	Galvanized mild steel of 6 mm thickness	493 mm x 320.94 mm x 450.00 mm	It does not twist and has ability to occupy more material (fabricated)
Shredding chamber	Ability to withstand cutter blade vibration and impact force and torque	Galvanized mild steel of 6 mm thickness	611.61 mm x 450.00 mm	Durable (fabricated)
Transmission Shaft	Must be strong	Stainless steel	492.40 mm long and ϕ 35 mm	It was machined
Cutter blade	Must be strong and have sharp cutting edges	Mild steel of 12 mm thickness	120 mm x 150 mm x 40 mm	It has strong and sharp edges for crushing (machined)
Gear reducer	Ability to increase and decrease the speed of the engine	Mild steel of 8 mm thickness	275 mm x 392 mm x 320 mm	Available (bought readymade)
Chain	Must be strong and not flexible	Chain	Size: 50, pitch: 15.88 mm , roller diameter: 10.16 mm	Stable (bought readymade)
Sprocket	Ability to have a good wear property	Mild steel	150 mm x 75 mm	Bought readymade
Bearing	Must be durable and strong	Mild steel	Flange bearing of 35 mm diameter	Bought readymade
Counter weight	Ability to withstand load of the shaft for balancing	Cast Iron block	200 mm x 75 mm	Available and durable
Channel	Must be able to withstand dead load imposed by the self-weight of the shredder	Angle iron of 6 mm thickness	1047 mm x 365 mm x 80 mm	Constructed
Bolts and nuts	Must be hard and durable	Alloy steel	Various sizes ranging from 13 mm to 24 mm	Bought readymade
Prime mover	Must be a medium or high speed engine	Petrol engine	13 HP Petrol Engine (GX 390)	Bought readymade

Machine Description

The shredder uses mastication principle to reduce the size of pet bottle fed into the crushing chamber through the hopper. The machine assembly is powered by a prime mover (13 HP petrol engine). The power from the prime mover is harnessed by direct coupling, reduction gear and chain drive. The reducer is linked to the prime mover through direct coupling. The reducer assists in bringing down the speed from the prime mover (2400 rpm) to 120 rpm. The speed is further reduced to 65 rpm and below through chain drive between reducer shaft and transmission shaft of the shredder assembly. Once materials are fed into the shredding chamber through the hopper, cutter blades on the shaft then grab the materials to masticate it into desired granular sizes. Masticated Pet bottles are afterwards discharged through discharge

unit. Figures 2, 3 and 4 are respectively the pictorial view, autographic projection and exploded view of the machine assembly.



S/N	COMPONENT	SPECIFICATIONS
1	Hopper	2mm Mild Steel Plate
2	Guide	2mm Mild Steel Plate
3	Frame	50x50x5mm i Mild SteelAngle iron
4	Chain	-
5	SpeedReduction Gear	Ratio 30 to1
6	Prime Mover	10hp Petrol Engine
7	Shredding Unit	-
8	Outlet	2mm Mild Steel Plate
9	Engine Seat	70x 70x7mm channel

Figure 2. *Pictorial view of the pet bottle shredder.*

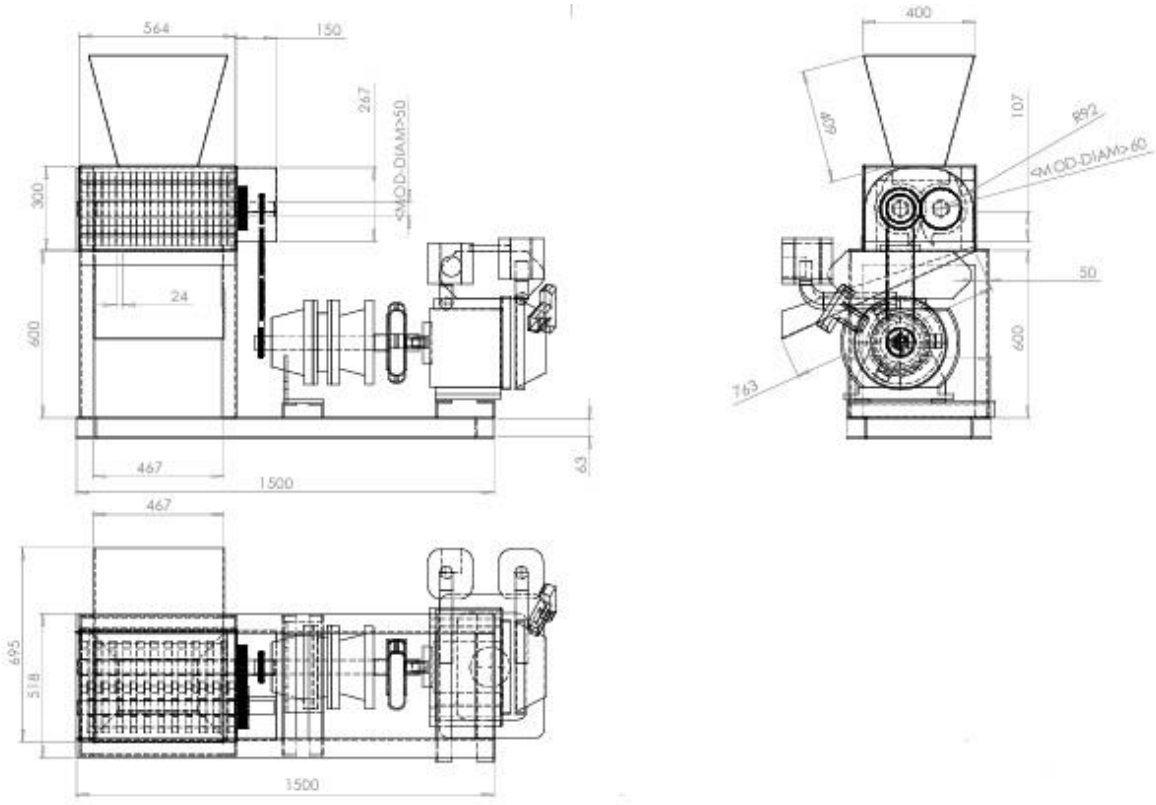
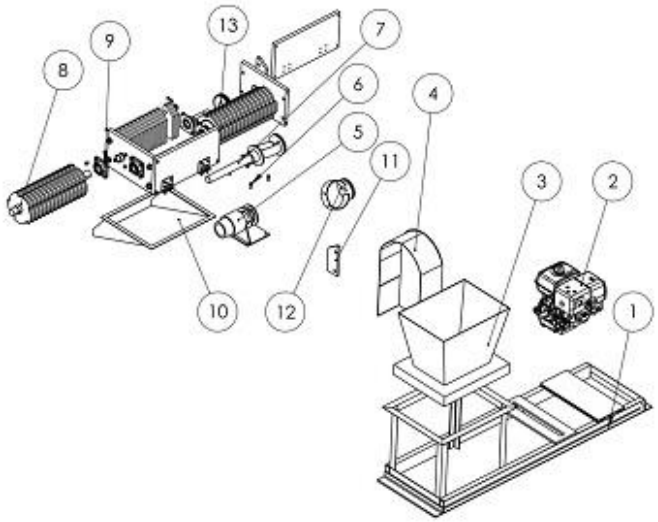


Figure 3. *Orthographic projection of pet bottle shredder.*



S/N	COMPONENTS
1	Support Stand Frame
2	Petrol Engine
3	Hopper
4	Gears Cover
5	Reducer Gear
6	Bolt and Nuts
7	Shaft
8	Cutters
9	Bearings
10	Outlet
11	Cutter Spacer
12	Coupling (rubber)
13	Spockets

Figure 4. *Exploded view of the machine assembly.*

Design Calculation of the Shredder

Hopper design

The hopper is trapezoidal in shape. It was designed to aid easy of material flow into the shredding chamber. Angle of repose, cross section area, mass flow rate and volume of plastic to be accommodated are the parameters considered in the design of the hopper.

Volume of hopper

Volume of the Hopper, $Vh = \frac{1}{3}\ x\ h\{A1 + A2\sqrt{A1 + A2}\ \}$ (1)

Where, A_1 = Area of top base in m^2

A_2 = Area of bottom base in m^2

h = Height of hopper in m = 251 mm = 0.251 m

V_h = Volume of hopper in m^3

$A_1 = 0.494\ x\ 0.45 = 0.223\ m^3$

$A_2 = 0.37\ x\ 0.35 = 0.1295\ m^2$

$Vh = \frac{1}{3} x\ 0.251\{0.223 + 0.129$

$5\sqrt{0.223 + 0.1295})\ \}$

$Vh = 0.0251m^3$ (See Figures 2 and 5 for details)

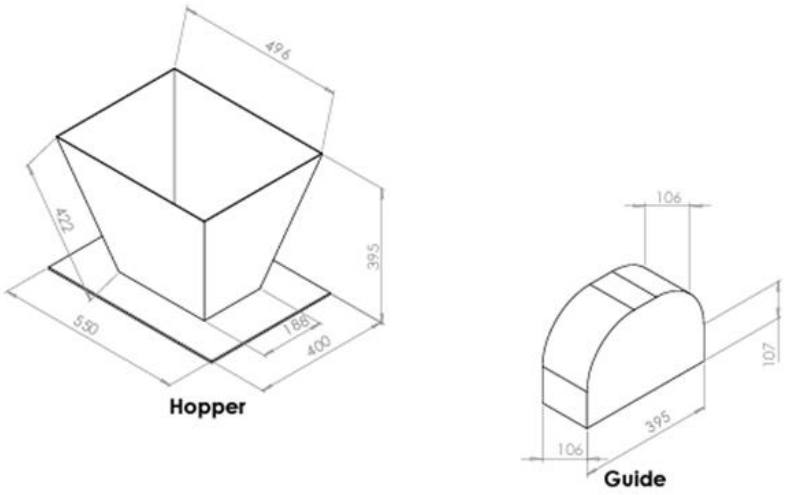


Figure 5. Hopper design.

Angle of repose

Angle of repose, ∅ is otherwise known as angle of pour. It is a function of coefficient of both sliding friction(μs) and rolling friction (μr) (Khurmi and Gupta, 2004).

$$\emptyset = \tan^{-1}(\mu s) \quad (2)$$

μ_s is 0.54 (Engineering Toolbox, 2004) for recyclable plastic like PET bottles.

By using Equation 2, the angle of repose can then be found.

$\emptyset = \tan^{-1}(0.54) = 28.4^0$.
Angle of repose is therefore 28.4^0

Number of PET bottle in the hopper

Volume of PET bottles in the shredding chamber, V_{pet} $\pi r^2 h$

Where r is the radius of the PET bottle (cm) = 3.5 cm = 0.035 m
h is the height of the PET bottle (cm) = 26 cm = 0.26 m
$V_{pet} = \pi \ x \ 0.035^2 \ x \ 0.26 = 0.001001 \ m^3$

$$Number\ of\ PET\ Bottles = \frac{Volume\ of\ Hopper}{Volume\ of\ PET\ Bottles} = \frac{0.0251}{0.001001}$$

$$Number\ of\ PET\ Bottles\ the\ hopper\ can\ take\ at\ a\ time = \ 25.07 \ \approx 25\ bottles$$

The hopper can therefore take 25 pieces of PET bottles at once.

Chain drive design

Chain drive is one of the drive mechanisms used in harnessing power produced by the prime mover. The power harnessed is then directed to the transmission shaft through the drive chosen to set the entire assembly in motion. Chain drive was the drive of choice used to transmit power from the reduction gear linked to the prime mover (petrol engine) to the transmission shafts responsible for mastication of materials under consideration.

Pitch diameter of sprocket

The pitch diameter is a function of the chain pitch and the number of teeth in the sprocket. The pitch diameter of sprocket is therefore given by Equation 3 (Srivastava *et al.*, 2012).

$$PD = \frac{P}{Sin(\frac{180}{N})} \quad (3)$$

Where P= the chain pitch,
N= Number of teeth in the sprocket
PD= Pitch diameter.

For small sprocket of 19 teeth and 12.7 mm pitch, the pitch diameter is given as

$$PD = \frac{12.7}{Sin(\frac{180}{19})} = \frac{12.7}{sin9.47} = \frac{12.7}{0.1645} = 77.20\ mm$$

For big sprocket of 29 teeth and 18.45 mm pitch, the pitch diameter is given as

$$PD = \frac{19.2}{Sin(\frac{180}{29})} = \frac{19.2}{sin6.21} = \frac{19.2}{0.1081} = 177.61\ mm \approx 178\ mm$$

Length of chain

The length of chain can be determined using Equation 4 (Srivastava *et al.*, 2012).

$$\frac{L}{P} = \frac{2C}{P} + \frac{N1+N2}{2P} + \frac{(N2-N1)^2}{\left\{4\pi^2\left(\frac{C}{P}\right)\right\}} \quad (4)$$

Where C is the center distance between the sprockets; N_1 and N_2 are number of teeth on the two sprockets.
If the center distance between the two sprockets is taken as 800 mm and chain pitch for standard roller chain according to ANSI standard is 3.2 mm, the length of chain is then given as:

$$\frac{L}{3.2} = \frac{2x800}{3.2} + \frac{19+29}{2x3.2} + \frac{(29-19)^2}{\left\{4\pi^2\left(\frac{800}{3.2}\right)\right\}} = 500 + 7.5 + 0.0101 = 507.51$$

$$\frac{L}{3.2} = 507.51$$

Therefore, L = 3.2 x 507.51 = 1624.03 mm
Hence, chain length L = 1.624 m

Chordal speed variation of sprocket

$$\frac{\Delta v}{v} = \frac{\pi}{N}\left\{\frac{1}{sin\left(\frac{180}{N}\right)} - \frac{1}{tan\left(\frac{180}{N}\right)}\right\} \quad (5)$$

Where the chain velocity is v = NPn; P = pitch and n = angular speed in rev s^{-1} (Srivastava *et al.*, 2012).

Chain velocity estimation

$$V = N1P1n1 = N2P2n2 \quad (6)$$

Where the chain velocity is v = NPn in the driving sprocket or driven sprocket; P = pitch and n = angular speed in rev/s (Srivastava et al, 2012).

If angular speed, n is 65 rpm = 65/60 = 1.08 rev. s^{-1}; N_1 = 19, and P_1 = 12.7 mm, then:

$$V = 1.08\ x\ 19\ x \frac{12.7}{1000} = 0.261\ ms^{-1}$$

For angular speed of 25 rpm, sprocket of 29 teeth and pitch of 18.45 mm, then:

$$V = 25\ x\ 29\ x \frac{18.45}{1000} = 13.38\ ms^{-1}$$

In calculating chordal speed variation at speed n1 of 25 rpm, sprocket teeth of 29 teeth and pitch of 18.45 mm,

$$\frac{\Delta v}{v} = \frac{\pi}{N}\left\{\frac{1}{sin\left(\frac{180}{N}\right)} - \frac{1}{tan\left(\frac{180}{N}\right)}\right\} = \frac{\pi}{29}\left\{\frac{1}{sin\left(\frac{180}{29}\right)} - \frac{1}{tan\left(\frac{180}{29}\right)}\right\}$$

$$= \frac{\pi}{29}\{9.25 - 9.195)$$

$$= \frac{\pi}{29} x\ 0.55 = 0.00596$$

Therefore, chordal speed variation, $\frac{\Delta v}{v} = 0.596\ \%$

Reduction gear assembly

The reduction gear has speed ratio of 1:30 for the 13 Hp petrol engine. The net output speed of rotation of the prime mover is 3,600 rpm; net torque is 26.4 N m at 2,500 rpm. Net output Power, P= 13 Hp = 0.746 x 13 = 9.7 kW.

Since the reduction gear has speed ratio of 1:30, the speed is brought down to: n $= \frac{3600}{30} = 120\ rpm$. The speed is further stepped down by chain drive linking the reducer shaft to driving shaft of the shredder. The reduced speed is after wards transmitted to the driving and driven shafts run by spur gears on them. The speed is further stepped down by chain drive.

Input power requirement

The input power measurement can be determined from the name plate information of the prime mover used to power the machine. It can also be determined from the drive for the transmission shaft of the machine. In this endeavor, the input power for the shredder was calculated based on torque requirement of the transmission shafts. Power requirement of the driving and the driven shaft is calculated using the formula in Equation 7 (Belonio, 2004).

$$P = \frac{2\pi NT}{60{,}000}\ (KW) \qquad (7)$$

Where N= final speed of rotation of transmission shaft in rpm = 65 rpm

T = torque requirement of the transmission shaft = 25.725 Nm.

$$P = \frac{2\pi\ x\ 65\ x\ 25.725}{60{,}000} = 0.1752\ KW = 175.2\ W$$

Torque requirement

$$T = F \times r \quad (8)$$

Where F is the total load on the shafts and r is the radius of the shaft (Ossian, 2023).

F= 1470 N (see Equation 7 for details).

$r = \frac{35}{2\ x\ 1000} = 0.0175\ m$

$T = 1470\ x\ 0.0175 = 25.725\ Nm$

Transmission shaft design

Shaft design consists primarily of the determination of the correct shaft diameter to ensure satisfactory strength and rigidity when the shaft is transmitting power under various operating and loading conditions. Shafts are usually in cross-section and may be either hollow or solid. The shaft considered for design in this research brief is solid cylindrical shaft (See Figure 6 for details).

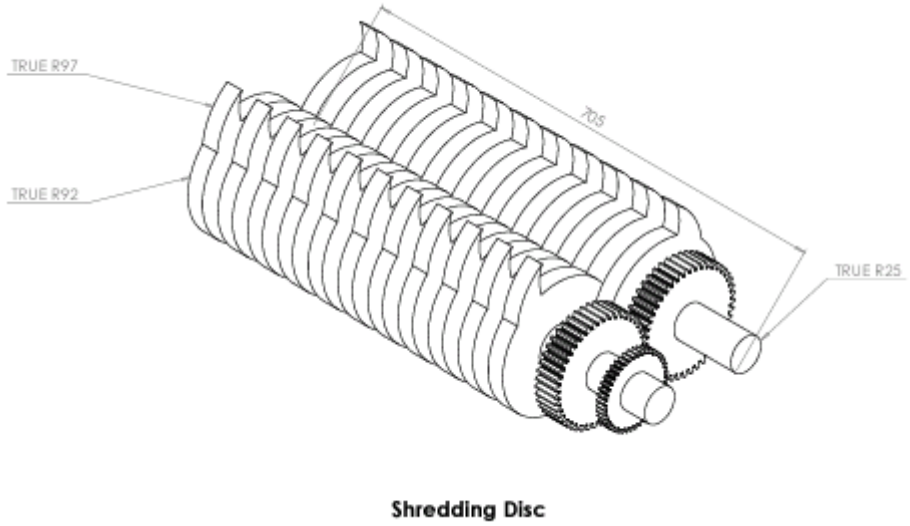


Figure 6. *Shafts design.*

The ASME code equation for solid shaft diameter is as given in equation in Equation 9 (Hall *et al.*, 2017).

$$d^3 = \frac{16}{\pi\ Ss}\sqrt{\{(KbMb)^2 + (KtMt)^2\}} \quad (9)$$

To determine the shaft diameter, the following parameters are given:
K_b = 2, K_t = 1.5 (fatigue factors for solid shaft), G= 10 x 10^9 Nm^{-2} (stainless steel shaft parameter), Ss = 55 MNm^{-2} (Maximum allowable stress for solid shaft), MB = 172 Nm (from bending moment calculation), M_T = 26.4 Nm (torsional moment is from name plate of prime mover).

$$d^3 = \frac{16}{\pi\ Ss}\sqrt{\{(KbMb)^2 + (KtMt)^2\}}$$

$$d^3 = \frac{16}{\pi\ x\ 55\ x\ 10^6}\sqrt{\{(2\ x\ 172)^2 + (1.5\ x\ 26.4)^2\}}$$

$d = \sqrt[3]{\{\frac{16}{\pi\ x\ 55\ x\ 10^6}\sqrt{\{(2\ x\ 172)^2 + (1.5\ x\ 26.4)^2\}}\}}$

$d = \sqrt[3]{\{9.26\ x\ 10^{-8}\ x\ \sqrt{\{344^2 + 39.6^2}}$

$d = \sqrt[3]{\{9.26\ x\ 10^{-8}\ x\ \sqrt{\{119904.31\}}}$

$d = \sqrt[3]{3.2065\ x\ 10^{-5}}$

d = 0.0318 m

d ≈ 32 mm

Diameter of shaft section for each shaft can be taken as 35 mm

Shear Force and Bending Moment Calculation

Force analysis

Finding reactions R_A and R_B at the bearing section:

Weight of spur gears, W_1 = 350 N;

Weight of blades on the main shaft in the shredding chamber, W_2 = 700 N;

Weigh t of the counterbalance W_5 = 200 N;

Weight of the main Shafts W_3 = 200 N;

Weight of materials (plastic) to be processed per operation, W_4 = 20 N.

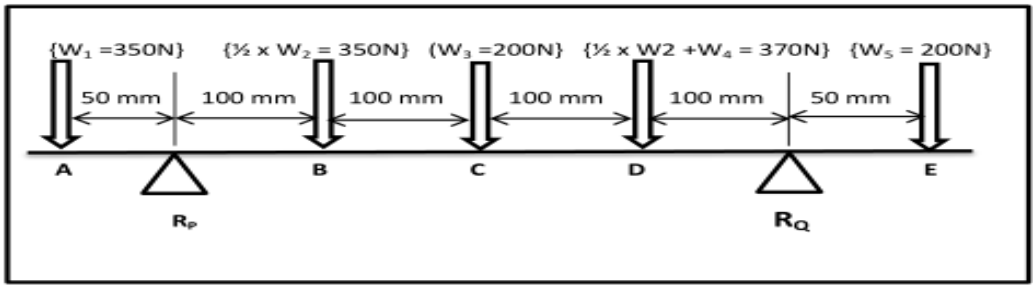


Figure 7. *Force analysis on the transmission shafts.*

The reactions R_P and R_Q are at the supports (the bearing sections)

ΣM about R_B = 0,

$$\Sigma M\ (CCW) = \Sigma M\ (CW) \quad (10)$$

Where CW is clockwise moment and CCW is anticlockwise moment (Anyakoha, 2016).

$$R_P + R_Q = W_1 + W_2 + W_3 + W_4 + W_5 \quad (11)$$

Where R_P and R_Q are respectively reactions at the two supports (Anyakoha, 2016).

$R_P + R_Q$ = 350 + 700 + 200 + 20 + 200 = 1470N

$\Sigma M\ (CCW)$ = (W_1 x 0.45) + {(½ x W_2) x 0.3} + (W_3 x 0.2) + {(½ x W_2 + W_4) x 0.1)}

= 350 x 0.45 + 350 x 0.3 +200 x 0.2 + 370 x 0.1

= 157.5 + 105 + 40 + 37

$\Sigma M\ (CCW)$ = 339.5 Nm

$\Sigma M\ (CW) = R_P$ x 0.4 + W_5 x 0.05

= 0.4R_P + 200 x 0.05

= 0.4R_P + 10

From analysis above:
$0.4R_P + 10 = 339.5$
$0.4R_P = 339.5 - 10 = 329.5$
$R_P = 823.75$ N
From Equation 2, $R_Q = W_1 + W_2 + W_3 + W_4 + W_5 - R_P$
$R_Q = 1470 - 823.75 = 646.25$ N
$R_Q = 646.25$ N
See Figures 7 and 8 for details of shear force and bending moment diagram.

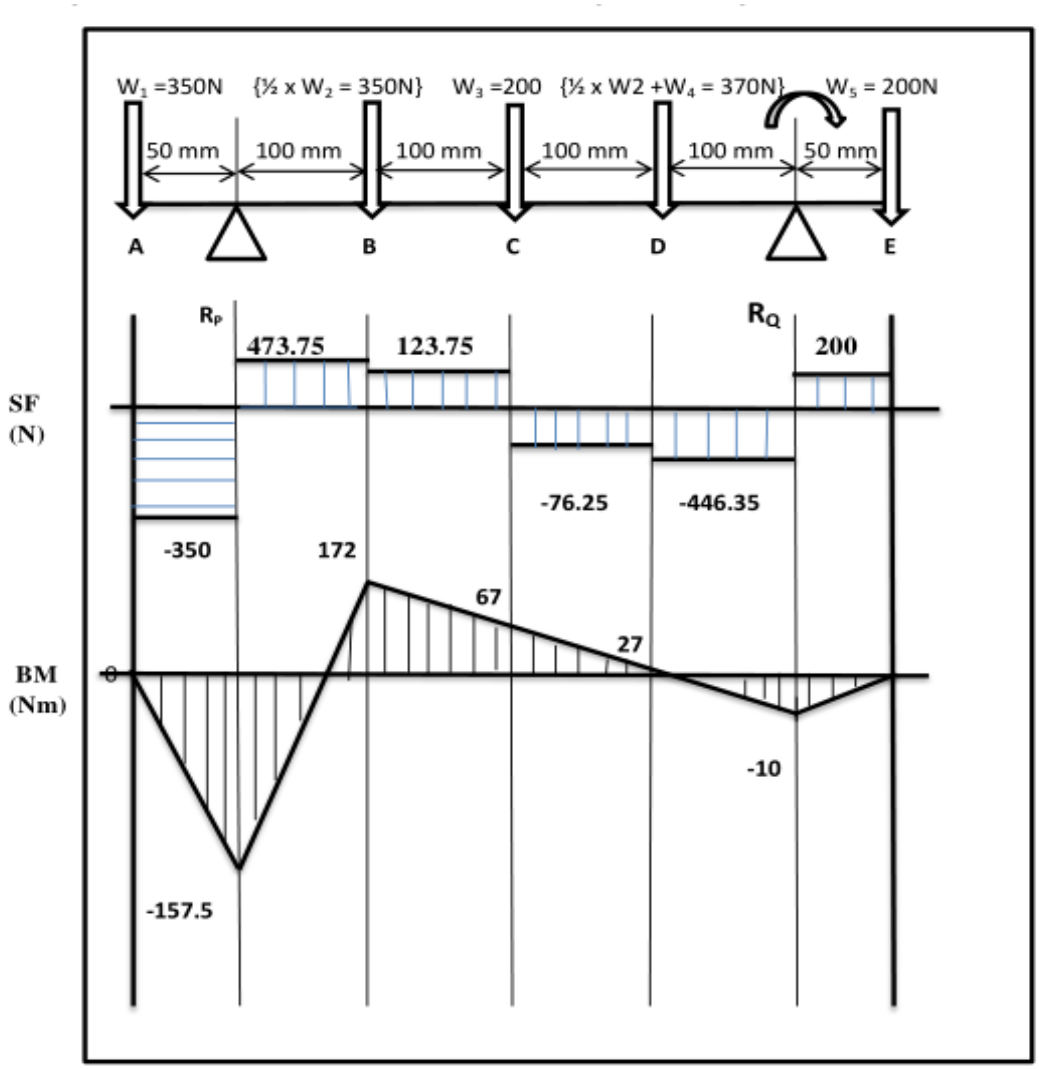


Figure 8. *The shear force and bending moment diagram.*

Σ*M* about a turning point is zero. IF R_A is taken as reference point, the resultant moment at each point is as given below:
W_A: $M_A = W_1$ x 0.45 = 350 x 0.45 = - 157.5 Nm
W_{RP}: $M_{RP} = M_A + R_P$ x 0.4 = -157.5 + 823.75 x 0.4
= -157.5 + 329.5
$M_{RP} = 172$ Nm
W_B: $M_B = M_{Rp} - W_2$ x 0.3 = 172 – 350 x 0.3
$M_B = 172 - 105$
$M_B = 67$ Nm

$M_C = M_B - W_3$ x .2 = M_B - 200 x 0.2
W_C: M_C = 67 – 40 = 27 Nm
$M_D = M_C - \{½ \text{ x } W_2 + W_4 = 370N\}$ x 0.1
W_D: M_D = 27 – 370 x 0.1 = - 10 Nm
R_Q: $M_{Rq} = M_D + 0$ = - 10 Nm
W_5: $M_E = M_{RB} + W_5$ x 0.05
M_E = - 10 + 200 x 0.05 = -10 + 10
M_E = 0
M_{bmax} = maximum bending moment on the transmission shaft
M_{bmax} = 172 Nm

Stress Analysis of Transmission Shafts
Using the bending moment value (calculated) in Figure 9 to determine the following type of stresses experienced by the transmission shafts:

Bending stress

$$\sigma b = \frac{\{Mb \; x \; Ymax\}}{I} \quad (12)$$

y = c (shaft radius in meter) = $\frac{0.035}{2} = 0.0175 \; m$

I = second moment of inertia (m^4)
$Mb = Bending \; moment \; of \; the \; shaft \; in \; Nm = 172 \; Nm$

$$I = \frac{\pi d^4}{32} = \frac{\pi \; x \; 0.035^4}{32} = 1.47 \text{ x } 10^{-7} \text{ m}^4 \quad (13)$$

(Gopal, 2010).

$$\sigma b = \frac{\{172 \; x \; 0.0175\}}{I}$$

$$= \frac{\{172 \; x \; 0.0175\}}{1.47 \; x \; 10^{-7}} = 2.04 \; x \; 10^7 Nm^{-2} = 20.4 \; MPa$$

Bending stress, σb is therefore 20.4 MPa

Normal stress

$$\sigma n = P/A \quad (14)$$

Where P is total load on the shaft in N and A is cross sectional area of shaft in m^2 (Gopal, 2010).

P = 1470 N, $A = \frac{\pi d^2}{4} = \pi \; x \frac{0.035^2}{4} = 0.000962 \; m^2$

σn = 1470/ 0.000962 = 1,528,066.53 Pa
Normal stress, σn on the shafts is 1.53 $M \; Pa$

Torsional stress

$$\sigma t = \frac{Mt\ x\ r}{J} \quad (15)$$

Where Mt is torsional moment of shaft, r the radius and J the polar moment of inertia (Gopal, 2010).

$$J = \frac{\pi d^4}{64} = \pi\ x \frac{0.035^4}{64} = 7.37\ x\ 10^{-8}\ m^4$$

$$\sigma t = \frac{21.79\ x\ 0.0175}{7.37\ x\ 10^{-8}} = 4.93 \text{ MPa}$$

Torsional Stress, σt on the shaft assembly is therefore 4.93 MPa

Shear stress

$$\tau = \frac{16}{\pi d^3}\sqrt{Mb^2 + Mt^2} \quad \text{(allowable)} \quad (16)$$

d = shaft diameter, Mb = bending moment, Mt = torque or torsional moment and τ = shear stress (Gopal, 2010).

$$\tau = \frac{16}{\pi\ x\ 0.035^3}\sqrt{(172^2 + 26.4^2} = \frac{16}{\pi x 0.035^3}\ x\ \sqrt{(30280.96)}$$

τ = 20.67 M Pa (below 55 M Pa which is maximum allowable value for solid shaft)

Principal stress

$$\sigma max = \frac{\sigma x + \sigma y}{2} \pm \sqrt{\left\{\frac{(\sigma x - \sigma y)^2}{2} + \sigma xy^2\right\}} \quad (17)$$

σx = Normal stress in axial axis, $\sigma x = normal\ stress\ in\ radial\ axis,\ \sigma xy$ = shear stress (Gopal, 2010).

$$\sigma max = \frac{\sigma x + 0}{2} \pm \sqrt{\left\{\frac{(\sigma x - 0)^2}{2} + \sigma xy^2\right\}}$$

$$\sigma max = \frac{1.53 + 0}{2} \pm \sqrt{\left\{\frac{(1.53 - 0)^2}{2} + 20.67^2\right\}}$$

$\sigma max = 21.46\ MPa$
Principal Stress, σmax is therefore 21.46 M Pa

Critical design stress

Critical Stress is the minimum amount of the stress that is exerted by the external force acting over the shaft assembly, which is required for initiating the motion towards causing shaft failure.

$$\sigma cr = \frac{\pi E}{(L/r)} \quad (18)$$

$\sigma cr = critical\ stress$ (N m^{-2})

L/r = slenderness ration (Gopal, 2010).
E = young modulus of stainless steel shaft used (Nm^{-2}) = $210\ x\ 10^9\ Nm^{-2}$
L = length of shaft (m) = $0.5m$
r = radius of shaft (m) = $0.0175m$

$$\sigma cr = \frac{\pi\ x\ 210\ x\ 10^9}{\left(\frac{0.5}{0.0175}\right)^2}$$

$$\sigma cr = 6.6\ x \frac{10^{11}}{816.33} = 8.1 \text{ x } 10^8 \text{ Pa}$$

$$\sigma cr = 0.81 \text{ GPa}$$

Shaft Design for Torsional Rigidity

Rigidity is based on the permissible angle of twist. The amount of twist permissible depends on the particular application and varies about 0.3˚ per meter for machine tool shafts to about 3˚ per meter for line shafting.

According to SAME on solid circular shaft,

$$\theta = \frac{584MtL}{Gd^4} \quad (19)$$

$\theta = angle\ of\ twist\ (degree)$
L = length of shaft (m) = 500 mm - designed
Mt =torsional moment (Nm) = 4.93 x 10^6 Nm (name plate)
G = torsional modulus of elasticity (Nm^{-2}) = 80 x 10^{12} Nm^{-2} - standard
d = shaft diameter = 35 mm - Calculated
$R = D/2$ = 35/2 = 17.5 mm = 0.0175 m

$$\theta = \frac{584\ x\ 24.6\ x\ 0.5}{80\ x\ 10^{12} x\ 0.0175^4} = 0.0168^\circ$$

$\theta = 0.0168^\circ$. Since the value is less than 3˚ per meter (3˚ / m >>> 0.0168˚/m), angle of twist of the 0.5 m long transmission shaft is within permissible range.

Principle of operation

The description of a typical experiment was used to explain the experimental procedure. The PET bottle shredder uses mastication principle to shred materials fed into it. During working process, its prime mover drives the transmission shafts of the machine with a low speed and strong shredding torque to masticate materials to be processed. These speed and torque are then transmitted to revolving cutter blades on the driving and driven shafts moving in an interwoven manner. However, utilizing the gap between counter rotating blades gives rise to cutting edges of plastic shredder, thereby masticating the large pieces of PET bottles, tin can, or paper processed into desired granular sizes (see Figures 12, 13 and 14 for more details).

Materials for Evaluation and Variables Considered

Materials used for evaluation of the plastic shredder are Paper Catton, Tin Can and PET Bottles, Sensitive measuring scale, stopwatch and recording materials. Variables considered during evaluation are speed of rotation and shredding capacity.

Performance evaluation

To evaluate the machine's performance at different transmission shaft rotation speeds, PET bottles, Tin cans, and paper were employed. The rotational speed was in the range of 25 rpm to 65 rpm. An electronic weighing balance was used to measure the weight of the evaluation materials. The goal of doing this was to help calculate how many kg of materials will pass through the machine in an hour. The duration of the shredding exercise was also calculated using a stop watch. The results from each material evaluated were tabulated and analyzed to determine the shredding capacity in 1 hour or one day of 8 hours operation.

Method of Analysis of Results

Null hypothesis for variables considered is *Ho*: $0.5 \leq r \leq 1$; while alternative hypothesis is H_1: $r < 0.5$. Bivariate Linear regression was the statistical model used to understand the relationship between the predictor and the response variable. Y is response variable, βo is intercept on y axis, X_1 / Xn is the predictor, β_1 / β_n is the regression coefficient and ε is the model error. Variable X, being the predictor is the speed of rotation of the shredder in revolution per minutes (rpm); and variable **y** being the response variable is the shredding capacity in kilogram per hour (kg h^{-1}). Analysis toolPak of Microsoft excel was used to analyze the relationship between the predictor and the response variable. The general model for both bivariate and multivariate data for linear regression analysis is as presented in Equation 20 below (Zach, 2020).

$$y = \beta o + \beta 1X1 + \beta nXn + \varepsilon \quad (20)$$

Cost Estimation of PET Bottle Shredder

Cost of engineering products like newly developed PET bottle Shredder can broadly be grouped under direct or indirect cost (Hasiehurst, 1981). Direct cost is the cost of factors which are directly attributed to the manufacture of a specific product (i.e. materials and labour costs). Indirect cost on the other hand is that indirectly attributed to the manufacture of a specific product, such as overhead cost (usually expressed in percentage of direct labour cost) (Ajav *et al.*, 2018). The costing of the newly designed and fabricated shredder was based on the detailed factorial estimate method (Sinnot, 1993). This is because fabrication of the machine is complete and detailed breakdown and estimation of component parts is possible. The cost analysis of the machine is shown in Table 2 below.

Table 2. Bill of Engineering Quantity and Measurement (BEME).

S/N	Materials	Specification	Quantity	Unit Price (N)	Total Amount (N)
1	Petrol engine	13.0 hp petrol engine	1	95,000	95,000
2	Plate (mild steel)	12 mm	1	45,000	45,000
3	Shaft	30 mm	2	20,000	15,000
4	Plate	5 mm	1	35,000	35,000
5	Sprocket	130/75	1	5,000	5,000
6	Sprocket	200/75	1	10,000	10,000
7	Bearing	-	2	3,250	7,500
8	Counter Balance Weight	5 kg	1	10,000	10,000
9	Welding and Turning	-	-	45000	45,000
10	Bolt & Nut	-	-	3,000	3,000
11	Blade	269/74 mm	6	1,670	10,000
12	Transport	-	-	7,000	7,000
13	Miscellaneous	-			12,500
	TOTAL				**300,000**

i. Materials Cost = ₦ 300,000

ii. Direct Labour Cost: (Machining of Main Shaft , Bending, painting) = ₦ 15,000

iii. Indirect/Overhead Cost: = 20% of ₦ 300,000 = ₦ 60,000

Grand-total = Material cost + Labour cost + Overhead cost **= ₦ 300,000 + ₦ 15,000+ ₦ 60,000 =** ₦ 375,000

At $ 1.00 = ₦ 458.59

₦ 375,000 = $ 817.72

RESULTS AND DISCUSSION

The shredder developed was evaluated with PET bottles at various speed of rotation ranging from 25 rpm to 65 rpm. The speed was varied for each batch processed to establish the speed at which the shredding capacity is optimum. The result is as shown in Table 3 below. The weight of materials processed was kept constants for all the speed level tested. Highest shredding capacity was observed at 65 rpm. Beyond this speed, machine uneven vibration was observed. It was also observed that the time it took to shred each batch reduces as the speed of rotation increases.

Table 3. Shredder evaluation using PET bottles.

	Weight (g)	Time (s)	Speed (rpm)	Shredding capacity (kg h^{-1})
1	157	32	25	17.66
2	157	28	35	20.19
3	157	24	45	23.55
4	157	15	55	37.68
5	157	10	65	56.52

Versatility of the machine for other materials like empty tin can and paper was also tested. The impact of various speed of rotation of the prime mover on materials

evaluated was observed and reported in Tables 4 and 5 below. The weight was also kept constant throughout the process. In Table 4, shredding capacity was lowest (13.32 kg h^{-1}) at 25 rpm and highest (29.60 kg h^{-1}) at 65 rpm. The shredding capacity of the machine was observed to be higher when PET bottle (52.52 kg h^{-1}) was processed as compared to Tin can (29.6 kg h^{-1}). This could be due to the fact that ultimate tensile strength of PET bottle (220 MPa) was higher than that of Tin can (150 MPa). For the shredding process, Figures 8, 9 and 10 are respectively the charts of the shredding capacity of PET bottles, paper and empty Tin can.

Table 4. *Shredder evaluation using empty tin can.*

S/N	Weight (g)0/	Time (s)	Speed (RPM)	Shredding capacity (kg h^{-1})
1	148	40	25	13.32
2	148	34	35	15.67
3	148	28	45	19.02
4	148	24	55	22.20
5	148	18	65	29.60

In Table 5, the lowest and highest shredding capacity obtained are respectively 14.8 kg h^{-1} and 42.09 kg h^{-1}. It was observed that the machine is also versatile for shredding paper which can later be made into pulp to form egg crates used at poultry farm. It was more convenient for the machine to shred paper than other materials used for evaluation. The only thing observed with it is that it is not as compact as other materials are. This could be responsible for delay in picking before shredding.

Table 5. *Shredder evaluation using paper.*

S/N	Weight (g)	Time (s)	Speed (RPM)	Shredding capacity (kg h^{-1})
1	152	37	25	14.80
2	152	30	35	18.24
3	152	27	45	20.27
4	152	19	55	28.80
5	152	13	65	42.09

Bivariate linear regression was the statistical model used to understand the relationship between the ***explanatory variable*** (speed of rotation) and the ***response variable*** (shredding capacity). The results of the analysis are as shown in Tables 6 and 7 below. The pictures of the machine assembly during evaluation exercise and product of evaluation are as shown in Figures 10, 11 and 12. The formula in Equation 21 was used to determine the shredding capacity of each material processed (Abdulkadir *et al.*, 2020).

$$Shredding\ Capacity = \frac{m}{t}\ (kgh^{-1}) \quad (21)$$

m is the mass of material processed by the shredder or weight of shredded materials fed in in kilogram - the material is either PET bottle, Tin can or Paper.
t is the time it took to process the material – it is measured in hour.

The charts of shredding analysis presented in Figure 8 shows the relationship between shredding capacity and speed of rotation of the transmission shaft. PET

bottle was picked for the analysis since the design favors PET bottles shredding more perfectly as it is the highest on the list (56.52 kg h^{-1}). From the graph, it can be deduced that increase in speed of rotation of transmission shaft leads to corresponding increase in quantity of plastic shredded per time. At 25 rpm, the quantity shredded in 1 hour is 17.66 kg. When the speed is considerably increased, the quantity shredded also increased. At 65 rpm, 56.52 kg was shredded in 1 hour. Beyond this speed, machine uneven vibration was observed. If the machine is operated for 8 hours in a day at the limit of the observable speed, it can favorably shred up to half a ton (452.16 kg day^{-1}).

The results also show the machine is versatile for shredding other waste packaging materials generated around farm on daily basis. The paper shredded can be pulped and made into poultry egg crates and paper print used in building industry.

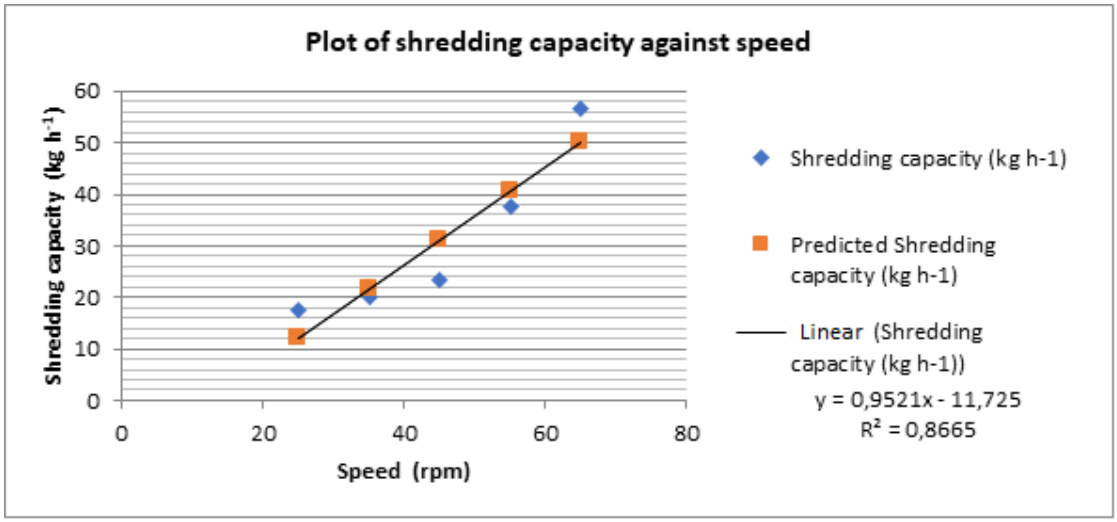


Figure 9. *Shredding capacity at various speed using PET bottles.*

The results presented in Tables 6 and 7 show that 5 observations were used for the model of the predictor and response variable. The coefficient of determination, R square in Table 6 (0.867) implies 86.7 % of the variation in the shredding capacity can be explained by the speed of rotation experienced (PET bottles). The multiple R value, 0.9308 reveals there is strong level of correlation or linear relationship between the explanatory variable (speed) and response variable (shredding capacity). It also implies that null hypothesis defined is within acceptable limit. The standard error, 2.53 is larger than the coefficient of the predictor (speed) which is 0.95 rpm. On the average, the observed value of predictor falls 2.53 rpm from the regression line (see Tables 6 and 7 for details).

Table 6. *Regression statistics for PET bottles.*

Regression Statistics	
Multiple R	0.93086928
R Square	0.86651762
Adjusted R Square	0.82202349
Standard Error	2.52617
Observations	5

Table 7 shows the analysis of variance (ANOVA) of the regression statistics. From the table, it can also be inferred that the number of independent variables in the model is 1 as regression degree of freedom (df) is 1 while total df is 4. F value in Table 7 is 19.48 and the Significance F is 0.0216. The F value assists in testing the hypothesis that the slope of the independent variable is zero. The Significance F is otherwise called the p value for the null hypothesis. It assists in confirming that the coefficient of the independent variable is zero. Since the p-value is below 0.05, it implies there is 95% confidence that the slope of the regression line is not zero. Hence, there is significant linear relationship between speed of rotation and shredding capacity of the machine. For individual p-value in Table 7, it can be inferred that the predictor (speed) is statistically significant – meaning the predictor is applicable for the model.

Table 7. *Analysis of variance for PET bottles evaluation.*

ANOVA

	Df	*SS*	*MS*	*F*	*Significance F*
Regression	1	906.49441	906.4944	19.47488	0.02159
Residual	3	139.64059	46.54686		
Total	4	1046.135			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*
Intercept	-11.7245	10.17678	-1.15208	0.332765	-44.11154
Speed (rpm)	0.9521	0.21575	4.413035	0.021592	0.26550

Coefficients and intercept presented in Table 7 can be used to express linear regression model stated in Equation "20". The response variable, y can be established from the parameters in Table 6. (Intercept on y axis) is -11.7245 kg h^{-1} while ε, being the model error has value of 0.9521. Therefore, response variable y in Equation "20" is expressed as: $Y= \mathbf{0.952X_1 - 11.725 \pm 2.53}$

Figure 10. *Front view of the developed shredder assembly.*

Figure 11. *Machine evaluation exercise with tin can and paper.*

Figure 12. *Products of machine evaluation exercise.*

Variable $\mathbf{X_1}$ in the model is the speed of rotation of the shredding process; βo is intercept on y axis, ε is the model error and variable **Y** is the shredding capacity in kg h^{-1} ($y = \beta o + \beta 1X1 + \varepsilon$). For example, for every unit increase in speed of rotation of the machine, shredding capacity increases commensurately. The machine reached highest shredding capacity for PET, paper and can respectively as 56.52 kg h^{-1}, 42.09 kg h^{-1} and 29.60 Kg h^{-1} at 65 rpm. Beyond this optimal speed, uneven vibration of the machine assembly is experienced. Also, when the machine is operated below 25 rpm, it results in machine eventual seizure and stoppage. Similar things were observed for the model of predictor and response variable of ***paper*** and ***empty tin can***. The machine has comparative advantage over diesel or electric motor-powered engine as it is less stressful to operate and economical to run and maintain. It has shredding capacity that can manage daily waste generated from soft drink, can or paper in a farm, academic institution, shopping mall, market, school and training institute. If the machine is given wide publicity, the menace caused by nonbiodegradable materials like plastic will be ended.

CONCLUSION

The world's inability to keep up with the management of exponentially rising output of plastic wastes has made plastic pollution emerged as one of the most urgent environmental threats. In addressing the menace of plastic pollution in developing economy like Nigeria, PET bottle shredder was developed and evaluated in this study. Plastic shredder is a machine used to cut recyclable plastic materials into smaller pieces of granules. Plastic shredder was developed in this study for small scale shredding of PET bottles. The machine developed was made of mild steel of 12 mm thickness to avoid seizure of parts and eventual machine failure while in use for extended period of time. Machine performance was evaluated using empty PET bottles. The shredder gave the highest shredding capacity of 56.52 kg h^{-1} at 65 rpm. Versatility of the machine was tested for other materials like empty Tin can and paper waste. At 65 rpm, the machine gave shredding capacity of 42.09 kg h^{-1} for paper and 29.60 kg h^{-1} for Tin can. The cost of production of the machine is $817.71. The speed of rotation for process optimization is 65 rpm. Machine design of shredder used in industries was scaled down in this research brief to make the machine attractive and affordable for small scale processors. If the machine is widely adopted, the menace caused by nonbiodegradable materials like plastic will be ended. More also, it will help all stake holders involved to embrace habit of value addition as they turn their daily waste generated to wealth. PET plastic shredding therefore plays a crucial role in combating plastic waste nuisance and promoting a circular economy.

The following recommendations are given about the machine while in operation:

i. To use the machine above 65 rpm, the machine must be installed and damped.

ii. The machine will give better shredding capacity results if bailer is first used to compress the materials to be shredded.

iii. The provision in the machine assembly for direct coupling of the petrol engine to the reducer should be housed.

iv. The machine can be adopted for home use to encourage culture of value addition.

v. More evaluation exercises should be carried out on the machine for process optimization.

vi. More research works should be done to develop other machines involved in effective waste management. The machines include among others the crusher, extruder, granulator, washing machine, bale breaker, plastic melting and molding machine, etc.

DECLARATION OF COMPETING INTEREST

The authors (M.A. Okusanya, C.B. Ogunlade and S.D. Oluwagbayide) hereby declares that there is no conflict of interest what so ever on this work.

CREDIT AUTHORSHIP CONTRIBUTION STATEMENT

Muyiwa Abiodun Okusanya: Conceptualization, investigation, methodology, writing – original draft.
Christopher Bamidele Ogunlade: Formal analysis, data curation, validation, fabrication.
Samuel Dare Oluwagbayide: Conceptualization, visualization, fabrication, review, and editing.

ETHICS COMMITTEE DECISION

This article does not require any ethical committee decision.

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Turkish Journal of Agricultural Engineering Research

Turk J Agr Eng Res *(TURKAGER)*

https://dergipark.org.tr/en/pub/turkager
https://doi.org/10.46592/turkager.1356210

ISSN: 2717-8420
2023, 4(2), 178-190

Research Article

Responce Surface of Drying Parameters on Some Physical Properties Related to Floatability of Extruded Fish Feeds

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Article Info

Received: 06.09.2023 **Accepted:** 27.10.2023 **Published:** 31.12.2023

ABSTRACT

Fish feeds drying plays a major role in the aquaculture industry by ensuring preservation and quality of feed for effective growth and development of farmed fish. Optimization the drying parameters such as drying temperature, drying air velocity and relative humidity plays a crucial role in achieving Response Surface Methodology is a useful to optimized variables/factors more practically as compared to just the statistically significant test for a particular point. The aim of this research to optimize the drying process of an extruded fish feeds which affect the floatability of the feeds. 2000 g of the extruded feeds was dried in a continuous flow belt dryer. The experiments were performed at air temperature of 60, 70, 80, 90 and 100°C, air velocities of 0.7, 0.8, 0.9, 1.0 and 1.2 m s^{-1} and drying belt linear speeds of 50, 55, 60, 65 and 70 rpm. The dried extruded fish feed was subjected to extensive physical properties which are: unit density (kg m^{-3}), water stability (%), sinking velocity and relative absorption ratio. The surface response of each of this physical property of the dried extrudates' were determined. The result shows that the operational parameter can optimally explain about 90.45%, 93.72%, 95.98% and 70.77% change in the density, water stability, sinking velocity and the relative absorption ratio respectively of the extrudate via quadratic function. The optimum predicted values for air temperature of 97.49° C, conveyor belt speed of 50 rpm and air velocity of 1.10 m s^{-1} were obtained for the dryer within the range of the input parameters.

Keywords: *Fish feeds drying, Rejoinder surface, Ropiness, Water stableness, Relative feed-water intake, Sinking speed*

To cite: Ogunnaike F (2023). Responce Surface of Drying Parameters on Some Physical Properties Related to Floatability of Extruded Fish Feeds. *Turkish Journal of Agricultural Engineering Research (TURKAGER), 4(2), 178-190. https://doi.org/10.46592/turkager.1356210*

INTRODUCTION

The demand for seafood continues to rise throughout the continent of the world and a aquaculture has emerged as a sustainable solution to meet this growing needs. The success of aquaculture operations had been reported to rely heavily on the quality and composition of fish feeds (Hasan and Halder, 2019). Nigeria is the largest fish consumer in Africa and among the largest fish consumers in the World with over 1.5 million tons of fish consumed annually (Emmanuel *et al.*, 2014). Commercially, fish feeds are manufactured either as extruded floating or pelletized sinking feeds. Most fish farmers preferred extruded feeds to sink feeds because, extruded feed is buoyant and almost hydrophobic as such leaching is low compared to sinking feeds (Ighwela *et al.*, 2013). In the production of the extruded fish feeds, the most important factors that influence the quality and the capacity production is: the raw materials of fish feed, ingredients of raw material, feed formulation design, drying process and feed producing machines. Also, the drying process is very important in the production of quality dried extruded fish feeds (Heras *et al.*, 2019). Jaescgke and Senge (2018), reported that in understanding the effects of drying on the physical properties of dried extruded fish feeds is vital for optimizing feed production and ensuring the delivery of nutritious and palatable feeds to farmed feeds. Jafaryan *et al.* (2020) reported that the physical properties of fish feeds plays an importance role in the determining the floatability which in turn affects the growth performance of the fish. The buoyancy of fish feed is majorly affected by its density. The density of fish feeds is determined by various factors such as ingredients used in formulating the feed, moisture content and processing technique (Duru *et al.*, 2019). Furthermore, the physical and mechanical properties of fish feed pellets are important to understand its behavior during processing, drying, transporting, packaging and floatability during fish feeding (Khater *et al.*, 2014). Aydar (2018) opined that one of the most commonly used experimental designs for optimization is the response surface methodology because it allows evaluation of multiple factors and their interactions on one or more response variables. Literature is full of effects of physical properties of extruded fish feeds but few research had been reported on the evaluation of drying parameters which affect floatability of fish feeds using surface response method. The objective of this research is to optimize the drying parameters on some physical properties related to floatability of extruded fish feeds.

MATERIALS and METHODS

Feed constituents were purchased from a local Akure, Ondo State, Nigeria market. The feed constituents were formulated as proposed by Liu *et al.* (2020). The formulated feeds were extruded using a screw extruder. 2500 g of the extruded fish feeds were weighed using a digital weighing balance (Model BLC3002, precision of 0.0001 g), The weighed extruded feeds were dried by using a continuous flow dryer which was developed at the University of Technology, Akure. Five drying temperatures of 60 to 100°C at 10°C intervals (Kurt, 2012), air drying velocity of 0.7 to 1.2 m s^{-1} at an interval of 0.1 m s^{-1} as proposed by Torres and Dincer (2011) for drying of fish feeds and belt speed of 50 to 70 rpm at an interval of 5rpm was used in drying the extruded feeds. The dried extruded

feeds were made liable to comprehensive physical properties which are density, water stability, sinking velocity and relative absorption ratio.

Measurement of the Dried Extrudate Physical Properties

Density of the dried extruded fish feeds

The dried extrudates were cut into 25.4 mm using a razor blade. A kerro electronic balance (Model BLC3002) was used to determine the mass and the length of the sectional dried extrudate was determined using a digital caliper (Mitutoyo Inc, Japan). The density of the extrudates was determined using Equation 1.

$$p = \frac{M_z}{V_z} \quad (1)$$

Where
p is the density of the extrudates (kg m^{-3}), Mz is the mass of the dried extrudates (kg) and Vz is the volume of the dried extrudates (m^3)

The sinking velocity of the extrudate

The time taken for 10 dried extrudates of length 25.4 mm each to reach the bottom of a 200 ml measuring cylinder filled with distilled water was monitored. This was replicated five times. The sinking velocity (Equation 2) was calculated according to Chevenana *et al.* (2007b).

$$S_v = \frac{D_c}{T_m} \quad (2)$$

Where
Sv is the sinking velocity (m s^{-1}), *Dc* is the distance travelled by the dried extrudates (m) and *Tm* is the time taken (s)

Water stability of the extrudate

10 pieces of the dried extrudates were weighed using a kerro electronic balance (Model BLC3002). This was later placed inside a nylon sieve which is tied with a string and inserted into a bowl containing pond water for 30 minutes. After 30 minutes of immersion, the feeds were sun-dried for 3 days and the weight was recorded as M30 representing the final weight after 30 minutes of immersion. Water stability was calculated using Equation (3) as reported by Fagbenro and Jauncy (1995).

$$Water\ stability = \left(\frac{M_{30}}{M_1}\right) X\ 100 \quad (3)$$

Where M_{30} is the weight of the extrudates after 30 minutes immersion and drying and M_1 is the initial dry weight of the extrudates.

Relative absorption rate of the extrudate

The relative absorption ratio is the measure of the volume of water absorbed in relation to the initial weight of the dried extrudates. This was calculated using Equation (4) has reported by NRC (2011).

$$RAR = \left(\frac{M_2 - M_1}{M_1}\right) x\ 100 \quad (4)$$

Where M_2 is the mass of the wet extrudates (kg) M_1 is the initial mass of the dry extrudates (kg) and $M_2 - M_1$ is the weight gain after immersion in water (kg).

Data Analysis

Microsoft Excel (Microsoft Cooperation 2010) was used for graphical descriptions of the data. Optimization of the relationship between the factors was conducted using Design Expert (9).

RESULTS AND DISCUSSION

Figure 1a, 2a and 3a shows the optimal surface plot of the density, sinking velocity, water stability and the relative absorption rate as affected by the drying temperature and conveyor speed of the continuous flow belt dryer respectively. Figure 1b, 2b and 3b shows the optimal surface plot of the density, sinking velocity, water stability and relative absorption rate as affected by the conveyor speed and air velocity of the continuous flow belt dryer respectively while Figure 1c, 2c and 3c shows the optimal surface plot of the density, sinking velocity, water stability and relative absorption rate as affected by the air velocity and drying temperature of the continuous flow belt dryer respectively. Table 1 shows the optimal goal and range of optimality while Table 2 depicts the optimal solution of the dried extrudate.

Table 1. *Optimal goal and range of optimality of the dried extrudates.*

Name	Goal	Lower Limit	Upper Limit	Lower Weight	Upper Weight	Importance
A: Conveyor speed	is in range	50.00	75.00	1	1	3
B: Temperature	is in range	60.00	100.00	1	1	3
C: The air velocity	is in range	0.80	1.20	1	1	3
Floatability	maximize	20.000	99.997	1	1	3
Water stability	maximize	6.448	65.856	1	1	3
Expansion ratio	maximize	0.988	1.080	1	1	3
Relative absorption ratio	minimize	13.021	54.817	1	1	3
Sinking velocity	minimize	0.581	5.292	1	1	3
Density	minimize	545.604	854.545	1	1	3

Table 2. Optimal solution of the dried extrudate.

s/n	Conveyor speed	Temperature	Air velocity	Floatability	Water stability	Expansion ratio	Relative absorption ratio	Sinking velocity	Density	Desirability	
1	50.00	97.50	1.10	87.4728	58.0959	1.0260	38.0781	1.2507	586.4950	0.6707	Selected
10	50.00	97.16	1.10	87.0924	57.9071	1.0262	37.6189	1.3192	587.9754	0.6707	
11	50.00	97.36	1.11	87.4423	58.6180	1.0261	38.3176	1.2510	586.1012	0.6706	
12	50.00	96.96	1.11	87.0342	58.5571	1.0263	37.8971	1.3234	587.5674	0.6706	
13	50.00	98.22	1.10	88.1321	57.7763	1.0256	38.5704	1.1361	584.5508	0.6705	
14	50.00	96.14	1.11	86.2367	58.5996	1.0267	37.1906	1.4603	590.2833	0.6701	
15	50.00	98.75	1.09	88.5270	57.1006	1.0252	38.6481	1.0712	583.8783	0.6700	
16	50.00	99.31	1.09	89.1585	57.3882	1.0250	39.4496	0.9517	581.4435	0.6694	
17	50.00	99.23	1.06	88.6902	55.4759	1.0244	38.0961	1.0563	584.9507	0.6679	
18	50.00	95.23	1.14	85.7220	60.3094	1.0269	37.7128	1.5319	590.5703	0.6677	
19	50.00	95.85	1.17	86.7377	62.5480	1.0256	40.0180	1.3292	584.8455	0.6624	
20	50.00	100.00	1.03	88.9854	53.1115	1.0226	37.5049	1.0202	586.3408	0.6615	
21	50.00	91.78	1.19	82.9624	62.1844	1.0271	36.9902	1.9590	599.1380	0.6549	
22	74.69	93.82	1.05	71.5636	52.8656	1.0796	43.4311	2.0329	645.3319	0.6329	
23	74.69	93.84	1.05	71.5627	52.8123	1.0796	43.4098	2.0333	645.4550	0.6329	
24	74.67	93.76	1.05	71.5315	52.9705	1.0796	43.4401	2.0379	645.1940	0.6329	
25	74.73	94.02	1.05	71.6603	52.5933	1.0796	43.4282	2.0170	645.6374	0.6329	
26	74.72	94.12	1.06	71.9259	53.1843	1.0796	43.8975	1.9734	643.5260	0.6328	
27	74.80	94.26	1.04	71.7171	52.0715	1.0796	43.3216	2.0051	646.5831	0.6327	

Estimate the response surface of the dried extrudate density

Figure 1a- c depicts the optimal surface plot of extrudate density versus operational parameters of the machine. The optimal solution shows that the density of the extrudate exhibit a quadratic relationship with the operational parameter with coefficient of determination value of 0.90 which shows that the operational parameter can optimally explain about 90.45% change in the density of the extrudate via quadratic function. Furthermore, the maximum fish feed extrudate density of 854.55 kg m^{-3} was recorded when the machine was operated at the lowest air temperature of 60°C, the lowest air velocity of 0.8 m s^{-1} and 70 rpm of the conveyor speed while the minimum value of the density of 545.60 kg m^{-3} of dry sample was recorded when the wet sample was dried at the highest temperature of 100°C and 1.0 m s^{-1} air velocity with the lowest conveyor speed of 50 rpm. The result of this study was in a close range with the value of 344±3.11 - 537±1.8 reported by Obirikorang *et al.* (2015) while studying the effects of dietary inclusions of oilseed meals on physical characteristics and feed intake of diets for the Nile Tilapia (Oreochromisniloticus). Considering the experimental range of 60°C-100°C drying temperature, 0.8 m s^{-1} - 1.2 m s^{-1}, air velocity and 50 rpm – 75 rpm conveyor speed as operational range of optimality and taking the experimental output range of 545.60 kg m^{-3} to 854.55 kg m^{-3} as the range of optimality and the optimal density of the extrudate was obtained by minimizing (Table 1) the quadratic function which resulted to 586.59 kg m^{-3} (Table 2) and this will be obtained when the continuous flow belt dryer was operated at the drying temperature temperature of 97.49°C, conveyor speed of 50 rpm, and air velocity of 1.102 m s^{-1} with high value of desirability of 0.86 which shows that over 86% of the optimal goal will be attained if the machine was operated at the optimal operational condition.

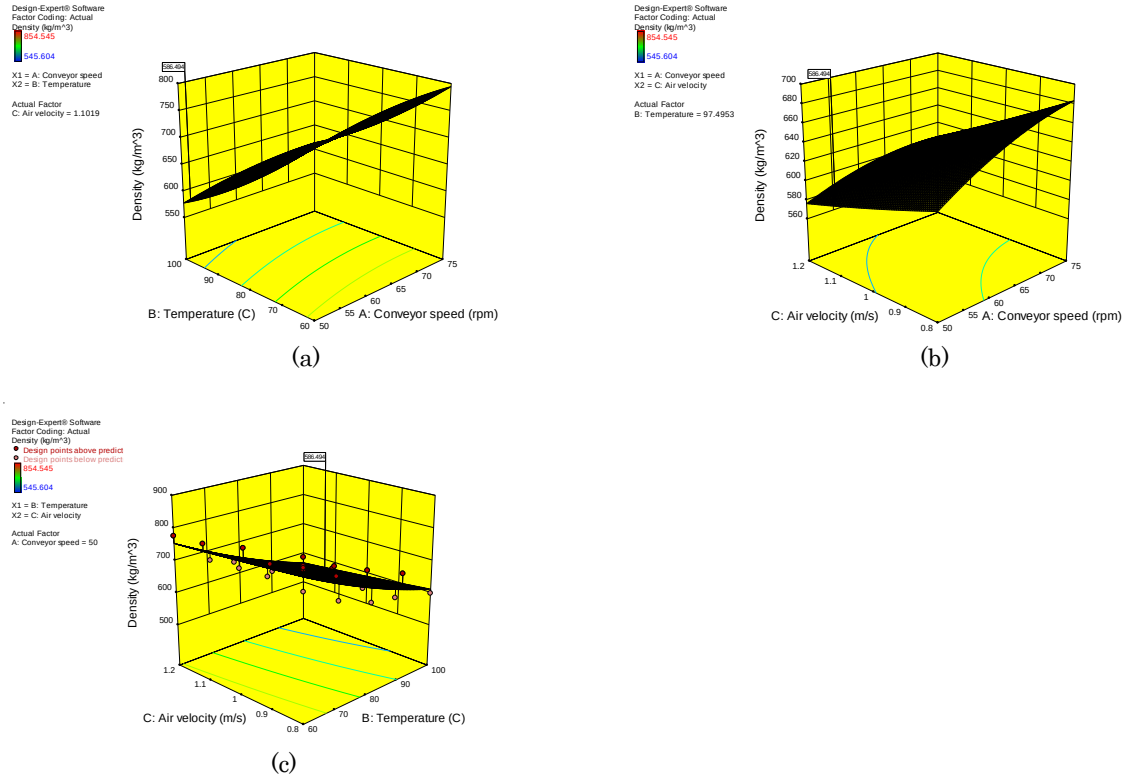


***Figure 1(a–c)**. Optimal surface plot of extrudate density versus operational parameters of the machine.*

Estimate response surface of the dried extrudate water stability

The water stability of the dried fish feed extrudate under different machine operational conditions shows that the maximum water stability of 65.86% of the fish feed extrudate was recorded when the machine was operated at the highest air temperature of 100°C, the highest air velocity of 1.2 m s^{-1} and the lowest conveyor speed of 50 rpm while the minimum value of the water stability of 6.45% of the dry sample was recorded when the wet sample was dried at the lowest temperature of 60°C and lowest air velocity of 0.8 m s^{-1} with 60 rpm conveyor speed.

The result of this study is lower than the range of value (84.50±0.19-93.96±0.45%) reported for water stability of fish feed by Obirikorang *et al.* (2015) while studying the effects of dietary inclusions of oilseed meals on physical characteristics and feed intake of diets for the Nile Tilapia (Oreochromisniloticus) and De-Cruz *et al.* (2015) reported 11.47-17.67% as the range of water stability of fish feed during the study of the influence of processing parameters on the extrusion behaviour and quality properties of the feed pellets and this result fall within the range of value obtained in this study. The optimal solution (Figures 2 a-c) shows that the water stability exhibits a quadratic relationship with the operational parameter with the coefficient of determination value of 0.93 which shows that the operational parameter can optimally explain about 93.72% change in the water stability via quadratic function. Considering the experimental range of 60°C -100°C drying temperature, 0.8 m s^{-1} – 1.2 m s^{-1}, air velocity and 50 rpm – 75 rpm conveyor speed as operational range of optimality, Also, taking the experimental output range of 6.43% - 65.85% as the range of optimality and the optimal water stability was obtained by maximizing (Table 1) the quadratic function which resulted to 58.11% (Table 2) and this will be obtained when the continuous flow belt dryer was operated at the drying temperature of 97.495°C, conveyor speed of 50 rpm, and air velocity of 1.102 m s^{-1} with high value of desirability of 0.8695 which shows that over 86% of the optimal goal will be attained if the machine was operated at the optimal operational condition.

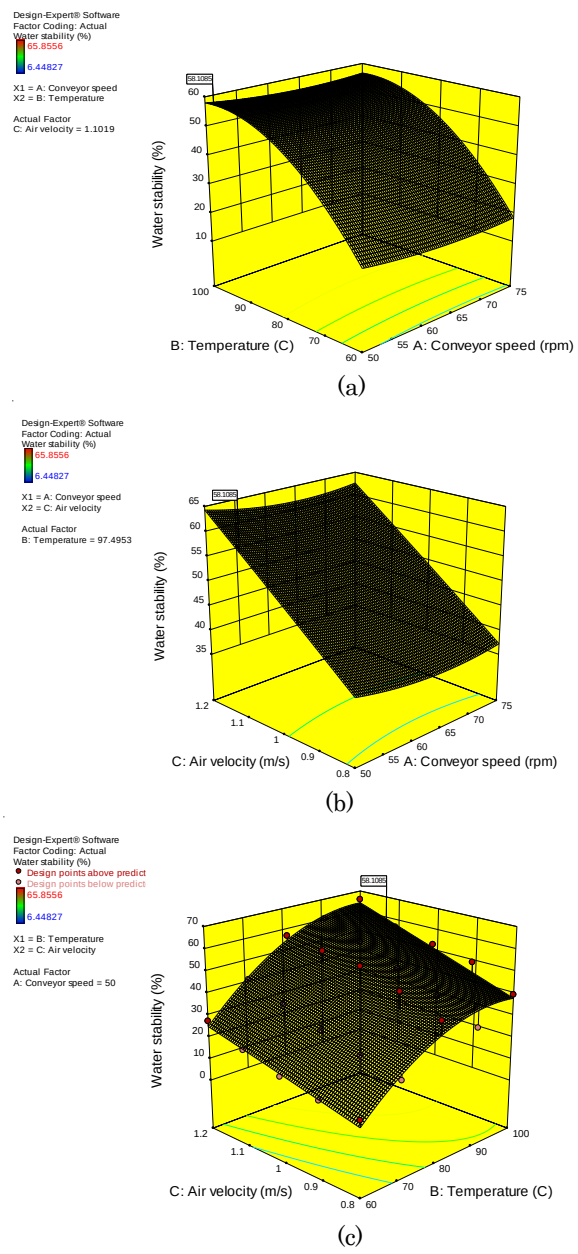


Figure 2 (a – c). *Optimal surface plot of water stability versus operational parameters of the machine.*

Estimate response surface of the dried extrudate sinking velocity

Figure 3a shows the optimal surface plot of the sinking velocity as affected by the drying temperature and conveyor speed of the continuous flow belt dryer and Figure 3b shows the optimal surface plot of the sinking velocity as affected by the conveyor speed and air velocity of the continuous flow belt dryer while Figure 3c shows the optimal surface plot of the sinking velocity as affected by the air velocity and drying temperature of the continuous flow belt dryer. The maximum sinking velocity of 5.2×10^{-4} m s^{-1} of the fish feed extrudate was recorded when the machine was operated at the lower air temperature of 60°C, the lowest air velocity of 0.8 m s^{-1} and 65 rpm conveyor speed while the minimum value of the sinking velocity of 5.8×10^{-5} m s^{-1} of dry sample was recorded when the wet sample was dried at the highest temperature of 100°C, and air velocity of 1.2 m s^{-1} with conveyor speed ranging between 60 and 65 rpm. A similar value of 0.02 - 0.05 m s^{-1} was reported by

Umar *et al.* (2013) for the sinking velocity during the study of the influence of processing parameters on the extrusion behavior and quality properties of the feed pellets. However Tyapkova *et al.* (2016) also reported 10.1 to 7.4 cm s^{-1} as the range of expansion ratio of feed while studying the physical properties of extruded aqua feed with a combination of sago and tapioca starches at different moisture contents and the value of 11.47-17.67 cm s^{-1} reported by Kraugerud and Svihus (2011) is higher than the value obtained in this study. The optimal solution shows that the sinking velocity exhibits a quadratic relationship with the operational parameter with the coefficient of determination value of 0.95 which shows that the operational parameter can optimally explain about 95.98% change in the sinking velocity via quadratic function. Considering the experimental range of 60°C-100°C drying temperature, 0.8 m s^{-1} - 1.2 m s^{-1}, air velocity and 50 rpm-70 rpm conveyor speed as operational range of optimality, Also, taking the experimental output range of 5.8 x 10-5 mm s^{-1} – 3.29 x 10^{-4} mm s^{-1} as the range of optimality and the optimal sinking velocity of the extrudate was obtained by maximizing the quadratic function which resulted to 1.25 x 10^{-4} mm s^{-1} and this will be obtained when the continuous flow belt dryer was operated at the drying temperature of 97.49°C, conveyor speed of 50 rpm, and air velocity of 1.102 cm s^{-1} with high value of desirability of 0.85 which shows that over 85% of the optimal goal will be attained if the machine was operated at the optimal operational condition.

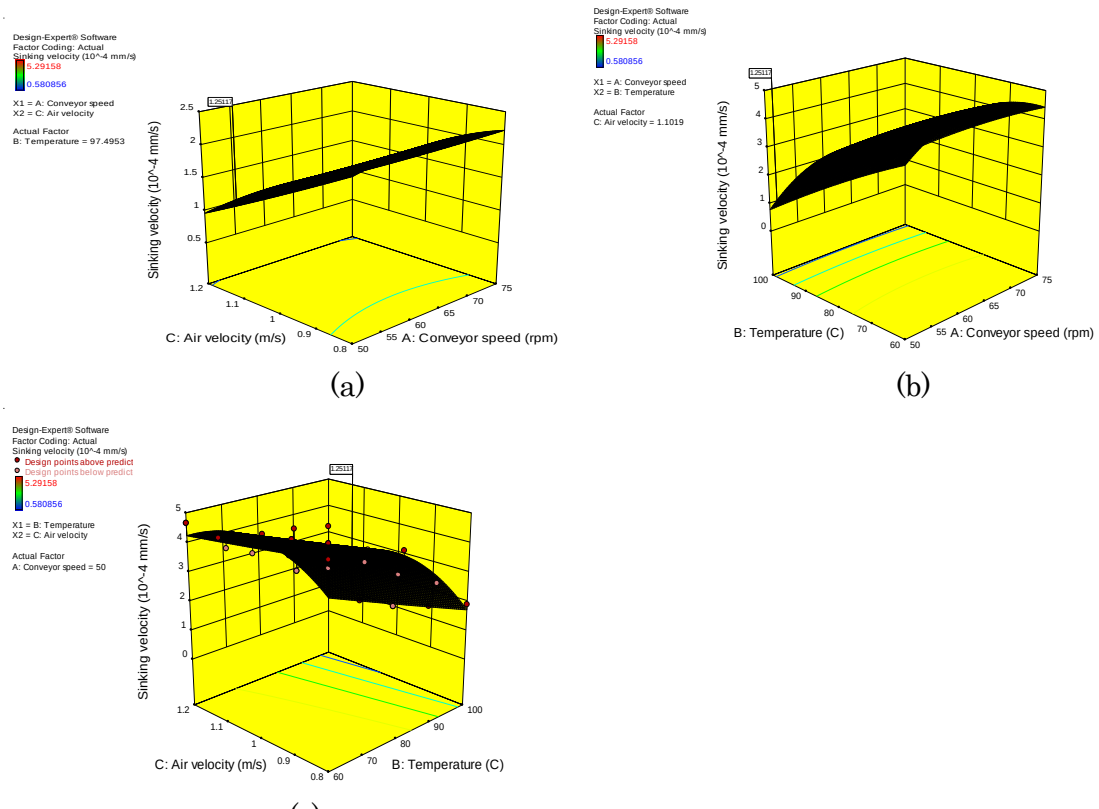
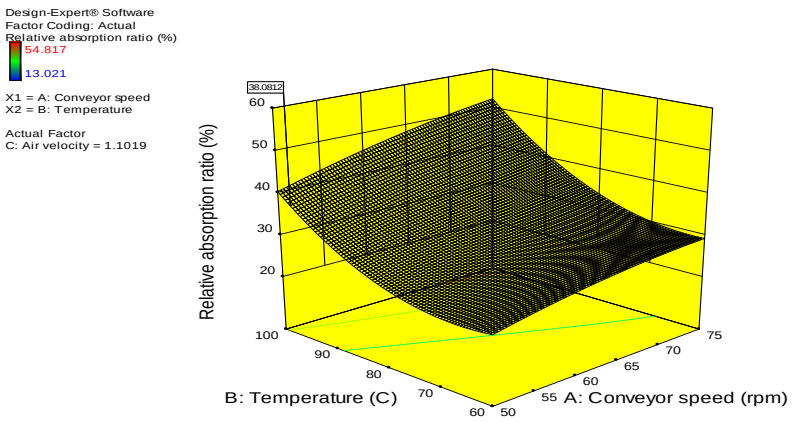


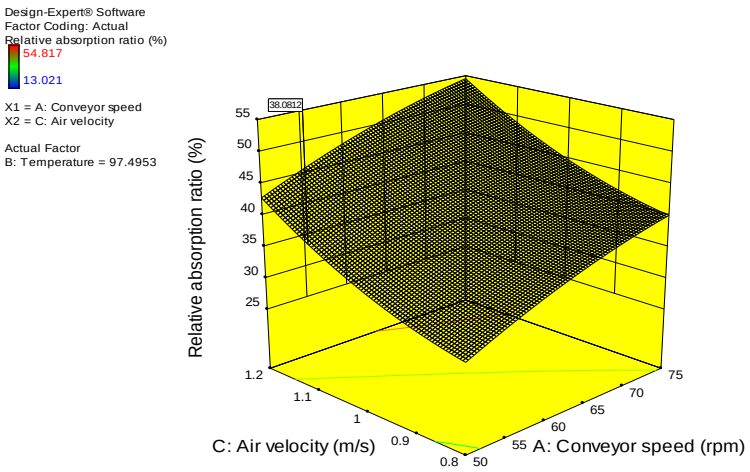
Figure 3(a – c). *Optimal surface plot of sinking velocity versus operational parameters of the machine.*

Estimate Response Surface of the Relative Absorption Rate

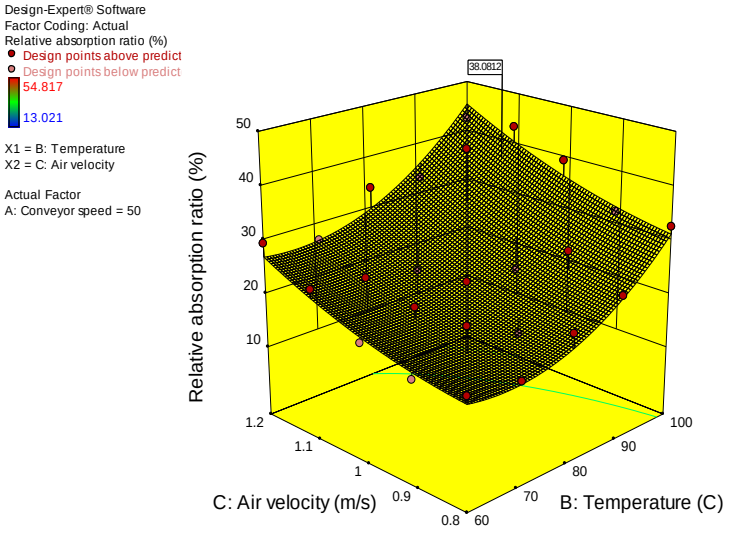
Figure 4a shows the optimal surface plot of the relative absorption rate as affected by the drying temperature and conveyor speed of the continuous flow belt dryer and Figure 4b shows the optimal surface plot of the relative absorption rate as affected by the conveyor speed and air velocity of the continuous flow belt dryer while Figure 4c shows the optimal surface plot of the relative absorption rate as affected by the air velocity and drying temperature of the continuous flow belt dryer. The optimal solution shows that the relative absorption rate exhibits a quadratic relationship with the operational parameter with the coefficient of determination value of 0.90 which shows that the operational parameter can optimally explain about 90.97% change in the relative absorption rate via quadratic function. Considering the experimental range of 60°C-100°C drying temperature, 0.8 m s^{-1} – 1.2 m s^{-1}, air velocity and 50 rpm-70 rpm conveyor speed as operational range of optimality, Also, taking the experimental output range of 13.02%–54.81% as the range of optimality and the optimal relative absorption rate of the extrudate was obtained by minimizing (Table 1) the quadratic function which resulted to 38.08% (Table 2) and this will be obtained when the continuous flow belt dryer was operated at the drying temperature of 97.49°C, conveyor speed of 50 rpm, and air velocity of 1.10 m s^{-1} with high value of desirability of 0.40 which shows that over 49% of the optimal goal will be attained if the machine was operated at the optimal operational condition.



(a)



(b)



(c)

Figure 4(a –c). *Optimal surface plot of relative absorption ratio versus operational parameters of the machine.*

CONCLUSION

This research provided valuable insights into the intricate relationship between various processing parameters and the resulting characteristics of the dried extrudate feeds' physical properties. This systematic exploration helps in optimizing the production, enhancing nutritional content and overall quality of fish feeds. The optimum predicted values for air temperature of 97.49°C, conveyor belt speed of 50 rpm and air velocity of 1.10 m s^{-1} were obtained for the dryer within the range of the input parameters. It is recommended that further research should be done on the response surface of buoyancy, expansion ratio and other physical properties of dried extruded fish feeds as this will contribute to sustaining the growth of the aquaculture sector.

DECLARATION OF COMPETING INTEREST

The authors declare that they have no conflict of interest.

CREDIT AUTHORSHIP CONTRIBUTION STATEMENT

Funmilayo Ogunnaike is responsible for the various parts of this paper including.

ETHICS COMMITTEE DECISION

This article does not require any ethical committee decision.

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Turkish Journal of Agricultural Engineering Research

Turk J Agr Eng Res *(TURKAGER)*

https://dergipark.org.tr/en/pub/turkager
https://doi.org/10.46592/turkager.1362000

ISSN: 2717-8420
2023, 4(2), 191-202

Research Article

Design and Development of Smart Agricultural Greenhouse

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Article Info
Received: 17.09.2023 **Accepted:** 06.11.2023 **Published:** 31.12.2023

ABSTRACT

Food insecurity across the globe has necessitated the need to optimize crops productivity through automation and Internet of Things (IoT). This research was carried out to develop a smart greenhouse system where the soil nutrient level, air temperature and soil moisture content can be closely monitored through sensors and the Internet. The sensors – major input components of the structure – sent information to a NodeMCU ESP8266 microcontroller for interpretation, configuration and necessary actions by the output components of the smart structure. The output components of the smart structure are the liquid-crystal display (LCD), water pump, fan, heater and relay modules, while the C++ programming language was used. Remarkably, the intelligence aspect of the smart greenhouse is built on the smart algorithm. Based on the performance evaluation of the various system units, the irrigation, cooling, heating and fertilization units have an accuracy of 85%, 90%, 90% and 85% respectively. Interestingly, the performance rating of the prototype was very encouraging, which makes this smart system a reliable material to combat global food insecurity.

Keywords: *Algorithm, Food security, Programming language, Sensors, Smart greenhouse*

To cite: Asibeluo UZ and Ekruyota OG (2023). Design and Development of Smart Agricultural Greenhouse. *Turkish Journal of Agricultural Engineering Research (TURKAGER), 4(2), 191-202. https://doi.org/10.46592/turkager.1362000*

INTRODUCTION

Agriculture is a major contributor to several countries' Gross Domestic Product (GDP), accounting for about 24% of Nigeria's GDP and 14% of Africa's cumulative GDP (Statista, 2022). Food crisis has become a major global problem due to inequality between food production and increment in human population. According to Ballard (1996), substantial variation between farm product production and

consumption has caused a severe demand-supply mismatch, which has resulted in food insecurity leading to hunger and malnutrition. Crop protection (weeding, fertilizers application, irrigation and pest control) which is one of the essential aspects of crop production, is a tedious and time-consuming operation; hence the application of advanced techniques have played a very essential aspects in avoiding crop failure (Ekruyota and Uguru, 2021; Sahni *et al.*, 2021).

Modern technologies have not only improved the industrial sector but also the agricultural sector. This has improved the rate of food production and supply chain for farm products, thus mitigating the problem of food insecurity (Cao, 2022). Among these technologies are automation and smart technology (Artificial Intelligence) which help produce healthy farm products in appreciable qualities and quantities. These technologies used configured sensing devices to carry out basic agricultural activities, thus bridging the food production gaps created by insufficient human power (Ramirez-Asis *et al.*, 2022). Within the past two decades, the application of artificial intelligence (AI) and cloud have helped to enhance agricultural activities logistic to be more proficient and reliable (Srivastava *et al.*, 2018; Ben Ayed and Hanana, 2021).

Though some scientists have developed smart systems for agricultural production activities (Goap *et al.*, 2018; Ogidan *et al.*, 2019; Nurhasanah *et al.*, 2021), related literature starch reviewed that there is not integrated smart greenhouse that can monitor the soil moisture, air temperature and quality within the green house. Therefore, this research was aimed at developing a prototype of smart greenhouse where the soil water and nutrients content, together with the air temperature can be closely monitored for the benefit of crops production.

MATERIALS and METHODS

The study area

This research was conducted Ozoro community of Delta State, Nigeria. The area is located within the tropical rainforest region with dense vegetation, characterized by high temperatures and high humidity. Ozoro has two basic climatic seasons – wet and dry climatic seasons, experiences about 1800 mm per annual and temperature of 39±70°C. The rainy (wet) season is associated with high humidity, while the dry season is characterized by reduced rainfall and lower humidity (Uguru *et al.*, 2022).

Smart system architecture

The block diagram of the smart greenhouse structure is presented in Figure 1.

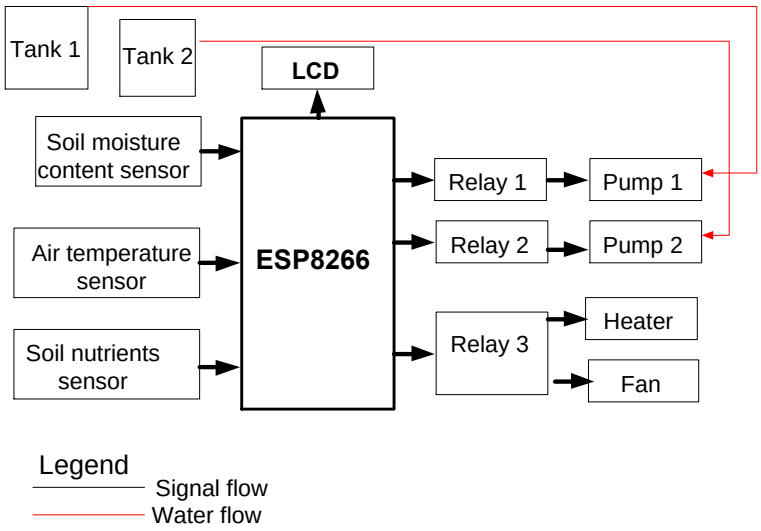

Figure 1. *The block diagram of the smart system.*

Essential components and their specifications

The components used for the automation are presented as follows:

Microcontrollers

A NodeMCU ESP8266 (32-bit RISC CPU Xtensa LX106) with a Wi-Fi module that has an operating voltage of 3.3V, SRAM of 64 KB, clock speed of 80 MHz and input voltage that ranges from 7 V to 12 V direct current (DC), was used for the construction of the greenhouse prototype. The Arduino was also used as a supportive microcontroller to run some of the applications in the smart green house.

Soil moisture sensor

A corrosion-resistant soil moisture sensor with an operating voltage ranging between 3.3 V and 5 V direct current, an operating current of 15 mA and PCB Size of 3.2 cm x 1.4 cm was used for the construction of the prototype. The corrosion- resistant probe was selected for the design because of some corrosive agricultural chemicals that will be applied to the soil during crop cultivation.

Temperature and humidity sensor

The DHT11 temperature and humidity sensor module with voltage range of 3 V to 5 V, power rating of 2.5 mA and temperature accuracy of ±2°C was used for the design of the smart structure. The DHT11 sensor can measure temperature within the range of 0°C to 50°C and humidity of 20% to 80% (±5%), which are consistent with the crop's environmental requirements.

Soil nutrient (NPK) sensor

The JXCT Soil NPK sensor with Modbus RS485, having a voltage range of 9 V to 12 V DC, operating environmental temperature that varied from 5°C to 45°C, and measuring range of 0 to 1999 mg kg^{-1} was selected during the design of the smart

greenhouse. This sensor gives high-speed measurement, while appreciable accurate results (Sensors, 2023).

Water pump

A water pump with the following specification: operating voltage ranging from 2.5 V to 6 V, operating current of 220 mA, water flow rate of 120 L h^{-1} and maximum head of 110 mm. Two of these pumps were used for the design; one controls the irrigation line, while the other controls the fertigation line.

Peripheral Component Interconnect (PCI) fan and heater

A waterproof PCI fan (model: TFD-12025H12B/KW(RB)) with these specifications 12 V DC, power rating of 0.33 A, speed of 2200 RPM and airflow rate of 113.2 $m^3 h^{-1}$ was used for the design. The waterproof fan was selected due to the moist environment of the greenhouse resulting from the irrigation process. Also, a 12 V space air heater with a power capacity of 50 W, which can heat up to 100±10°C was used for the design and development of the prototype.

Programming language used

The C++ language programming language was used to design and develop the smart greenhouse. The C++ language was used because it is elegant, flexible, safe and object-oriented (O'Reilly, 2021). The graphical user interface (GUI) was developed with the Blynk application for Android. Blynk app is highly compatible with several IoT applications and can easily interact with the Arduino microcontroller (Idama and Ekruyota, 2023).

Router module

A 3-port 10/100 Mbps wireless router module, with voltage a rating of 5 V, CPU frequency of 650 MHz, and 2.4G Wi-Fi transmission rate of 300 Mbps was used to connect the greenhouse to the internet.

The workflows

The flowcharts and algorithms of the smart greenhouse are presented in Figures 2, 3 and 4. Figure 2 shows that the soil moisture sensor reads the soil moisture level and transmits the data to the microcontroller for interpretation. Then the microcontroller determines if it is relevant to activate/deactivate the relay module in charge of pumping machine 1, which is in charge of irrigation based on the pre-set soil moisture content range. Then, in Figure 3, the DHT11 sensor detects the greenhouse air temperature and transmits the data to the microcontroller to determine whether to activate/deactivate the relay connected to the heater or the fan based on the pre-set temperature range. Also, figure 3 revealed that the soil nutrients sensor will measure the soil nutrients level and transmit the same to the microcontroller for interpretation. Then, the microcontroller will initial the process of activating the relay module in charge of pump 2 if the nutrient levels are below the pre-set values, if the nutrient level matches the upper limits of the plant's requirement, the relay will deactivate pump 2 and the fertigation procedure will terminate automatically.

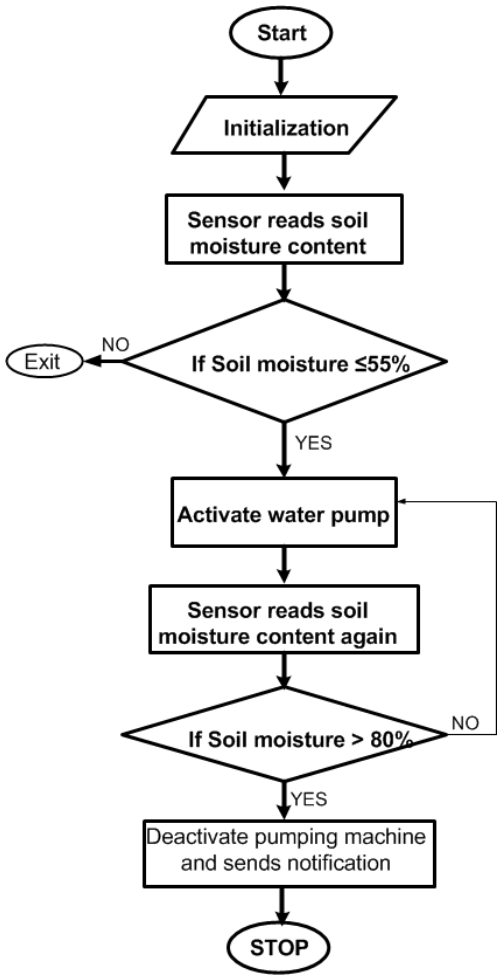

Figure 2. The flowchart of the irrigation unit.

Algorithm of the irrigation unit

STEP 1: START
STEP 2: Initialized the system.
STEP 3: Sensor reads the soil's moisture content.
STEP 4: If the moisture content is less than 55% go to step 5, else go to step 9
STEP 5: Activate the water pump for irrigation.
STEP 6: Sensor reads the soil's moisture content again after one hour.
STEP 7: If the moisture content is greater than 80% go to step 8, else go to step 5
STEP 8: Deactivate the pumping machine for irrigation.
STEP 9: STOP

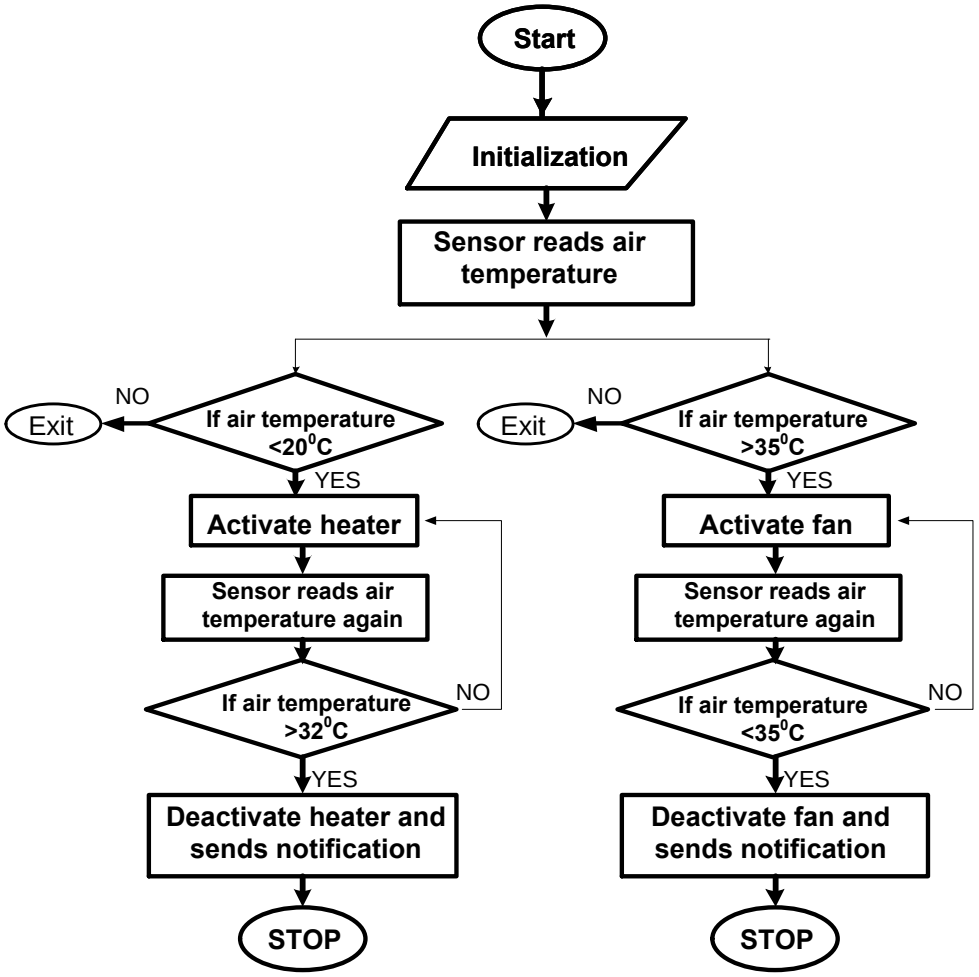

Figure 3. The flowchart of the cooling and heating units.

Algorithm of the cooling and heating sub-systems

STEP 1: START
STEP 2: Initialized the system.
STEP 3: Sensor reads the air temperature content
STEP 4: Check for input command (Low temperature, High temperature)
STEP 5: If low temperature go to step 6, else if high temperature go to step 10, else go to Step 15.
STEP 6: Activate the heater and send notification.
STEP 7: Sensor reads the air temperature again.
STEP 8: If the temperature is greater than 32°C go to next step 9 else go to step 6.
STEP 9: Deactivate the heater and go to step 15.
STEP10: If the air temperature is greater than 35°C go to step 11 else go to step 15
STEP11: Activate the fan.
STEP12: Sensor reads the air temperature again.
STEP13: If the air temperature is less than 35°C go to step 14 else go to step 11
STEP14: Deactivate the fan and send notification.
STEP15: STOP

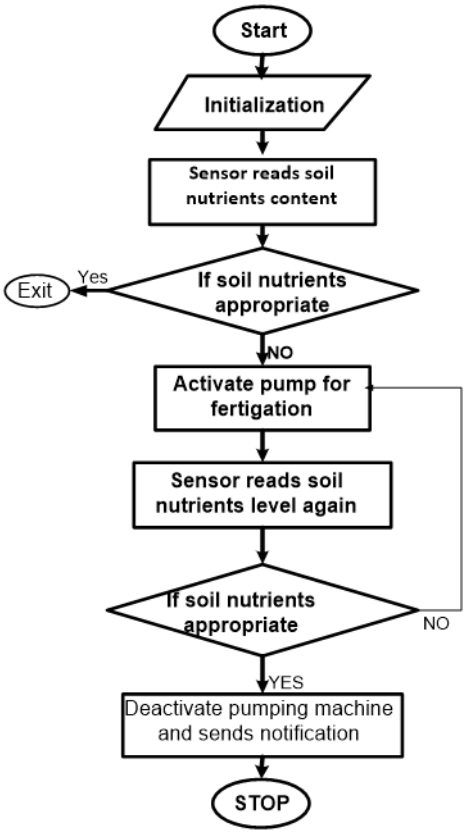

Figure 4. The flowchart of the fertigation sub-system.

Algorithm of the fertigation unit

STEP 1: START
STEP 2: Initialized the system.
STEP 3: Sensor reads the soil's nutrients level.
STEP 4: If the soil nutrients levels are not appreciated go to step 5, else go to step 9
STEP 5: Activate the pump for fertigation.
STEP 6: Sensor reads the soil's nutrients levels again after one hour.
STEP 7: If the nutrients levels in the soil are within the recommended level go to step 8, else go to step 5
STEP 8: Deactivate the fertigation pumping machine.
STEP 9: STOP

Testing

The system was tested for 20 hours, starting with fresh leached oven-dry soil (moisture content of about 10%). The greenhouse was placed under the sun between 9 am to 6 pm for two days. To evaluate the accuracy of the smart greenhouse, a digital handheld thermometer and soil meter were used to determine the temperature and soil moisture content of the greenhouse.

The interior temperature of the greenhouse was programmed to range between 240°C to 300°C, the moisture content was programed to vary from 60% to 80% and the nutrient values were programmed to range from 150 mg kg^{-1} to 400 mg kg^{-1}. Therefore, if any parameter designed for the smart system falls outside the pre-programmed values, a sensor will trigger the relay to start or stop the water pump, fertigation pump, fans or heater to regularize the situation. Additionally, the GUI

allows the user to Switch "ON" and "OFF" the systems if the need arises if there is a reliable internet network.

The temperature, soil moisture content and soil nutrient level of the greenhouse environment will be programmed according to the environmental requirement of the intended planted crop inside the greenhouse. According to Nurhasanah *et al.* (2021) reports, most vegetables and fruits require soil moisture content that ranges from 60% to 80% and environmental temperature that ranges from 240°C to 300°C. Environmental conditions outside the optimal range of a crop severely affect its production and performance (Ma *et al.*, 2016; Xue *et al.*, 2017; Awad *et al.*, 2022).

RESULTS AND DISCUSSION

The test results of the smart greenhouse are presented in Table 1. The findings revealed that the heating and watering of greenhouse crops can be done through automation and smart process, which is further confirmation of the researches carried out by Goap *et al.* (2018) and Nurhasanah *et al.* (2021). The increment observed in the greenhouse air temperature during the test running period can be linked to the external atmospheric conditions. It was noted from the results that pump 2 is rarely started when compared to pump 1; pump 2 was switch ON only three times (with 2 false positive), as against 10 times recorded in pump 2. This can be linked to lower nutrients depreciation rate in the soil, when compared to water under the same environmental conditions. Xue *et al.* (2017) stated that water consumption by plants tends to be higher than nutrient consumption. Since water is more volatile than most plants nutrients, therefore its ability to evaporate is higher than those plants' nutrients. A similar high-water consumption rate during automated irrigation was noted by.

Table 1. Results obtained from the greenhouse testing and evaluation.

	Soil moisture	Air Temperature	Nutrient level	Irrigation system	Heater	Fan	Fertigation
9:00 AM	12.6	20.6	Low	ON	ON	OFF	ON
10:00 AM	18.9	21.9	Low	ON	ON	OFF	ON
11:00 AM	24.1	24.6	Low	ON	ON*	OFF	ON
12:00 PM	30.7	26.5	Low	ON	OFF	OFF	OFF*
1:00 PM	51.3	28.1	High	ON	OFF	OFF	OFF
2:00 PM	67.4	32.8	High	ON	OFF	ON	OFF
3:00 PM	75.4	31.2	High	ON	OFF	ON	OFF
4:00 PM	88.2	26.8	High	OFF	OFF	ON*	OFF
5:00 PM	83.1	25.3	High	OFF	OFF	OFF	OFF
6:00 PM	82.8	24.1	High	OFF	ON*	OFF	OFF
9:00 AM	79.5	21.7	High	OFF*	ON	OFF	OFF
10:00 AM	73.9	23.3	High	OFF*	ON	OFF	OFF
11:00 AM	68.2	25.4	High	OFF	OFF	OFF	OFF
12:00 PM	62.8	27.9	High	OFF	OFF	OFF	OFF
1:00 PM	55.6	32.2	High	ON	OFF	ON	OFF
2:00 PM	60.3	31.6	High	ON	OFF	ON	OFF
3:00 PM	68.1	30.4	High	ON	OFF	ON	ON*
4:00 PM	77.3	27.2	High	OFF*	OFF	OFF	ON*
5:00 PM	83.5	25.6	High	OFF	OFF	OFF	OFF
6:00 PM	81.8	24.8	High	OFF	OFF	ON*	OFF

* = false results

Performance evaluation of the system

The irrigation unit

It was observed that the irrigation system gave false results in 3 outputs out of the 20 outputs.

Therefore, the performance of the smart irrigation system = $\frac{17}{17+3} \times 100 = 85\%$

Heating unit

It was observed that the heater gave false results in 2 outputs out of the 20 outputs.

Therefore, the performance of the automated heating system = $\frac{18}{18+2} \times 100 = 90\%$

Cooling unit

It was noted from the experimentation that the fan gave false results in 2 outputs out of the 20 outputs.

Therefore, the performance of the automated cooling system = $\frac{18}{18+2} \times 100 = 90\%$

Fertigation unit

It was noted from the experimentation that the fertigation system gave 3 false results out of the 20 outputs.

Therefore the fertigation system performance = $\frac{17}{17+2} \times 100 = 85\%$

Overall performance

The overall performance of the smart greenhouse = $\frac{85+90+90+85}{4}$ = 87.5%

Based on the results presented in Figure 5, it was observed that the soil moisture sensor has 85% accuracy, the DHT11 sensor has 90% accuracy and the soil nutrient sensor has 85% accuracy. The findings of this study that the smart greenhouse performance was above average; therefore, there was strong correlation between the hardware and the software. This indicates that the three sensors and the programming used in the development of the greenhouse can keep the air temperature, soil moisture and soil nutrients properly for proper growth and development of the crops planted inside the greenhouse. These achievements in the automation and using IoT to control essential parameters inside the greenhouse are similar to works done by Goap *et al.* (2018), Ogidan *et al.* (2019) and Nurhasanah *et al.* (2021). Therefore, this smart system will enhance the greenhouse production of fruits and vegetables, mainly by incorporating the soil nutrients analyzer into the smart system.

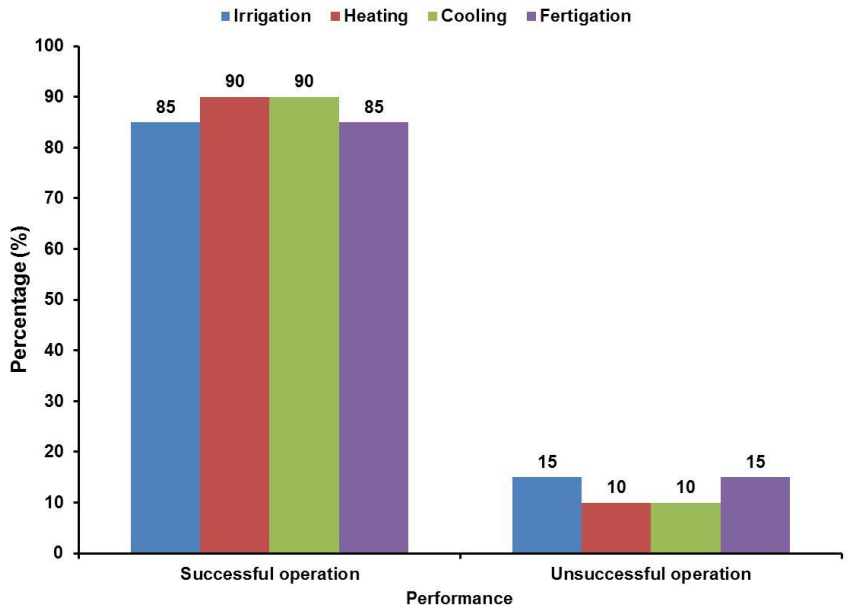

Figure 5. *The performance of the smart system.*

CONCLUSION

This system was developed to use automation and IoT to enhance crop production. The input components of the smart greenhouse include soil moisture sensor, soil nutrients sensor and temperature sensor; the process (microcontroller) components consist of the ESP8266 and associated Arduino; the output components comprise liquid-crystal display (LCD), water pump, fan, heater, and the relay modules, while the C++ programming language was used. Results obtained from the experimentations of the prototype structure revealed that the performance rating of the greenhouse was above average (87.5% efficiency). This depicted that the sensors,

hardware devices and coupled with the IoT can guarantee constant monitoring of a greenhouse soil nutrient level, moisture content and the environmental air temperature and condition. This will enhance the crops productivity and alleviate the problem of food insecurity ravaging Nigeria.

DECLARATION OF COMPETING INTEREST

The authors declare that they have no conflict of interest.

CREDIT AUTHORSHIP CONTRIBUTION STATEMENT

The authors declared that the following contributions are correct.
Ovuakporaye Godwin Ekruyota: Data analysis and review of the original draft.
Uzuazokaro Nathaniel Asibeluo: Designed the research Methodology and writing of the original draft.

ETHICS COMMITTEE DECISION

This article does not require any ethical committee decision.

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Turkish Journal of Agricultural Engineering Research

Turk J Agr Eng Res *(TURKAGER)*

https://dergipark.org.tr/en/pub/turkager
https://doi.org/10.46592/turkager.1343229

ISSN: 2717-8420
2023, 4(2), 203-224

Research Article

Application of Solar Energy to Liquify Beewax

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Article Info
Received: 15.08.2023 **Accepted:** 10.11.2023 **Published:** 31.12.2023

ABSTRACT

This study investigates the feasibility of using solar energy to melting recycled older combs and capping wax byproducts to prepare raw beeswax. The solar-driven beeswax melter comprises a stainless-steel container, a lean-to structure featuring polycarbonate sheet covers, a wooden solar heater, and parallel arrays of PV solar panels. The research contrasts three distinct approaches for melting beeswax: the conventional water bath technique, exclusive reliance on solar energy for melting, and combining solar energy and supplementary heat from solar panels. The traditional water bath method's effectiveness and the bulk temperature of the liquified beeswax were determined. In the case of the solar-powered wax melting setups, the process efficiency, bulk temperature of the melted wax, and various macroclimatic factors such as sunlight radiation, temperature, and relative humidity were documented. Based on the experimental outcomes, the beeswax melting efficiency was determined to be 73.4% for the traditional water bath method, whereas it escalated to 85.5% and 87.2% for the solar approaches, respectively. Hence, the utilization of solar techniques for beeswax melting is recommended.

Keywords: *Capping wax byproducts, Honeybee, Melting efficiency, Solar energy*

To cite: Al-Rajhi MAI, El-Serey SM and Elsheikha AM (2023). Application of Solar Energy to Liquify Beewax. *Turkish Journal of Agricultural Engineering Research (TURKAGER), 4(2): 203-224.* *https://doi.org/10.46592/turkager.1343229*

INTRODUCTION

Recently, the pursuit of sustainable and renewable energy sources has gained significant momentum. This is due to global efforts to address climate change and diminish carbon emissions.

Among these prospects, using solar energy has emerged as a promising avenue, harnessing the sun's power to generate clean and abundant electricity. Although solar panels are commonly associated with electricity generation, solar energy has the potential to revolutionize diverse aspects of our lives, extending beyond powering residences and businesses. An intriguing application lies in the liquefaction of beeswax, a versatile and natural substance with a myriad of applications. By harnessing solar energy to melt beeswax, we have the opportunity to not only tap into a replenishable resource but also advocate for environmental awareness and contribute to preserving bee populations. Honeybees utilize wax to construct their honeycombs. When they reach a specific age, typically around 12 to 18 days, fully developed wax glands on the lower part of their abdomen commence wax production in the form of thin scales. These bees possess eight glands that are responsible for the synthesis of wax. Roughly 3.629 kg of honey is needed to yield 0.455 kg of beeswax. Beeswax holds value not only as a precious commodity but also as a potential source of significant revenue. Regarding economic worth, a kilogram of beeswax holds more value than a kilogram of honey. Managing beeswax is more straightforward than honey, as it doesn't necessitate delicate packaging and isn't categorized as a food product. This distinction results in enhanced ease of transportation and storage (Bradbear, 2009). Furthermore, beeswax boasts a wide array of applications, encompassing the crafting of polish, candles, and delicate wax sheets termed "foundation" sheets. In the contemporary landscape, a significant share of the produced wax finds use in the cosmetics industry, spanning from depilatory wax to hand and face creams, lipsticks, and diverse pharmaceutical items such as ointments, pills, and suppositories. According to research by Gemeda and Kebebe (2019), on the global market, beeswax is valued three times more per unit than honey. As the Food and Agriculture Organization (FAO, 2022) projected, global beeswax production has reached a tally of 62.166 tons, with contributions from Asia, Africa, and America standing at 51%, 26%, and 22%, respectively. In the context of Egypt, the year 2020 witnessed a beeswax production of 113 tons, alongside the import of 61 tons, amounting to a value of 242 thousand dollars.

Bees employ the creamy-colored beeswax to construct their nest combs, with the color of pure beeswax varying from white to yellow to yellow-brown contingent upon factors such as pollen proportion and propolis pigments. Extraction of wax can be achieved through two primary methods: chemical and melting, as outlined by Sin *et al.* (2014). Additionally, repurposing old honeycombs involves obtaining wax by removing smaller comb components like wax capping, frames, and hive elements before honey extraction. This introduction explores the potential advantages, challenges, and implications of utilizing solar energy for beeswax melting, highlighting an innovative and eco-friendly approach to fulfilling our wax melting requirements.

Employing solar energy for melting beeswax brings forth several notable benefits. To begin with, it offers a sustainable and renewable energy source, minimizing dependence on fossil fuels and mitigating greenhouse gas emissions. This shift towards solar energy aligns with global endeavors to combat climate change and transition towards a cleaner energy landscape. Additionally, solar-energy melting systems present an economical solution since sunlight is abundant and free, negating the necessity for expensive energy sources and reducing operational costs for beekeepers, artisans, and small-scale businesses.

The use of solar energy to melt beeswax can be achieved through diverse solar thermal technologies. Solar wax melting structures, for instance, are purpose-built setups that utilize solar collectors to capture and transform sunlight into heat energy. Frequently crafted from reflective materials or solar panels, these collectors concentrate sunlight onto a surface designed to absorb heat, generating ample warmth to effectively liquefy beeswax. Innovative designs also incorporate insulation and storage mechanisms, prolonging the molten state of the wax and enhancing productivity and convenience.

The melting point of beeswax falls within the range of 62 to 65°C, necessitating substantial energy for its liquefaction. Wax softens at 35°C, rendering it pliable. To eliminate impurities, the wax must be separated from the comb using sunlight, hot water, or steam before extraction, as elucidated by Mutsaers *et al.* (2005). The creation of melter systems involves utilizing electrical and solar heat supply technologies due to their simplicity. Aluminum or stainless-steel containers are suitable for preserving the wax's color, ensuring a non-direct contact with the heat source, according to Bogdanov (2009). Application of heat energy prompts beeswax to absorb it, resulting in the breaking of intermolecular bonds. According to Khamdaeng *et al.* (2016), the phase shift temperature range spans 18 to 32°C, with the melting point within 30 to 60°C.

Additionally, Egypt boasts abundant sunlight resources, with an annual average of 3050 hours of sunlight. The direct normal irradiation levels fluctuate between 1970 and 3200 kWh m^{-2}, and the annualized total solar irradiance ranges from 2000 to 3200 kWh m^{-2}, as documented in the solar atlas. Consequently, Egypt's solar potential stands out and can be harnessed across diverse solar energy systems and sectors. Moharram *et al.* (2022) note that this encompasses the feasibility of implementing photovoltaic (PV) or concentrated solar power (CSP) plant setups.

The microorganisms accountable for diverse bee ailments, including European foul brood (EFB), American foul brood (AFB), and Nosema, might be present within deteriorated or aged honeycombs. Among renewable energy sources, solar energy stands out due to its environmentally friendly attributes, cost-efficiency, and ample availability for a significant portion of the year, coupled with manageable radiation intensity. Given the scarcity of investigations on the application of solar melting systems for beeswax recycling in Egypt, this study aimed to determine an efficient approach for wax liquefaction. The central goal was to yield top-notch wax blocks suitable for local utilization or exportation, fostering successful business endeavors.

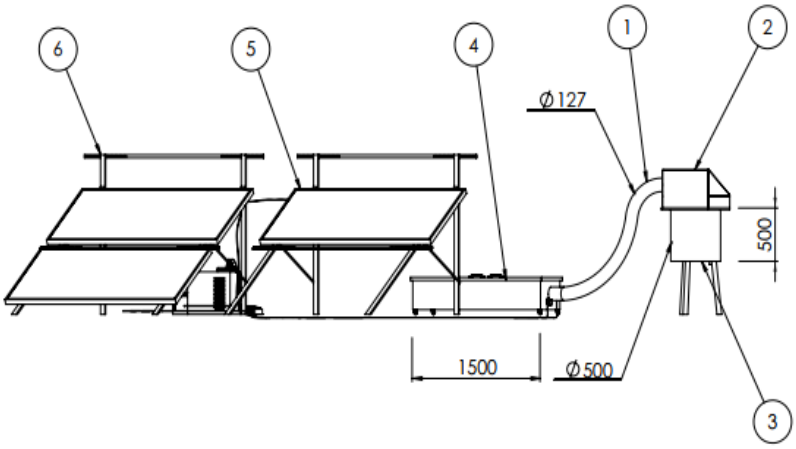
MATERIALS and METHODS

The trials were carried out at Damietta University's Faculty of Agriculture, situated at geographical coordinates of 31.4224°N latitude and 31.6575°E longitude. The research was conducted from August 30 to September 12, 2022, with the primary aim of examining how solar energy influences the process of liquefying raw beeswax. The wax melting took place during daylight hours, and temperature assessments were conducted from 07.00 to 17.00 to capture the temperatures within and outside the experimental setup, alongside any detected fluctuations in these measurements.

Materials

Unclean beeswax was procured from mature brood frames, the remnants left behind after heather pressing, and the wax that encases the cells. While cappings produce pristine wax, the beeswax derived from aged brood combs is commonly tainted.

Employing solar energy as its energy source, a solar wax extractor is utilized to swiftly and efficiently purify beeswax, elevating the internal temperature to 68-70 °C. The solar-energy wax melter consists of the components enumerated below, as depicted in the vertical diagram in Figure 1 and the photograph in Figure 2.



No.	Part name	No.off
1	Aluminum Pipe 5 in	1
2	Lean-to architectural Form	1
3	Stainless-steel Tank	1
4	Solar heater (Wooden heater)	1
5	Solar photovoltaic panels	3
6	Stand	2

Figure 1. *Illustrates the vertical perspective of the wax melter powered by solar energy.*

Figure 2. *Displays a photograph of the wax melter operated by solar energy.*

The tank, constructed from stainless-steel (3), possesses a diameter measuring 50 cm and a depth of 59 cm. The exterior surface is thermally insulated to minimize heat loss from its sides. The wax discs that have been prepared are positioned on a perforated stainless-steel tray with an area of 19.63 cm². The dimensions of the wooden framework for the Lean-to architectural Form (2) can be observed in Figure 3. Exccept the nickel-chrome-protected rear reflector, the entire extractor is enveloped in 2 mm-thick polycarbonate panels to optimize its exposure to solar energy. A solar energy meter was employed to measure the intensity of solar radiation during the experiment. It offered a precision of 10 W m^{-2}, a resolution of 0.1 W m^{-2}, and the ability to record a peak intensity of up to 2000 W m^{-2}.

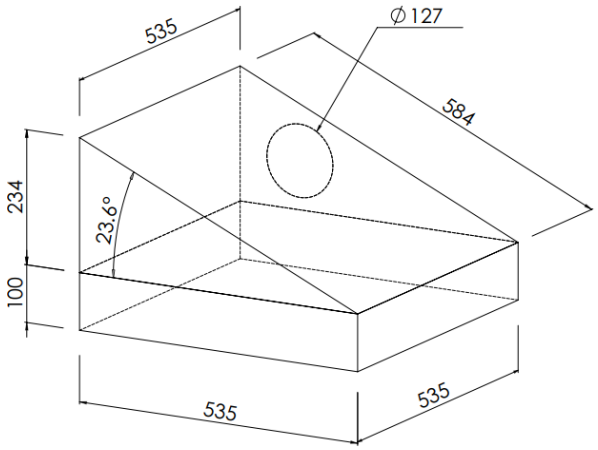


Figure 3. *Presents a schematic illustration of the Lean-to architectural structure.*

A ceramic plate was positioned beneath the thermal coil for safety and insulation purposes, to safeguard the solar heater (4). The thermal coil was attached to stainless-steel screws and placed within a wooden enclosure lined with fiberglass on the inside. This arrangement offers protection against burns and ensures effective insulation for the solar heater. The solar photovoltaic panels (5), comprised of three JSM-385M72 modules, were employed. A polycrystalline solar panel with the following specifications was utilized: designated peak power: 385 W, voltage at maximum power (Pmax): 40.29 V, current at maximum power (Pmax): 9.56 A, open-circuit voltage: 48.98 V, current under short-circuit conditions: 10.11 A, Maximum Series Fuse Rating: 20 A, Power Tolerance: 0~5 W, Maximum System Voltage: IEC1500V, Nominal Operating Cell Temperature: 45±2°C, and Operational Temperature: -40°C~+85°C. These panels were installed parallel and positioned at an ideal 30° angle relative to the horizontal plane. They were firmly affixed to a rectangular metal frame.

Methods

The experiment aimed to compare the conventional water bath technique with solar energy utilization for beeswax melting. In the water bath approach, a stove-heated aluminum pan was filled with water, and a smaller aluminum pan containing 500 g of beeswax was placed in it and heated over medium heat until wax melting occurred. In contrast, the solar-powered wax melter harnessed direct solar heat to liquefy the wax, obviating the need for comb storage. This method was assessed in two ways:

firstly, solely relying on solar energy, and secondly, integrating solar power with supplementary heat from solar panels. The latter technique employed hot air with an average velocity of 0.8 m s^{-1} and a temperature of 60°C. These variations aimed to generate raw wax via the solar-powered wax melter.

The appropriate tilt angle for an inclined surface was calculated using the equations proposed by Duffie and Beckman (2013) to achieve the lean-to architectural design and optimizing solar radiation absorption. These equations provide insights into determining the most suitable angle that ensures the highest solar radiation exposure.

$$\beta_o = cos^{-1}[cos(\phi)\,cos(\delta)\,cos(\omega) + sin(\phi)\,sin(\delta)] \quad (1)$$

$$\delta = 23.45\,sin\left[(360) + \left(\frac{284+n}{365}\right)\right] (2) \quad (2)$$

The geographical latitude angle (ϕ) for the research site (New Damietta) is 31.42°.

- The solar hour angle (ω) is determined using the formula 15 (Local Apparent Time - 12), where LAT denotes the local apparent time.

- The solar declination angle (δ) signifies the sun's positioning with respect to the celestial equator.

- The symbol "n" stands for the count of days following January 1st.

Assessed Parameters:

The experiment encompassed three distinct beeswax melting techniques: the traditional water bath approach, the utilization of solar energy alone for melting, and the utilization of solar energy combined with supplementary heat from solar panels. The measurements were categorized into primary and secondary segments:

Primary measurements were conducted for the water bath method and encompassed:

1) The overall temperature of liquefied beeswax.
2) Efficiency of the melting process.

Secondary measurements were carried out for the solar-powered wax melter and included:

1) Duration of beeswax melting.
2) Surrounding temperature.
3) Relative humidity.
4) Received solar radiation.
5) Overall temperature of liquefied beeswax.
6) Efficiency of melting, as defined by the equation [3] (Khamdaeng *et al.*, 2016):

$$EFF\% = \frac{M_i - M_f}{M_i} \times 100 \quad (3)$$

Where: EFF% represents the efficiency of melting (%), M_i signifies the initial mass (in grams), and M_f denotes the mass of beeswax that remains after the melting process (in grams).

7) The efficiency of the solar wax melter was determined using the subsequent equation [4].

$$\eta_c = \frac{P_{out}}{P_{in}} = \frac{(mC_p\Delta T+mL)}{P_{in}} = \frac{(mC_p\Delta T+mL)}{A_c I_b} \quad (4)$$

Where: ηc represents the system's efficiency (%), P_{out} stands for the output power (measured in watts), P_{in} indicates the input power, m denotes the rate of wax melting (in kilograms per hour), C_p signifies the specific heat of beeswax (0.476 kJ kg^{-1} K^{-1}), ΔT stands for the temperature difference (T_f - T_i), L represents the latent heat of fusion of beeswax (242.8191 KJ kg^{-1}), A_c is the collector's surface area (measured in square meters), and I_b represents the beam radiation (in watts per square meter).

Statistical Analysis

The collected data underwent analysis using Microsoft Excel, a software developed by Microsoft Corporation and headquartered in Redmond, WA, USA. The experiments were conducted over three distinct trials, and correlation analysis was employed to enhance the study's informativeness. Microsoft Excel 2016 was employed for generating the essential graphs utilized in the analysis process.

RESULTS AND DISCUSSION

Melting Approach Using Water Bath

The outcomes reveal that a phase transition from solid to liquid occurs in beeswax at an average temperature of 63.01°C. On average, it takes about 30.5 minutes to completely melt the beeswax (Figure 4). These results offer insights into the kinetics of this phase change, offering practical implications.

The efficiency of the water bath method in melting beeswax exhibited a range between 65.1% and 77.7%, with an average efficiency of 73.4%. This signifies that a notable proportion of the applied heat effectively contributes to the wax melting. The variability in efficiency values underscores how aspects such as heating rate, insulation, and container design can impact the overall efficiency of the procedure.

These findings align with prior investigations conducted by Krell (1996), Nuru (2007), and Bogdanov (2016). These studies also highlighted that the beeswax's melting point commonly falls between 61 and 66°C, ideally situated between 62 and 65°C. The convergence of results from multiple studies underscores the dependability and validity of the water bath technique for beeswax melting.

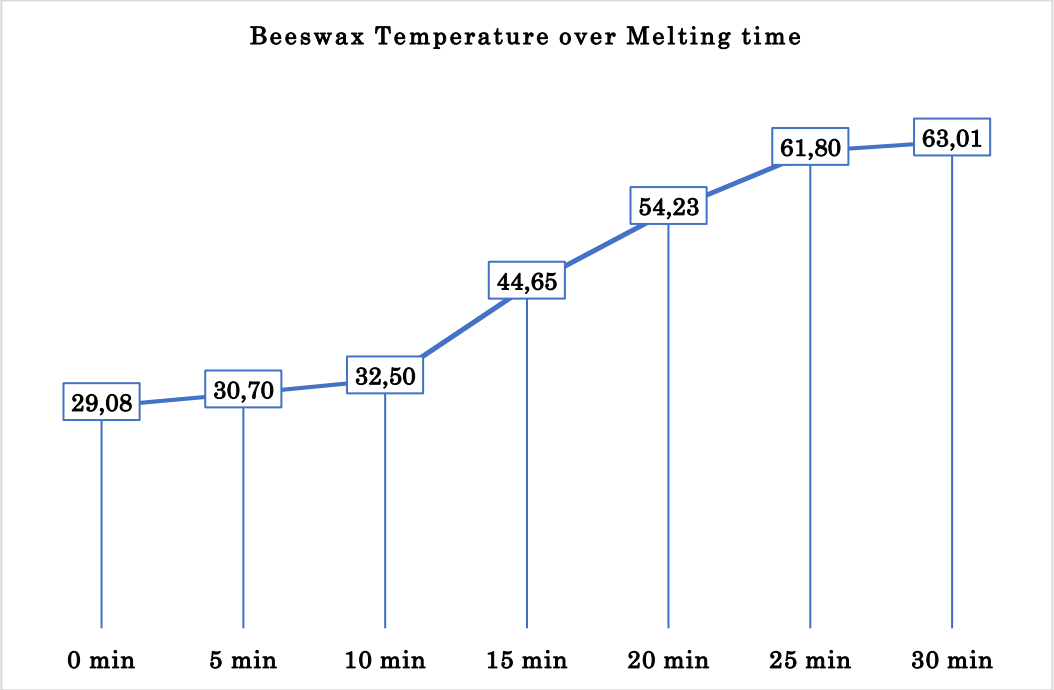


Figure 4. *Beeswax temperature during melting using a water bath.*

Utilizing Solar-Powered Wax Melter

In the initial configuration, the wax melting process spanned from 150 to 360 minutes, averaging 243.3 minutes. In contrast, the second configuration required 90 to 240 minutes, averaging at 183.3 minutes. These findings underscore the substantial reduction in melting time achievable through solar energy utilization compared to the water bath technique, which typically takes about 30.5 minutes.

The assessment of melting efficiency for the solar-energy wax melter was also conducted. In the first setup, melting efficiency ranged between 66.9% and 95.1%, with an average efficiency of 85.5%. Similarly, the second configuration exhibited melting efficiency from 81.4% to 92.1%, with an average efficiency of 87.2%. These outcomes underscore the superiority of the solar- energy wax melter over the conventional water bath method in terms of melting efficiency.

Incorporating of an external solar heater in the second configuration likely contributed to the heightened melting efficiency and reduced melting time. Sustaining an average temperature of 60°C and an average airflow velocity of 0.8 m s^{-1}, the solar heater likely amplified the heat transfer process, leading to quicker and more effective melting of the beeswax.

Solar Radiation Flux Incidence

To evaluate the solar radiation incident upon the wax melter, measurements were conducted on the solar collector's interior and exterior surfaces. During the initial six days of practical experimentation, the solar radiation incident within the collector ranged from 70 to 1037 W m^{-2}, while outside readings fluctuated between 84 and 1310 W m^{-2}. These measurements highlight the considerable range of solar energy availability and emphasize the necessity of accounting for radiation fluctuations to optimize the melting process.

The average hourly solar radiation accessible within the collector registered at 622.15 W m^{-2}, while external measurements showed 801.55 W m^{-2}. These values provide insights into the customary solar energy levels viable for beeswax melting. It's essential to acknowledge that these figures reflect the specific parameters of this study and could differ based on geographic location and time of year.

In the second configuration, the measurements within the collector spanned from 50 to 1014 W m^{-2}, with exterior readings ranging between 67 and 1190 W m^{-2}. This system's average hourly solar radiation was 776.60 W m^{-2} outdoors and 607.3 W m^{-2} indoors. These values underscore the inherent variability in solar radiation and the importance of optimizing the appproach to capture and utilize energy effectively.

The fluctuations in incident solar radiation measured externally, within the collector, and reflected from the vertical back wall throughout the experimental phase are depicted in Figure 5. This visualization offers a graphical representation of the dynamic nature of solar energy and the challenges associated with maintaining consistent heat input during the beeswax melting process.

The results emphasize the significance of vigilant monitoring and control of the solar energy system to accommodate variations in incident radiation. Approaches like efficient solar collector design, tracking mechanisms, and thermal storage systems can help mitigate the impact of fluctuating solar radiation and ensure a more stable heat source for melting beeswax.

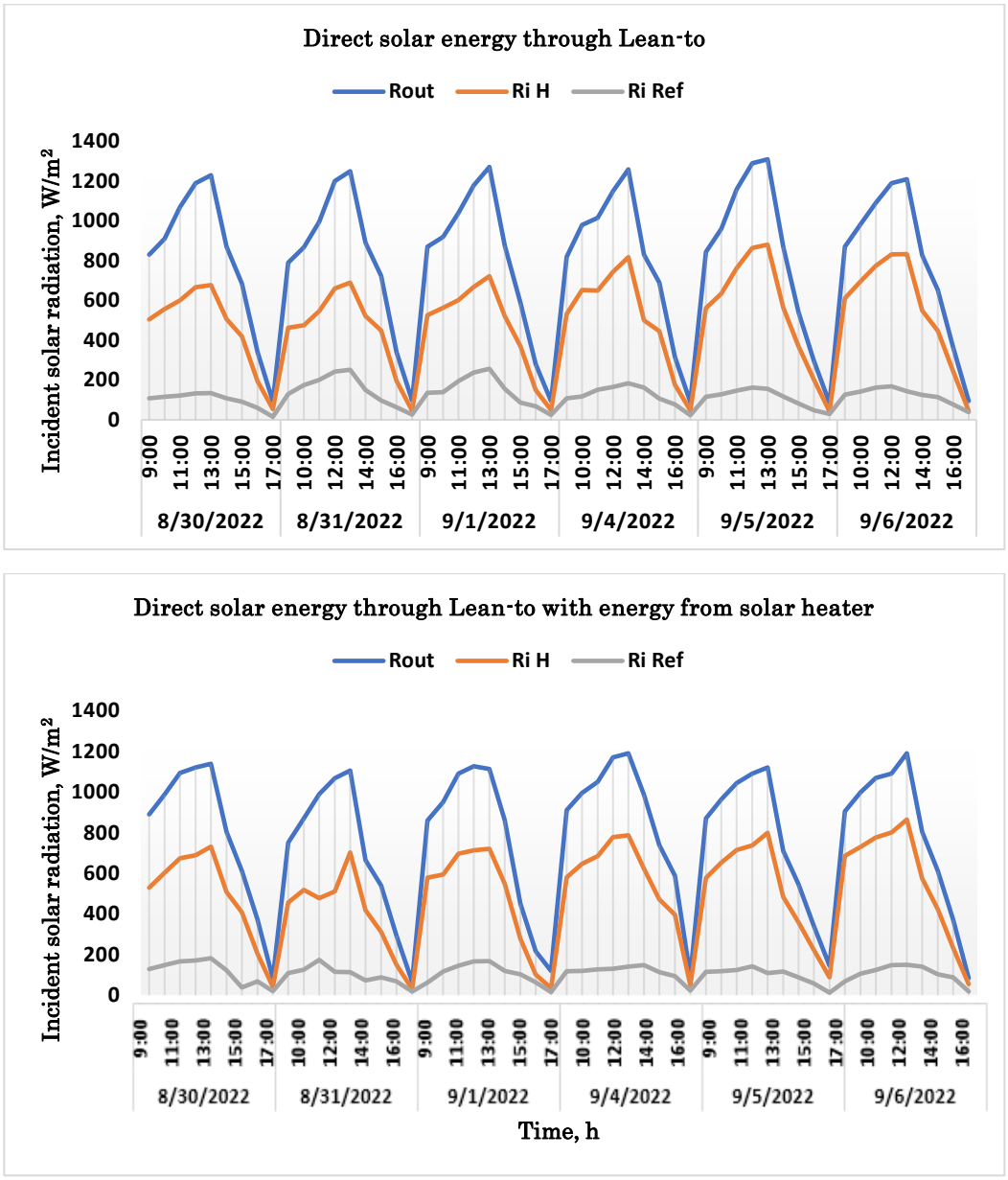


Figure 5. *Illustrates the daily variations in incoming solar radiation, both within and outside the collector, as well as the reflected radiation from the vertical-back wall during the experimental work for the two systems.*

Figure 6, as mentioned in the results section, likely portrays a visual representation of the connection between the solar radiation entering the collector and the solar radiation measured externally. This connection offers valuable insights into how effectively the transparent polycarbonate cover enables solar radiation to enter the collector.

Examining the relationship between the solar radiation entering the collector and the external measurements is pivotal for comprehending the efficiency of harnessing solar energy. This analysis can yield valuable information about the ability of the polycarbonate cover to transmit and effectively capture solar energy for the wax melting process.

Furthermore, the correlation between solar radiation within and outside the collector can help identify potential losses or inefficiencies in the system. Disparities

in solar radiation values may suggest factors like reflection, absorption, or dispersion of solar energy within the collector.

By meticulously adjusting the transparent polycarbonate cover's design, researchers and engineers can aim to maximize solar energy capture and minimize losses, thus improving the overall efficiency of the beeswax melting process. The results presented in this study originate from a straightforward power regression analysis conducted to establish a relationship between the changes in incident solar radiation within a solar collector and the incident solar radiation outside. Two distinct systems were investigated, each yielding its unique regression equation.

For the first system, where direct solar energy is captured through a Lean-to structure, the regression equation is as follows:

Equation: $y = 0.7628x + 10.763$ ($R^2 = 0.9788$)

This equation signifies that the incident solar radiation inside the Lean-to structure ('y') is influenced by the incident solar radiation outside ('x') according to this mathematical relationship. The high coefficient of determination ($R^2 = 0.9788$) indicates that this equation effectively explains and predicts changes in solar radiation within the collector based on external conditions. The strong correlation suggests that this system robustly responds to variations in solar radiation.

Moving on to the second system, which involves direct solar energy through a Lean-to with additional energy from a solar heater, the regression equation is:

- Equation: $y = 0.7838x + 1.5014$ ($R^2 = 0.9724$)

Once again, we observe a positive relationship between incident solar radiation inside and outside, albeit with a slightly different equation due to the influence of the solar heater. In this case, the R^2 value of 0.9724 still indicates a strong correlation, implying that the introduction of the solar heater does not significantly weaken the predictive power of the model. This result indicates that the system's performance remains robust and can be effectively characterized by this equation.

In both cases, it's important to note that 'y' represents the incident solar radiation inside the collector, while 'x' represents the incident solar radiation outside. These regression equations and associated R^2 values provide valuable insights into the behavior of these solar energy collection systems, assisting in their optimization and potential application in various contexts, such as renewable energy production and sustainable heating solutions. Further research and experimentation can build upon these findings to enhance the efficiency and effectiveness of such systems.

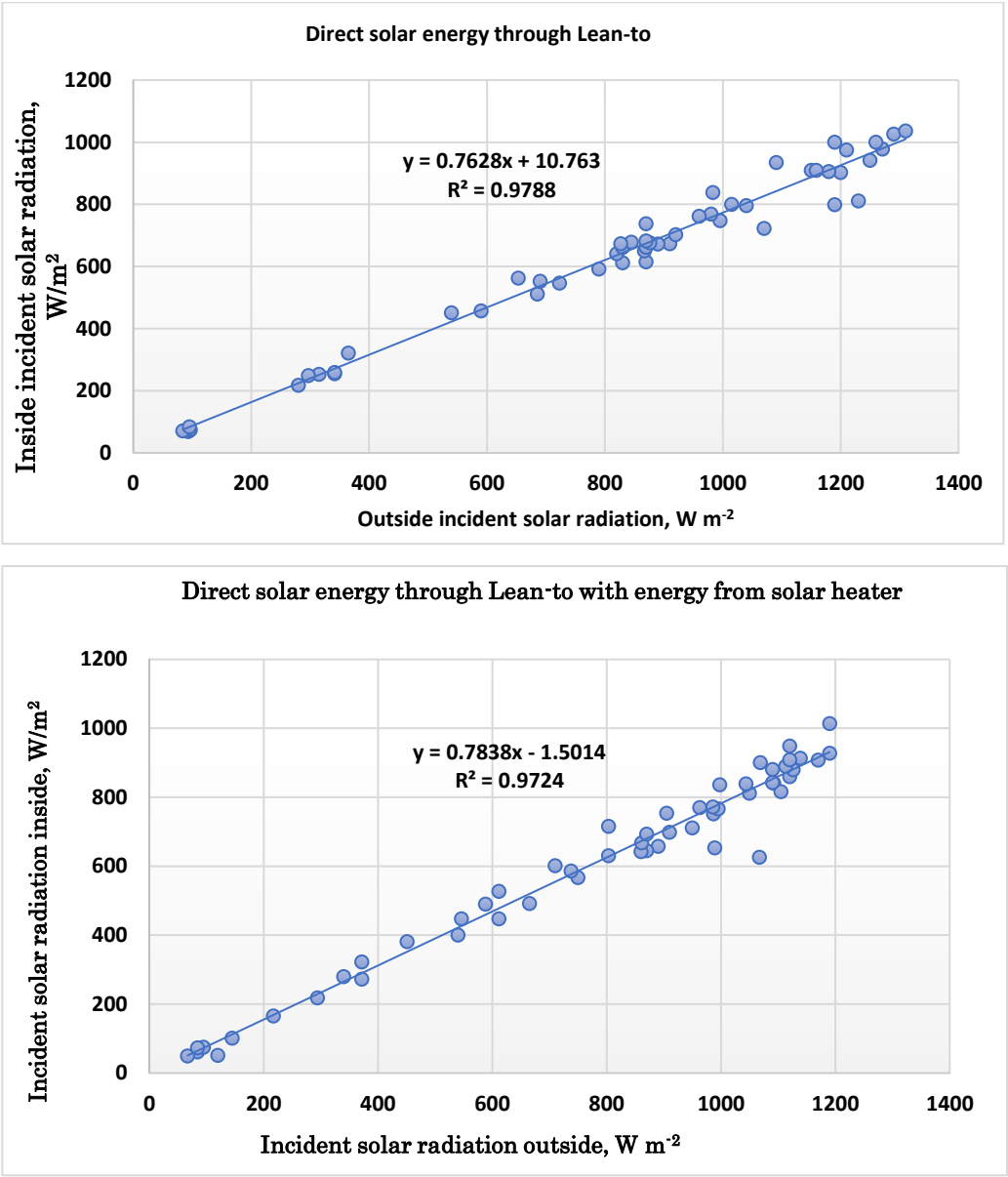


Figure 6. *Illustrates the relationship between the solar radiation incident within the solar collector and the solar radiation incident outside for the two systems.*

Environmental Temperature and Humidity Effects

The outcomes underscore the significance of temperature and humidity in the phase transition of a substance from a solid to a liquid state. The melting process involves raising a solid's internal energy, generally through heat application, which enables the solid to reach its melting point and undergo fusion (Sofekun *et al.*, 2018). In the case of beeswax, heat application is crucial for facilitating its transition to a molten state, necessitating the addition of latent heat, specifically the heat of fusion.

Throughout the experiment, the researchers documented the average hourly ambient temperatures outside and within a lean-to solar collector for two distinct systems. For the initial system, the average outdoor and indoor ambient temperatures were recorded as 29.85°C and 46.91°C, respectively. Similarly, for the second system, the corresponding values were 29.84°C outdoors and 46.25°C indoors. These measurements provide insights into the temperature conditions prevailing around the wax melter during the experimentation.

The outcomes also reveal the percentage rise in ambient temperature for each system. The first system demonstrated a 57.14% increase in ambient temperature, while the second exhibited a 55% rise. These findings illustrate the efficiency of the lean-to solar collector technique in significantly elevating the indoor ambient temperature within the wax melter.

Moreover, the researchers observed a significant influence of the indoor ambient temperature on the overall temperature of the beeswax by employing the lean-to solar collector technique under specific experimental conditions. It is plausible that Figures 7 and 7 visually represent this correlation, illustrating the link between indoor ambient temperature and beeswax temperature. The data analysis corroborated these observations, affirming the connection between indoor ambient temperature and beeswax melting temperature.

These findings underscore the pivotal role of ambient temperature in the beeswax melting process. Higher indoor ambient temperatures within the wax melter lead to more efficient heat transfer and subsequent beeswax melting. The lean-to solar collector technique, which capitalize on solar energy and fosters an elevated indoor ambient temperature, offers a mechanism for achieving effective beeswax melting.

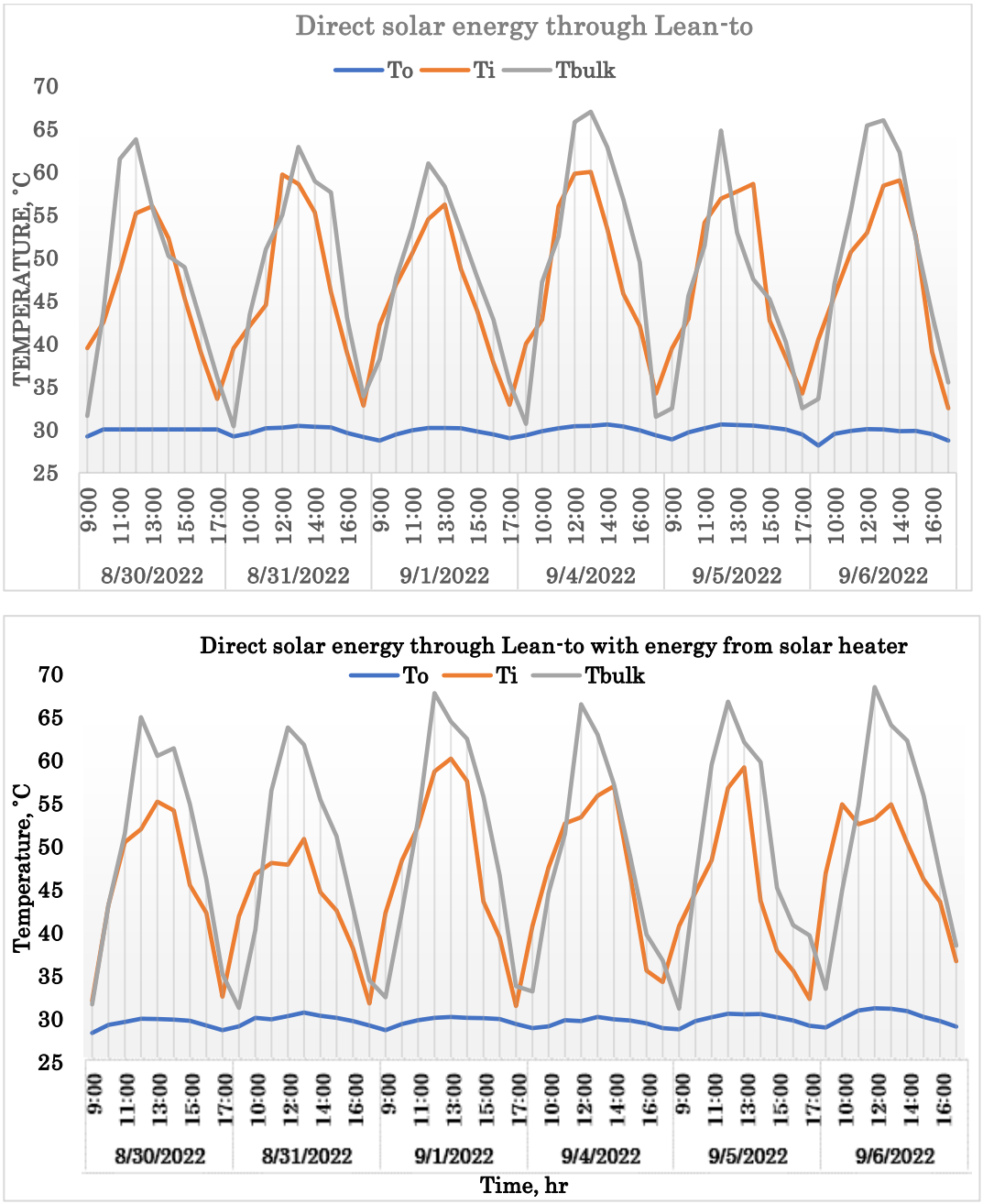


Figure 7. *Illustrates the daily variations in bulk and ambient temperatures both within and outside the solar collector throughout the experiment for the two different systems.*

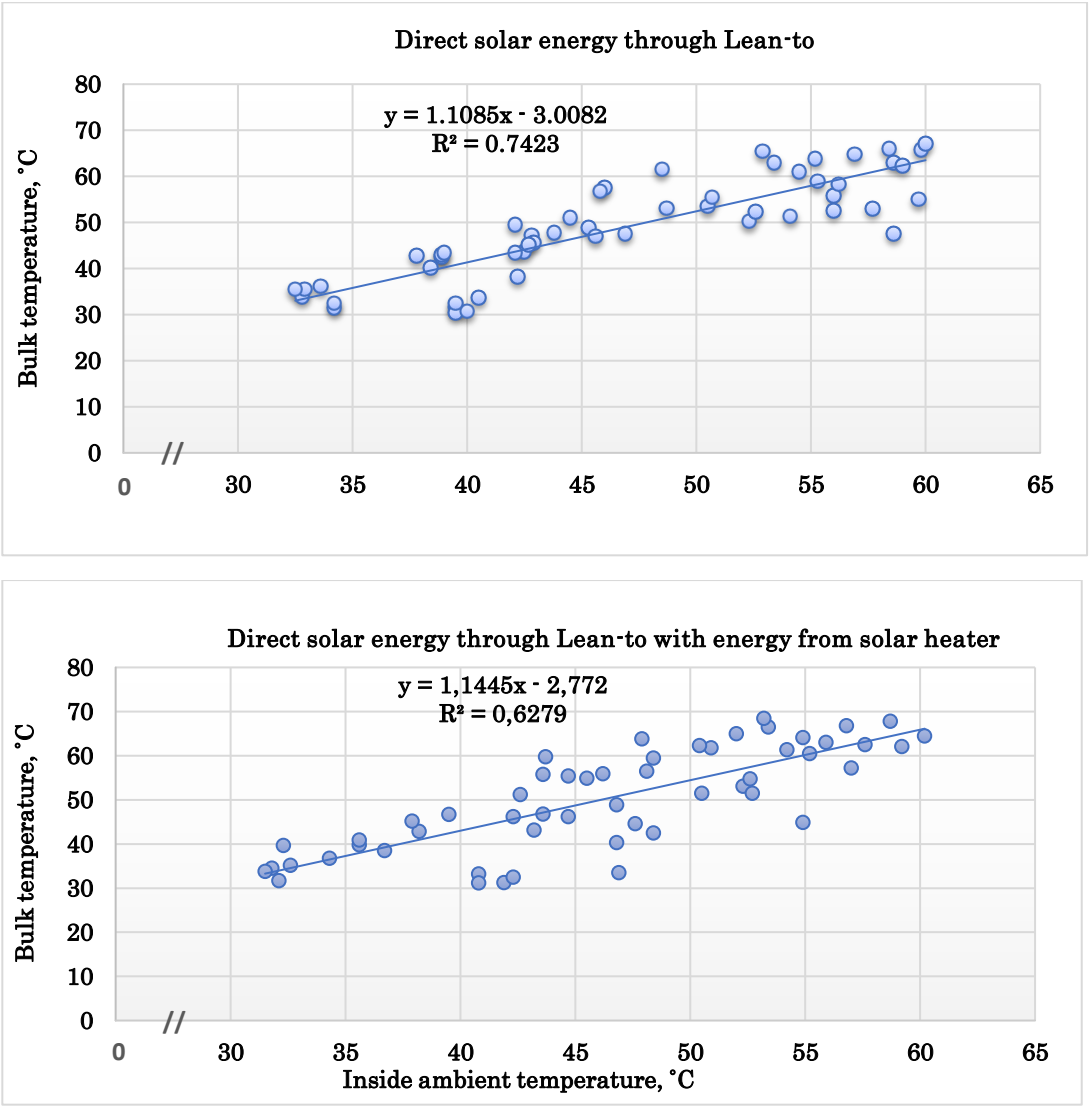


Figure 8. *Depicts the relationship between the bulk temperature of beeswax and the inside ambient temperature within the Lean-to solar collector for both of the studied systems.*

In the initial system, the solar collector's average indoor relative humidity was 36.1%, while the external humidity was 68.71%. Similarly, for the second system, the respective figures 8 were 38.28% and 71.24%. These measurements reveal the disparity in humidity levels between inside and outside the wax melter during the experiment.

The solar extractor, an integral part of the solar collector system, was crucial in diminishing indoor relative humidity. In the first system, the solar extractor effectively lowered the indoor relative humidity within the solar collector by approximately 32.61%. Similarly, in the second system, it reduced the indoor relative humidity by around 32.96%. These outcomes highlight the instrumental role of the solar extractor in maintaining lower indoor relative humidity levels within the wax melter.

These findings represent the outcomes of a power regression analysis that explores the relationship between the change in bulk temperature of beeswax and the inside ambient temperature within a Lean-to solar collector for two distinct

systems: one operating without additional energy input and another with energy input from a solar heater. The regression equations derived for these systems are as follows:

For direct solar energy through Lean-to (without additional energy input):

$y = 1.1085x - 3.0082 \quad (R^2 = 0.7423)$

For direct solar energy through Lean-to with energy from a solar heater (with additional energy input): $y = 1.1445x - 2.772 \quad (R^2 = 0.6279)$

These regression equations express the mathematical relationship between the bulk temperature (y) of the beeswax and the inside ambient temperature (x) within the Lean-to solar collector for the two studied systems. They provide a predictive tool to estimate the bulk temperature based on the inside ambient temperature for each system.

The R^2 value serves as an indicator of how well the regression equation aligns with the data points. It signifies the proportion of variance in bulk temperature that can be attributed to changes in the inside ambient temperature. In both cases, R^2 values are supplied to gauge the goodness of fit. A higher R^2 value suggests that the regression equation provides a better fit for the data. Notably, the system operating without additional energy input (direct solar energy through Lean-to) exhibits a slightly higher R^2 value (0.7423) in comparison to the system with energy input from a solar heater (0.6279). This implies that the bulk temperature of beeswax in the first system is more significantly influenced by changes in the inside ambient temperature.

These results bear practical significance in the realm of solar energy collection and utilization. They offer insights into how the bulk temperature of beeswax, likely utilized as a heat storage medium, responds to variations in the inside ambient temperature. Engineers and researchers can leverage this information to optimize the performance of Lean-to solar collectors under different energy input scenarios.

Conclusively, these regression outcomes provide valuable insights into the correlation between bulk temperature and inside ambient temperature in Lean-to solar collector systems. This knowledge lays the foundation for further research and optimization endeavors within the field of solar energy collection and utilization.

Figure 9 provides a visual representation of the fluctuations in indoor and outdoor relative humidity levels within the solar collector. This graphical illustration offers a clear insight into the divergence in humidity conditions and the efficiency of the solar extractor in reducing indoor relative humidity.

The impact of relative humidity on the beeswax melting process warrants consideration. Elevated humidity levels can impact heat transfer efficiency and lead to increased moisture content in the beeswax, potentially altering its characteristics. Thus, reducting indoor relative humidity levels within the wax melter contributes to sustaining optimal conditions for effective and consistent beeswax melting.

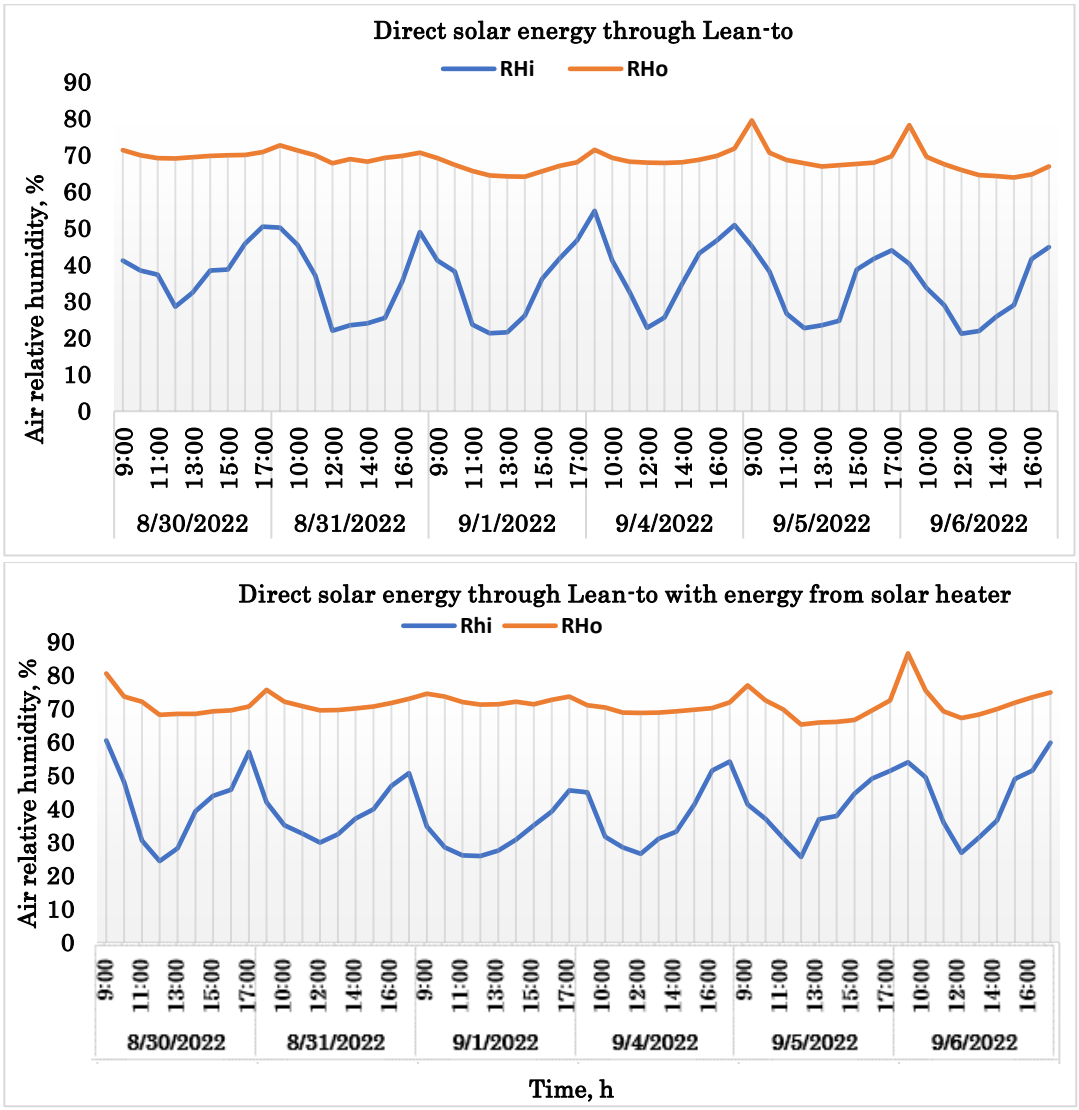


Figure 9. *Daily fluctuations in relative humidity inside and outside solar collector during the experimental work for the two systems.*

The study's outcomes reveal a distinct relationship between air temperature and relative humidity, particularly during daylight hours. These two factors are interconnected, and alterations in air temperature can impact the air's capacity to hold moisture.

Furthermore, the study showcases the solar collector's potential to decrease indoor relative humidity in contrast to outdoor relative humidity, while simultaneously elevating indoor temperatures beyond outdoor temperatures. This observation indicates that the solar collector establishes an environment where the air inside becomes drier and warmer than the external surroundings.

The decline in indoor relative humidity within the solar collector can be attributed to components like the solar extractor within the collector system. By effectively lowering relative humidity, the collector establishes conditions less conducive to moisture retention. This proves advantageous for beeswax melting, as reduced relative humidity prevents excessive moisture absorption by the wax, thus preserving its intended qualities.

At the same time, the rise in indoor temperature surpassing the outdoor temperature inside the solar collector accelerates the melting process. The

heightened temperature creates an environment more conducive to beeswax melting, reducing the time needed for complete melting. The increased indoor temperature facilitates efficient heat transfer, ensuring rapid achievement of the beeswax's melting point.

Additionally, the increased air's capability to retain additional water vapor from the melted beeswax implies that the warmer and drier air within the solar collector can effectively absorb and carry away the moisture released during melting. This aids in averting moisture buildup and ensures the melted beeswax retains its intended consistency and attributes.

These findings emphasize the advantages of employing a solar collector for beeswax melting. The solar collector raises indoor temperatures, expediting the melting process, and diminishes relative humidity, preventing moisture-related concerns and upholding the quality of the melted wax.

System Effectiveness

The study outcomes shed light on the efficiency of two distinct systems employed for beeswax melting. The initial system exhibited efficiency ranging from 31.4% to 61.6%, averaging 44.1%. On the other hand, the second system displayed a broader range of efficiency values, varying between 44.1% and 76.6%, with an average efficiency of 59.2%.

These efficiency measurements signify how effectively each system transforms solar energy into heat for the melting process. The second system, on average, demonstrated superior efficiency compared to the initial system, implying that it utilized available solar energy more efficiently.

It's important to note that the macroclimatic conditions surrounding the solar collector significantly impact the efficiency of the wax melting systems. Elements like incident solar radiation, ambient temperature, and relative humidity play vital roles in determining the overall efficiency of the systems.

Figure 10 likely presents a graphical depiction of the connection between system efficiency and the aforementioned factors. This visualization aids in comprehending how fluctuations in incident solar radiation, ambient temperature, and relative humidity influence the efficiency of the wax melting systems.

The correlation between system efficiency and incident solar radiation holds importance as solar energy is the primary heat source for the systems. Higher levels of incident solar radiation typically lead to increased energy input and, consequently, higher system efficiency.

The connection between system efficiency and ambient temperature underscores the significance of maintaining optimal temperature conditions for effective wax melting. Elevated ambient temperatures create a favorable environment for heat transfer, resulting in reduced melting time and improved system efficiency.

Similarly, the link between system efficiency and relative humidity highlights how moisture content in the surrounding air impacts the wax melting process. Lower relative humidity levels create a drier atmosphere, preventing excessive moisture absorption by the beeswax and preserving its characteristics, ultimately contributing to higher system efficiency.

Comprehending these correlations aids in identifying key factors influencing system efficiency and informs the optimization of wax melting systems. By

accounting for the effects of incident solar radiation, ambient temperature, and relative humidity, researchers and engineers can develop strategies to maximize system efficiency under varying macroclimatic conditions.

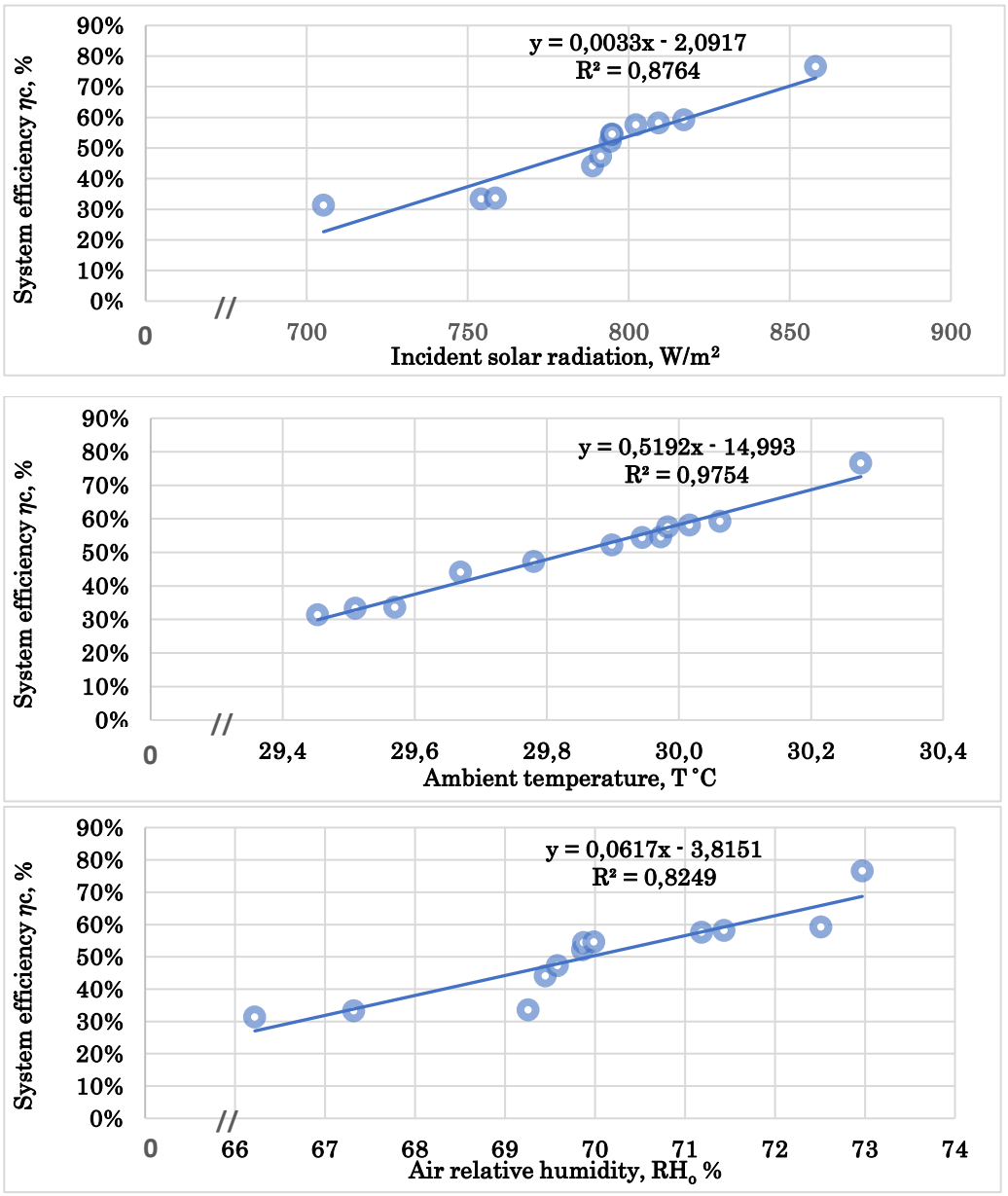


Figure 10. *Illustrates the direct correlation between system efficiency and incident solar radiation, ambient temperature, and relative humidity.*

The outcomes of the present investigation are in agreement with the research conducted by Khan *et al.* (2019), who investigated the relationship between daily candle production and variations in average solar radiation measured in W/m². In their study, Khan et al. employed solar energy to heat and liquify beeswax, a process akin to the one explored in the current study.

The results obtained by Khan et al. revealed a direct link between solar radiation intensity and the efficacy of the melting process. This implies that higher solar radiation levels lead to more effective wax melting. The findings of the present study,

which establish a connection between system efficiency and incident solar radiation, concur with these outcomes.

Furthermore, Khan *et al.* (2019) also identified a connection between ambient temperature and the efficiency of the melting process. The findings of the present study, which indicate the impact of ambient temperature on the beeswax melting process, are in harmony with this earlier research.

These consistent findings among studies provide substantial evidence that solar radiation and ambient temperature are crucial factors in the wax melting process. Utilizing higher solar radiation levels and maintaining elevated ambient temperatures contribute to more efficient and effective melting of beeswax.

The alignment of these results underscores the significance of incorporating solar radiation and temperature considerations into the design and optimization of wax melting systems. Maximizing the utilization of solar radiation potential and maintaining suitable ambient temperature conditions can substantially enhance the efficiency and productivity of candle production and other applications reliant on melted beeswax.

The primary objective of this study was to quantitatively analyze and establish the relationships between system efficiency and key environmental parameters. Understanding these relationships is essential for optimizing energy systems and adapting to varying environmental conditions.

For the relationship between system efficiency and incident solar radiation, the regression equation is y= 0.0033x - 2.0917 with an R^2 of 0.8764. In the case of system efficiency versus ambient temperature, the equation is y= 0.5192x - 14.993, and the R^2 is 0.9754. Finally, for system efficiency versus air relative humidity, the equation is y= 0.0617x - 3.8151, and the R^2 is 0.8249.

The linear form of these equations indicates a direct and proportional relationship between system efficiency and each environmental variable. Calculating the R^2 values allowed us to assess how well these regression models fit the data. These values represent the proportion of variance in system efficiency that can be explained by changes in the respective environmental variable.

The correlation between system efficiency and incident solar radiation is positive but moderately weak (R^2= 0.8764). This suggests that while solar radiation impacts efficiency, other factors may also contribute to variations in system performance. On the other hand, system efficiency and ambient temperature exhibit a very strong positive correlation (R^2= 0.9754), emphasizing that ambient temperature significantly influences system efficiency, with higher temperatures associated with increased efficiency. System efficiency and air relative humidity also show a positive correlation, albeit slightly weaker compared to temperature (R^2= 0.8249). Air relative humidity plays a role in system efficiency but to a lesser extent than temperature.

These results hold significant value for engineers and energy system designers. They can use these regression equations to optimize energy systems, taking into account how incident solar radiation, temperature, and humidity affect efficiency, leading to more efficient and reliable energy systems.

The robust correlation between system efficiency and ambient temperature underscores the importance of implementing climate adaptation measures. Strategies such as temperature control, cooling, or insulation can help maintain optimal efficiency under varying temperature conditions.

Furthermore, these relationships can be leveraged for energy forecasting and system planning. Understanding how system efficiency responds to environmental changes enables more accurate predictions of energy production and consumption, facilitating efficient energy management.

CONCLUSION

This study compared between two distinct beeswax melting approaches: the conventional water bath method and a solar-powered wax melter. The water bath method exhibited an average efficiency of 73.4% and required approximately 30.5 minutes on average to melt the beeswax. Conversely, the solar-powered wax melter demonstrated higher efficiency, averaging 85.5% and 87.2% for the two examined systems. Although the solar-powered method had longer melting times, ranging from 90 to 360 minutes, its superiority over the traditional method was evident.

The incident solar radiation flux played a pivotal role in the performance of the solar-powered wax melter. However, reliance on solar energy demands careful control due to fluctuations caused by factors such as clouds, fog, and time of day. The experiment documented changes in incident solar radiation inside and outside the solar collector, ranging from 70 to 1037 W m^{-2} and 84 to 1310 W m^{-2}, respectively. Similar fluctuations occurred in the second system, ranging from 50 to 1014 W m^{-2}inside and 67 to 1190 W m^{-2} outside. The transparent polycarbonate covering of the solar collector played a critical role in determining the amount of solar radiation entering the collector.

Ambient temperature and relative humidity also impacted the melting process. The average hourly ambient temperatures recorded outside and inside the solar collector were about 29.8°C and 46.9°C for the first system, and 29.8°C and 46.3°C, respectively, for the second system. The solar collector elevated the indoor temperature beyond the outdoor temperature, leading to shorter melting durations. Relative humidity inside the solar collector decreased by around 32.6% to 32.96% compared to outdoor relative humidity, enhancing the air's capacity to retain extra water vapor from the melted beeswax.

The efficacy of the solar-powered wax melter was influenced by macroclimatic conditions, incident solar radiation, ambient temperature, and relative humidity. The first system demonstrated an average efficiency of 44.1%, while the second system achieved an average efficiency of 59.2%. These findings underscore the direct correlation between system efficiency, solar radiation intensity, and ambient temperature.

DECLARATION OF COMPETING INTEREST

The authors hereby declare that there is no conflict of interest what so ever on this work.

CREDIT AUTHORSHIP CONTRIBUTION STATEMENT

Mohamed Ali Ibrahim Al-Rajhi: Conceptualization, design, data collection, manuscript drafting.
Sara Moufied El-Serey: Methodology refinement, data analysis, manuscript review and editing.
Ahmed Mohamed Elsheikha: Project supervision, guidance, manuscript review for scientific rigor.

ETHICS COMMITTEE DECISION

This article does not require any ethical committee decision.

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Turkish Journal of Agricultural Engineering Research

Turk J Agr Eng Res *(TURKAGER)*

https://dergipark.org.tr/en/pub/turkager
https://doi.org/10.46592/turkager.1378650

ISSN: 2717-8420
2023, 4(2), 225-238

Research Article

Design and Performance Evaluation of a Variable Speed Bucket Elevator

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Article Info
Received: 19.10.2023 **Accepted:** 23.11.2023 **Published:** 31.12.2023

ABSTRACT

The bucket elevator was designed and constructed at the Federal University of Technology Owerri, Imo state, Nigeria. A variable speed bucket elevator with dimensions of 0.3 m by 0.243 m and 0.47 m high with a base stand of 0.47 m high making the total height of 0.9 m was designed, evaluated and tested to determine the throughput capacity of the machine, which gave 0.176 tons h^{-1} at higher speed of 0.5 m s^{-1} with optimal efficiency at the centrifugal discharge force of 0.366 N when grain (cowpea) was elevated, and a throughput capacity of 0.109 tons h^{-1} at a slower speed of 0.4 m s^{-1} with optimal efficiency of 7.78% at the gravitational discharge force of 0.392 N when small lumpy material was elevated. 0.5 m s^{-1} and 0.4 m s^{-1} used for the experiment were obtained from the grooved step pulley with variable diameters, connected to a motor of 0.18 kW (1340 rpm) at the head, with a gear reducer of 189.7 rpm coupled to a vee belt. The result obtained during test running of the prototype model of the bucket elevator conveyor, shows that at variable speed, bucket elevator can convey different materials, which becomes an advantage instead of installing different conveyor while the same can perform the same function with a change in the pulley. This will become advantageous to low-income countries, where resources are meager to purchase different equipment whereas, a well-designed single elevator can perform variably and obtain same outcome.

Keywords: *Efficiency, Bucket elevator system, Progression, Variable speed, Nigeria*

To cite: Obineche CI, Unanka BO, Ezechike NU, Akuwudike AE and Ojiaku CA (2023). Design and Performance Evaluation of a Variable Speed Bucket Elevator. *Turkish Journal of Agricultural Engineering Research (TURKAGER), 4(2): 224-235. https://doi.org/10.46592/turkager.1378650*

INTRODUCTION

Bucket elevators can be described as machines that permit the continuous transportation of granular materials to a specific location under a given condition. They consist of a variable number of buckets attached to a moving belt or chain that conveys the motion to the buckets, for a complete mechanical description (Perez-Aparicio *et al.*, 2014). Similarly, Snehal *et al.* (2012) noted that bucket elevators are powered equipment for conveying bulk agricultural and industrial materials in a vertical path, consisting of an endless belt, or chain to which metallic buckets are fixed. In addition, Taher *et al.* (2014) stated that, bucket elevator and belt conveyor are the media of material transportation from one location to another in a commercial space.

However, it consists of buckets to contain the material, a belt or chain, either round link, roller or drive or belt tension, accessories for loading the buckets or picking up the materials for receiving the discharged material, for maintaining the belt and chain tensions for enclosing and protecting the elevator maybe vertical. Wolstencroft (2005) posited that during the design of bucket elevator for distribution, some facts were considered, such include, material conveyed and casing selection. Furthermore, He note that the material conveyed, and casing selection considerations include, high and low bulk densities, temperature, abrasiveness, corrosiveness, flow ability, moisture content, particle size and distribution. According to Maghirang *et al.* (2006) there are two main types of bucket elevators namely, gravity assisted and centrifugal discharged. Similarly, Gholami (2016) suggested that attention is to be paid to material change and discharge characteristics. In the same vein, Yashaswini *et al.* (2014) stated that the final selection of a bucket elevator should be made solely after careful consideration of all factors affecting the application. According to Gerber (2008), the bucket elevator with a variable speed mechanism for its operation, is built to handle high capacity up to 45,000 bushes per hour.

Furthermore, Dave (2008) stated that bucket elevators also apply variable speed drive systems of this kind for belt bucket elevator and chain drive systems. While Wolstencroft (2005) noted that, in designing a bucket elevator, the following points require consideration, material conveyed and casing selection. According to Sharma (2000) conveyors of various types and sizes are available in the production, mining and construction industries. He further stated that there are two types of conveyors: traction type and traction less type conveyors. Perez-Aparicio *et al.* (2014) noted that they comprise of a variable number of buckets attached to a moving belt or chain that transmits the motion to the buckets for a complete mechanical description. The current bucket elevator under use utilizes a single mechanism; the challenge becomes how we convey a sticky material and a dry granular material using the same elevator with rates of conveying different from others. Furthermore, Snehal *et al.* (2012) posits that current construction uses a rubber belt with plastic buckets. Pulleys several feet in diameter are used at the top and bottom. To this effect, a prototype model bucket elevator which utilizes different speed through the shafts with different pulley drive which operates at a variable speed using an electric gear motor was designed and evaluated to determine its flow rate and optimal conveying speed for some agricultural products.

MATERIALS and METHODS

The study was conducted at the Engineering workshop 3 of the Federal University of Technology Owerri, Imo State, Nigeria. The area experiences a mean daily minimum temperature range of 19-24°C and a maximum range of 28-35°C, average relative humidity of up to 80%, and a longer wet season which lasts from April-November (Ogbuagu and Okoli, 2013).

The materials and equipment used for the study include:

a. A gear motor of 0.18 kW power with 1340 rpm and gear speed of 81.6 rpm (calculated)
b. Metal sheets for the casing and buckets
c. Angle bar for the base stand and brazing
d. Two variable diameters pulley
e. Two rollers of 0.050 m diameters with a length of 0.183 m
f. Flat belt of 0.100 m wide
g. Four rubber cork for shock absorption at the pulleys and shaft contacts
h. Four industrial bearings with grease nipples
i. Seven buckets with 0.05 m spacing, 0.05 m depth, and 0.09 m length, project of 0.08 m
j. Rectangular inlet chute and discharge chute with 0.095 m wide and inclined at an angle of 45°
k. Two shafts of 0.260 m for the tail roller and 0.30 m for the head roller section.
l. Flat bar for the internal frame and brazing
m. Thirteen diameter nuts and bolts
n. Two drive vee-belts of different length
o. Four rings plate with 0.080 m diameters.

Description of the New Machine:

The bucket elevating conveyor is made up of steel metal pans, rubbers, irons and wood materials. The dimensions of the bucket elevator are 0.300 m length, 0.243 m and 0.900 m high, respectively. The height of the casing is 0.470 m, and the height of the base stand is 0.430 m, making its total height to be 0.900 m. The casing consists of different items such as pulleys, rollers, bearings belts, buckets, inspection doors, inlet and discharge chutes. The location of the electric motor is at the base stand of the bucket elevator, where the vee-belt is connected to the drive pulley of the bucket elevator. The casing size and clearance are fabricated in a standard of 0.470 m high with a makeup section of 0.430 m, which gives the overall height of the bucket elevator. The single casing section used was pressed, welded and bolted construction. The casing section was made to be removable for inspection or maintenance.

Design considerations and calculations

Three principal variables in the design of a bucket elevator were considered, and they are:

1. Bucket size and pitch (spacing)
2. Belt speed
3. Diameter of head and tail pulleys.

The buckets are mounted on the belt so that the back of the buckets can bend as the mounting bolts are partly pulled into the belt. With thin-walled narrow buckets made of sheet steel for this elevator. The back is flexible enough to follow the shape of the roller shell.

Bucket size= width × projection × depth (1)

= 0.05 m × 0.08 m × 0.05 m

= 0.0002 m^3

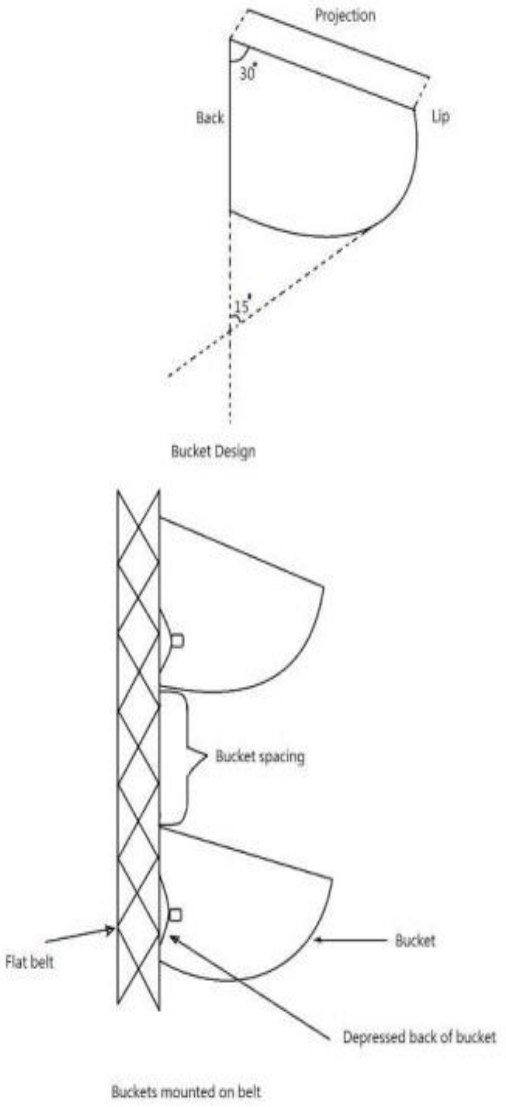

Figure 1. *Bucket design and bucket mounted on belt.*

The head section is a robust, pulley welded construction, with removable head section for easy access to the driving shaft pulleys. The shape of the head section is a function of bucket designed, pulley diameter and belt speed. This allows for free turning and less wearing. The angle of wrap and the friction between belt and the roller are important to know, a conventional bucket elevator has an angle of wrap of 180°.

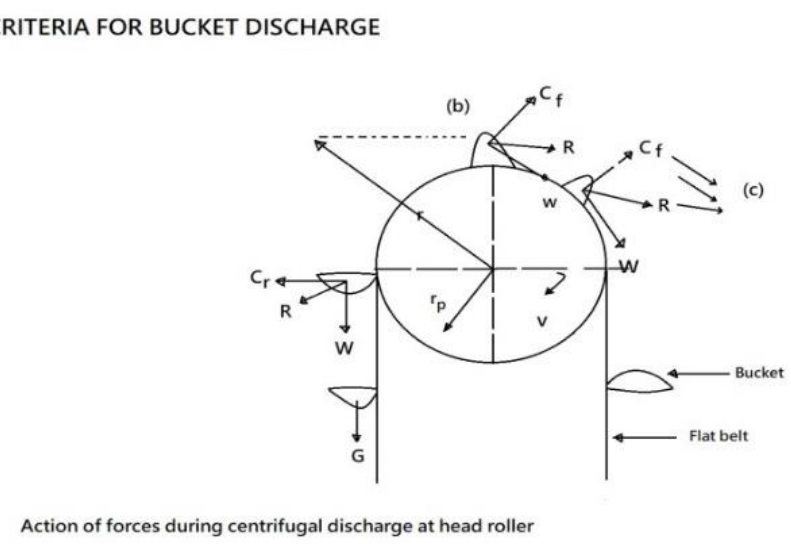

Figure 2*. Action of forces during centrifugal discharge at head roller.*

Where:
$r_{p=}$ Pulley (roller) radius (m)
r= Radius from the center to the bucket edge= (0.135 m)
G= Weight of load carried (kg)
W= Mg= Gravitational force (N)
R= Resultant force (N)
C_f= Centrifugal force (N)
V= Belt speed (m s^{-1})
G= Acceleration due to gravity= 9.81 m s^{-2}
M= Mass of the product = 40 g
B= Angle of throw= 15°

The boot section of the bucket elevator is bolted and assembled to follow for proper maintenance and replacement of the pulley (roller), shaft, liner material and so on. The loading chute is located so that the pickup of the product by the buckets takes place above the center line of the return pulley. The return pulley provides the means for turning the belt and for the tensioning of the belt. The drive pulleys (head vee-pulley) of variable diameters are 30 mm and 50 mm. This variation allows for variable speeds (slow and high speeds) when connected to a motor with the help of different belt lengths. The internal rollers which carry the flat belt are made of wooden material suitable for the flat belt to rotate with less wearing.

Relationship Between Belt Speed, Pick Up and Bucket Discharge

When a product mass turns around a pulley, it is influenced by two forces.
1. Gravitational force, which is oriented downwards with magnitude W.

$$W = Mg \quad (2)$$
$$= 40 \times 10^{-3} \times 9.81$$
$$= 0.392 \text{ N}$$

2. Centrifugal force, C_f whose, radial of the rotational center is oriented out wards, with magnitude (Sondalini, 2004).

$$C_f = \frac{W.V^2}{g\ x\ r} cos\ \beta = \frac{M.V^2}{r} cos\ \beta \quad (3)$$

But, $V^2 = g \times r \times cos\beta$ (4)

$= 9.81 \times 0.135 \cos (15°)$

$V^2 = 1.28\ m\ s^{-1}$

$$C_f = \frac{40\ x\ 10^{-3} x\ 1.28}{0.135} cos\ 15°$$

$= 0.366$ N

If W and C_f are equally large, then the resultant, R, will be oriented at right angles onto the front of the bucket. The product mass will be in equilibrium. The magnitude of R can be measured on a scale, and it will be $\sqrt{2} \times W$. Figure 2 illustrates that when W decreases, C_f increases, and the resultant R decreases. With the bucket position of Figure 2 in position 'b' the resultant R= 0, if both forces C_f and W are equal and opposite. With this condition of equilibrium

$$W = C_f \text{ that is } W = \frac{W.V^2}{g.r} = V^2 = g\ r \quad (5)$$

In this case, the product mass in the bucket is in a state of equilibrium, without the tendency to be thrown out, however, with the ability to flow freely if later the resultant of both forces increases downward. If W and C_f are equally large, there will be no spillage of the product in position 'b'. Similarly, in position 'c', the resultant 'R' works towards the mouth of the bucket and urges the product mass, which is no longer subjected to the counter pressure of the bucket lip to move towards the discharge chute. Hence, the resultant 'R' still increases, and the product is discharged. The through-off curve has a parabolic shape (trajectory).

In position 'b', we have belt speed,

$$V = \frac{2\pi rN}{60} \quad (6)$$

Where, N = Amount of rotations per minutes of the driving shaft

$$\frac{(2\pi rN)^2}{60} = g \times r \quad (7)$$

$$N = \frac{30}{\sqrt{r}}\ rpm = \frac{30}{\sqrt{0.135}} = 81.65\ rpm \quad (8)$$

Belt speed $V = \frac{2\ x\ 3.142\ x\ 0.135\ x\ 81.65}{60} = 1.154\ m\ s^{-1}$

(Kurmi and Gupta, 2014).

Effect of Forces

i. Centrifugal forces effect of a higher belt speed. We first consider the driving shaft. In this case, the contents of the bucket in position 'a' in Figure 2 is subjected to a greater force C_f the direction of C_f shows that part of the product will be spilled over the bucket lip. The spilled product returns to the upgoing part of the elevator.

ii. Gravitational discharge effect of a slow belt speed. In the upper half of the pulley (roller) in Figure 2, a filled bucket in position 'a' will not spill because the resultant 'R' only slightly deviates from W in size and dissection.

Belt Speeds from the Variable Pulley Diameters

For pulley 'A' with diameter d= 30 m= 0.03 m,
R= d/2= 0.015 m

But $N_1 = \frac{30}{\sqrt{r1}} = \frac{30}{\sqrt{0.015}} = 244.9$ rpm
$N_2 = \frac{30}{\sqrt{r2}} = \frac{30}{\sqrt{0.025}} = 189.7$ rpm

Belt speed, $V_A = \frac{2\pi r N_i}{60} = \frac{2 \; x \; 3.142 \; x \; 0.015 \; x \; 244.9}{60} = 0.5$ m s^{-1}
For pulley 'B' with diameter d= 50 mm= 0.05 m,
R= d/ 2= 0.025 m

Belt speed $V_B = \frac{2\pi r N2}{60} = \frac{2 \; x \; 3.142 \; x \; 0.025 \; x \; 189.7}{60} = 0.4$ m s^{-1}
(Kurmi and Gupta, 2014)

The Handling Capacity (Throughput Capacity)

The shape of the bucket is influenced by load characteristics throughput capacity which is given as;

$$Q = \frac{3.6 \; GV}{t_b} \quad (9)$$

Where,

$$G = i_o e \psi \quad (10)$$

e= Bulk density of load (kg m^{-3})
ψ= Coefficient of filling= 0.7
i_o= Geometric volume of each bucket in m^3= 0.0002 m^3
t_b= Bucket spacing (pitch) in meter = 0.12 m

Bulk density of load,

$$e = \frac{mass}{volume} \quad (11)$$

$\frac{40 \; x \; 10^{-3}}{0.0002} = 200$ k g m^{-3}

However, G= 0.0002 × 200 × 0.7
=0.028 kg ≈ 0.000028 tons

For gravitational discharge,
Throughput capacity for gravitational discharge,

$$Q_I = \frac{3.6 \; GV_A}{t_b} \quad (12)$$

$= \frac{3.6 \; x \; 0.028 \; x \; 0.5}{0.12} = 0.109$ tons h^{-1}

Similarly, throughput capacity for centrifugal discharge,

$Q_2 = \frac{3.6\ GV_B}{t_b}$

$= \frac{3.6\ x\ 0.028\ x\ 0.4}{0.12}$ = 0.176 tons h^{-1}

Belt selection: the following parameters were considered for the selection; the belt length in meters, the belt type (flat and vee-type) and the power transmitted.

Belt type

A conventional agricultural v-belt for drive and more woven flat bucket cannier were chosen.

The belt length is given as,

$L_1 = \pi/2 + d_{p1} + h_c + h_s$ (13a)

$L_2 = \pi/2 + d_{p2} + h_c - h_m$ (13b)

Where,

d_{p1}= Diameter of drive pulley 'A'= 0.03 m

d_{p2}= Diameter of drive pulley 'B'= 0.05 m

h_c=Height of bucket casing= 0.47 m

h_m= Height of motor from the base to the casing

L_1= Length of belt for pulley 'A'

L_2= Length of belt for pulley 'B'

Therefore, $L_1 = \frac{3.142}{2} + 0.03 + 0.47 + 0.22 = 2.286 - 1 = 1.29$ m

And $L_2 = \frac{3.142}{2} + 0.05 + 0.47 + 0.22 = 2.306 - 1 = 1.31$ m

Tension on the Belt

Power of motor = $(T_1 – C_f)\ (L_1/Q_1)\ V_A$, for belt on pulley 'A' (14a)

Power of motor = $(T_2 – C_f)\ (L_2/Q_2)\ V_B$, for belt on pulley 'B' (14b)

Where,

T_1= Belt tension on pulley 'A' in Newton

T_2= Belt tension on pulley 'B' in Newton

V_A= Speed of belt on pulley 'A' in m s^{-1}

V_B= Speed of belt on pulley 'B' in m s^{-1}

$(T_1 – C_f)\ (L_1/Q_1)V_A$= Motor power (0.18 kW)

$(T_1 – 0.366)\ (1.29/0.109)0.5 = 0.18$

T_1= 0.483 N

Similarly,

$(T_2 – C_f)\ (L_2/Q_2)V_B$ = motor power

$(T_2 - 0.366)\ (1.31/0.176)0.21 = 0.18$

T_2= 0.482 N

Torque on the Shaft, Ts

$T_s = \frac{1000\ x\ P}{2\pi\ x \frac{N}{60}}$ (15)

Where P = motor power = 0.18 kW

$T_s = \frac{1000\ x\ P\ x\ 60}{2\pi\ x\ N} = \frac{1000\ x\ 0.18\ x\ 60}{2\ x\ 3.142\ x\ 81.65}$

T_s= 21.05 N m

Belt Friction Resistance, F

$F = \mu\ Me\ g$ (16)

Where, μ= Coefficient of friction= 0.33
Me= Effective total mass of all moving parts = 200 g
g= Acceleration due to gravity = 9.81 m s^{-2}
F = 0.33×200×9.81
= 647.46 N

Experimental Procedure and Calculations

The elevator unit, the head section, the boot section, the base stand, the electric gear motor, inlet and outlet chutes were set up as shown in Figure 2.
For each inlet coefficient of filling 40 g of grain (cowpea) and oil bean seed were introduced into the bucket elevator at different time. As the material were being elevated, the belt speed, tension, height lifted, time of flight, torque, throughput capacity, optimal efficiency was determined and recorded.

Determining the Optimal Efficiency

$Optimal\ efficiency = \frac{power\ output}{power\ input} \times 100\%$ (17)

Where,

Power output= $\frac{QH}{3.67}$ *in kilowatts* (18)

Power input= Power from motor= 0.18 kW
For gravitational force,

Power output= $\frac{Q_1 H}{3.67} = \frac{0.109\ x\ 0.47}{3.67}$ (19a)

= 0.014 kW

Optimal efficiency= $\frac{0.014}{0.18} \times 100\%$

= 7.78%

For centrifugal force,

Power output= $\frac{Q_2 H}{3.67} = \frac{0.176\ x\ 0.47}{3.67}$ (19b)

= 0.0225kw

Optimal efficiency= $\frac{0.0225}{0.18} \times 100\%$

= 12.55%

Calculation of the Throw into Chute and Chute Size

The standard trajectory formula was used, $S = U \times t + 0.5 \times a \times t^2$ (20)

Where,
S= Displacement (m)
U= Initial velocity (m s^{-1})
a= Acceleration due to gravity, g = 9.81 m s^{-1}

t= Time (s)

The horizontal component at top dead center of the pulley was acceleration due to gravity in the horizontal direction is zero is given by:

$S_h = U \times t$ (m) (21)

The vertical component at top dead center was velocity in the vertical direction is zero is given by:

$S_v = 0.5 \times a \times t^2$ (22)

The calculation of the horizontal and vertical positions of the product for every 0.1 seconds of flight time was shown in table 2.

Chute Size

Area of the discharge chute= area of the inlet chute= $0.08 \times 0.04 = 0.003$ m^2

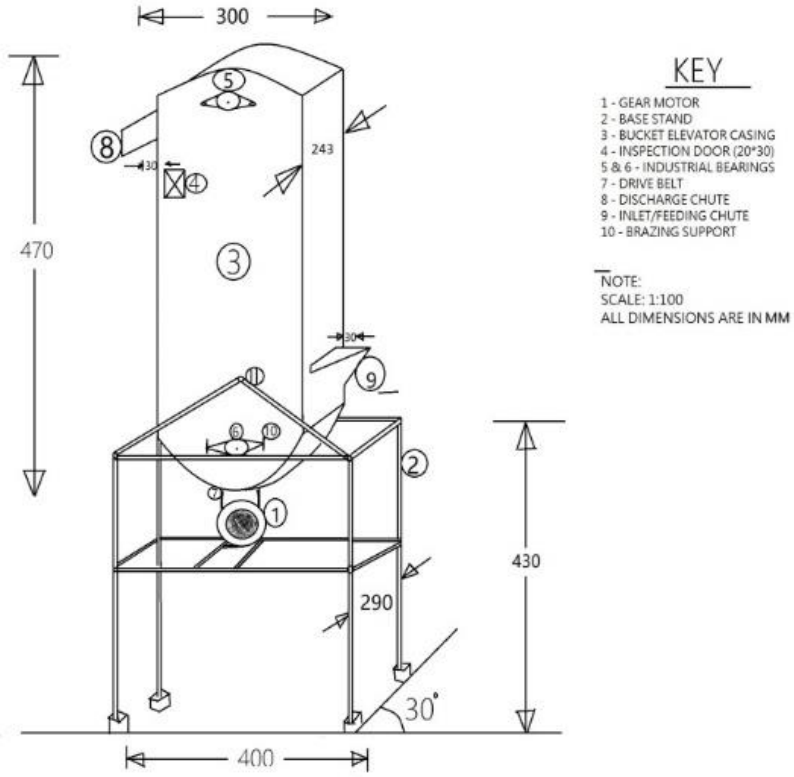

Figure 3. *Pictorial view a variable speed bucket elevator.*

RESULTS AND DISCUSSION

The various result obtained from the experimental determination of the variable speed bucket elevator are displaced in Table 1 and 2, while the relationships are represented graphically in Figure 3, 4, 5 and 6, respectively. The physical explanation for the variation of outcomes with the drawback parameter comes from the fabricated dynamism that is introduced by the fictional mechanisms (Bravo *et al.*, 2011).

Table 1. Variable speed performance.

Section	Material used	Belt Length (m)	Belt Speed (m s^{-1})	Shaft torque (N m)	Belt Tension (N)	Load Bulk Density (kg m^{-1})	Throughput Capacity (ton hr^{-1})	Optimal Efficiency (%)
High speed centrifugal Discharge force (0.366 N)	Grain (Beans/Cowpea)	1.290	0.500	21.050	0.484	200.000	0.176	12.550
Slow speed gravitational discharge force (0392 N)	Lumpy material (oil bean seeds)	1.310	0.400	21.050	0.482	200.000	0.109	7.780

Table 2. Throw into chute of horizontal and vertical position.

Time (sec)	Horizontal displacement (m)	Vertical displacement (m)
0.1	0.12	0.050
0.2	0.24	0.195
0.3	0.36	0.440
0.4	0.48	0.780
0.5	0.60	1.220

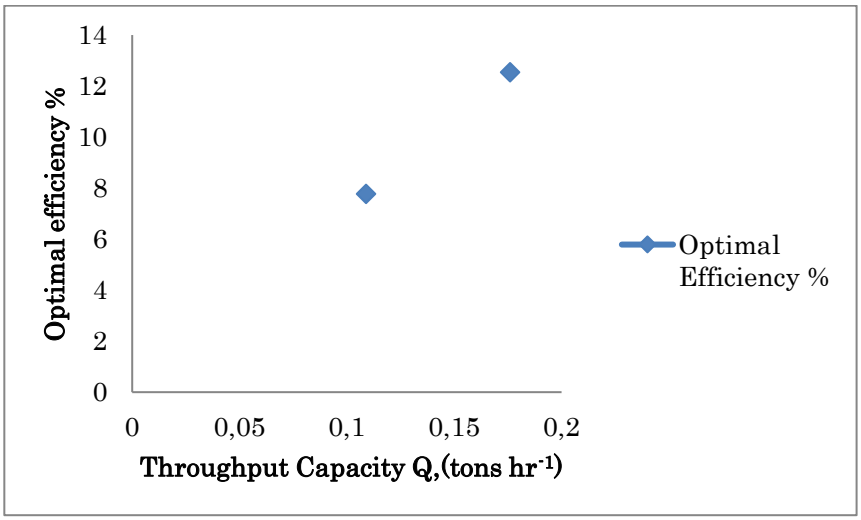

Figure 4. *Optimal efficiency as a function of throughput capacity.*

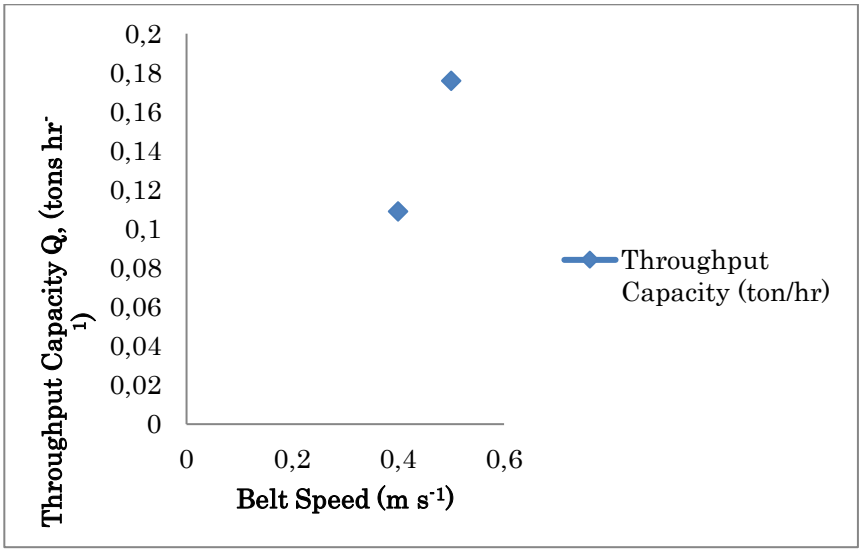

Figure 5. *Throughput capacity as a function of belt speed.*

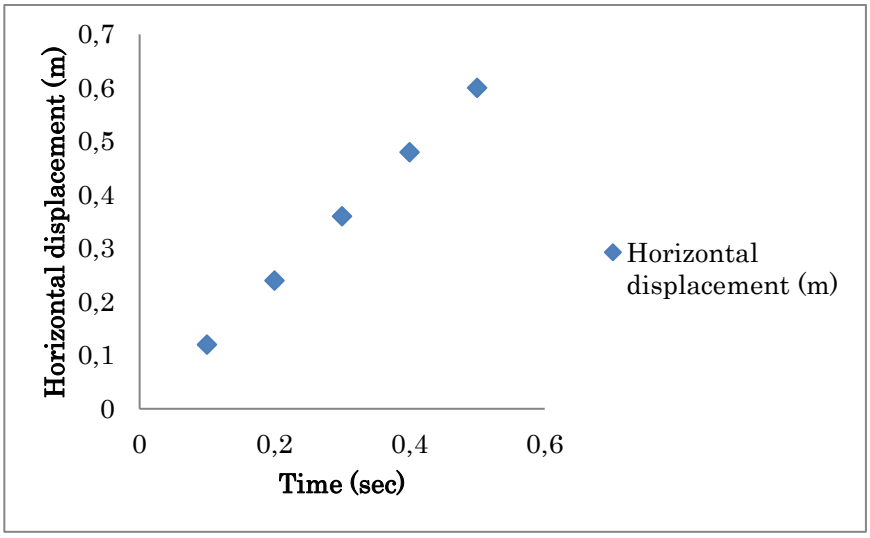

Figure 6. *Horizontal displacement as a function of time.*

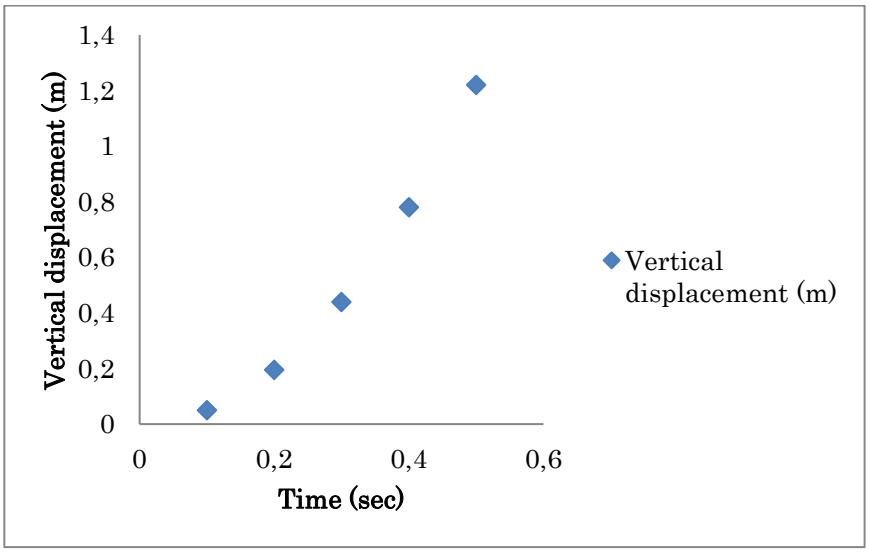

Figure 7. *Vertical displacement as a function of flight time.*

Figure 4 shows that the optimal efficiency of the machine increases linearly as its throughput capacity rises progressively. The fact that the optimal efficiency obtained from the experimental test carried out on the bucket elevator fabricated increases with throughput ca4pacity agrees with every other theoretical assumption available, although there is a discrepancy in the rate with which they vary. Hence, the relationship between throughput capacity and belt speed shown in Figure 4, conformed to the theoretical assumption made, which states that the throughput capacity of the machine increases as the speed of the belt increases, and that the variation of the drive pulley of the bucket elevator brought about this machine increase in the speed of belt. At higher speed, agricultural materials like grain (cowpea) were effectively elevated and discharged at the discharging chute, while at slow speed, a lumpy agricultural material like oil bean seeds were elevated and discharged, respectively. Figure 5 and 6 shows, the performance of the machine when the values of throw into chute were determined at its horizontal and vertical displacement of the elevated material. The result and the graphs showed that as the time of flight of the machine increased, the horizontal and vertical displacement of elevated products increased as they are thrown into the discharge chute. These show linearly and curve linearly lines of best fit of the machine's performance on the graphs.

CONCLUSION

A variable speed bucket elevator was designed and evaluated using a variable diameter pulley and two different agricultural materials to test the machine developed. The bucket elevator examined shows optimal efficiency of 12.55% with a throughput capacity of 0.176 ton h^{-1} obtained as a result of the high speed from the belt, which discharges grains centrifugally while 7.78% optimal efficiency that corresponds to the throughput capacity of 0.109 ton h^{-1} were obtained from the slow speed of the belt, which discharges lumpy materials like oil bean seeds gravitational as initially designed. The optimum output of the machine during operation were calculated to be 0.0225 N for the centrifugal force of 0.366 N and 0.014 kW for the gravitational force of discharge by 0.392 N, compared to the motor power of 0.18 kW as an input power.

The project work on the design and evaluation of a variable-speed bucket elevator is a profitable venture. It is both technically feasible and economically viable and should be considered for implementation in food processing industries and local farms. Additionally, it was worth recommending that agricultural and design engineers, to prevent and minimize costly expenses and waste of time, a variable speed elevator should be installed and used in food processing industries in place of different bucket elevators for other work purposes. There should be further research on the shape of buckets and motor sizes that are appropriate to convey and elevate different agricultural products to the area of processing or storage units like silos. In the same vein, a variable speed motor should be considered, if there will be any, which will be connected directly to the head pulley of the elevator, which will reduce much power loss due to the length of the drive belt and the weight of the moving parts.

DECLARATION OF COMPETING INTEREST

The authors hereby declare that there is no conflict-of-interest whtasoever.

CREDIT AUTHORSHIP CONTRIBUTION STATEMENT

Christopher Ikechi, OBINECHE: Conceptualization, writing original draft and methodology.
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Nkechi Udochukwu, EZECHIKE: Formal analysis and review
Anthony Emeka AKUWUDIKE: Validation
Chinwendu Augustina OJIAKU: Visualization and editing.

ETHICS COMMITTEE DECISION

This article does not require any ethical committee decision.

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Turkish Journal of Agricultural Engineering Research

Turk J Agr Eng Res *(TURKAGER)*

https://dergipark.org.tr/en/pub/turkager
https://doi.org/10.46592/turkager.1387174

ISSN: 2717-8420
2023, 4(2), 239-250

Research Article

Utilization of Plant Waste Materials as a Partial Replacement of Cement and Fine Aggregates in Concrete Production

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Article Info

Received: 07.11.2023 **Accepted:** 04.12.2023 **Published:** 31.12.2023

ABSTRACT

The research focused on possibility of producing high quality concrete by the way of adding plant waste materials like sugarcane bagasse ash (SBA), rice husk (RH) and cassava starch (CS) to concrete mixtures. Varying percentages of SBA (0, 5, 10, 15% - weight of the cement), rice husk (0, 5, 10, 15% - weight of the fine aggregates) and cassava starch (0, 1, 2, 3% - weight of the cement) were incorporated into the concrete mixtures design. Comprehensive laboratory investigations were done on the concrete's workability (slump), density and mechanical strength, to establish the impact of these organic materials on the mechanical parameters of the concrete produced. The laboratory test results show that SBA and CS augmented the concrete slump rate whereas, the rice husk retarded the concrete's workability. The result of the density indicated that the rice husk and SBA reduced the concrete's density; however, the cassava starch caused substantial increment in the concrete's density. On the concrete mechanical properties, it was noted from the results that the compressive strength was boosted by the incorporation of SBA and CS. The maximum compressive strength (23.7 N mm^{-2}) was recorded through by substituting the cement with 10 and 2% of SBA and cassava starch respectively, in the presence of 10% RH as partial replacement of the sand. This study findings had revealed the potential of SBA, rice husk and cassava starch combinations in the right mixture design, to produce light-weight concrete material having sustainable high compressive strength.

Keywords: *Concrete, Environmental sustainability, Green admixture, Mechanical properties, Sustainable cement*

To cite: Tachere OZ, Akpenyı-Aboh ON, Akpokodje OI and Nyorere O (2023). Utilization of Plant Waste Materials as a Partial Replacement of Cement and Fine Aggregates in Concrete Production. *Turkish Journal of Agricultural Engineering Research (TURKAGER), 4(2): 239-250.*
https://doi.org/10.46592/turkager.1387174

INTRODUCTION

Concrete, a cement matrix particulate composite product is widely used in the building industry. Concrete is known for its considerable strength and resilience, making it an appropriate material for numerous structural applications. Apart from the substantial compressive strength of concrete, it is high resistance to ultraviolet radiation, nuclear reaction, and most chemical exposure (Amalraj and Ilangovan, 2023). Concrete has flexibility characteristic with excellent mechanical properties. The versatility of concrete makes it useful in several domestic and industrial structural applications, such as radiation shields, bridges, dams, industrial floors, towers, rigid pavement, vibration dampener, and management structures (Nishant *et al.*, 2016; Akpokodje *et al.*, 2019).

The mechanical behaviors of concrete are influenced by the types of materials used for its' production, and their mixing ratio. The main primary materials used to produce concrete are-cement, water, fine aggregates (commonly referred to as sand) and coarse aggregates commonly referred to as gravel), and in some cases secondary materials (admixtures) and reinforcement materials (steel rods, fibres) are introduced into the concrete to increase its mechanical properties and environmental friendliness (Eboibi *et al.*, 2022; Niaki *et al.*, 2022; Amalraj and Ilangovan, 2023). Apart from enhancing the workability of the fresh concrete, water aids complete hydration reaction of the cement. But excessive volume of water caused the formation of lower quality of tobermorite gel, leading to the production of concrete with lower compressive strength (Salem and Pandey, 2017; Akpokodje *et al.*, 2021). To achieve concrete with preferable compressive strength, the water-cement ratio, primary and secondary materials should be carefully adjusted and monitored to attain the specific requirements of the concrete produced.

Cement is the main binding material used in concrete production, but there are several research into substituting this inorganic material (cement) with sustainable green (organic) materials, to provide strength and durability to concrete (Memon *et al.*, 2022). Concrete production comes with a substantial environmental hazard, as about 5% of the world's greenhouse gases (GHS)-that are responsible for global climate change, comes from cement and coarse aggregates production, which are primary materials used for the concrete production (Lee *et al.*, 2018). The utilization of ashes produced from agricultural materials, as supplementary cementitious materials during concrete production, is a great environmentally sustainable and economically viable approach to address the organic waste disposal issues (Akram *et al.*, 2009).

Research into innovative admixtures and green materials for concrete production is ongoing, since civil engineering construction industry tends to seek more sustainable and cost-effective materials for building construction (Usman *et al.*, 2016; Shafiq *et al.*, 2018; Saleh *et al.*, 2020). Sugarcane bagasse is a fibrous residue obtained through the processing of sugarcane into sugar and related sugarcane products. The ash obtained through the combustion of the bagasse is used as a green substitute for cement during concrete production. It is essential that the volume of the admixture (sugarcane bagasse ash-[SBA]) used for the concrete is not high enough to reduce the compressive strength and stability of the concrete produced (Memon *et al.*, 2022). Literature review revealed several reports on the

application of SBA in concrete technology, as potential partial replacement material for cement during concrete production (Chusilp *et al.*, 2009; Xu *et al.*, 2018; Anjos *et al.*, 2020). However, related literature search revealed no information on the hybridization of SBA, cassava starch and rice husk during concrete production, to create concrete with realistic physical, electrical, thermal and mechanical properties. Therefore, the aim of this study is to produce high strength sustainable concrete through hybridization of SBA, rice husk and cassava starch. The successful utilization of agricultural waste materials in concrete technology will enhance effective waste management and production of environmentally friendly concrete structures.

MATERIALS and METHODS

Materials

A Portland Limestone Cement having a grade of 42.5 was used in this study. This cement is in compliance with Nigerian Industrial Standards (NIS) and Standards Organization of Nigeria (SON) guidelines, and it is used for several civil engineering applications.

Furthermore, the fine aggregates used for the concrete production were riverbed sand commonly called "sharp sand"; while the coarse aggregates used were granite of size 19 mm, obtained from the quarry were used for the concrete produced in this study. Additionally, cassava starch (CS), rice husk (RH) and sugarcane bagasse ash (SBA) used as admixtures were obtained from farm structure laboratory of the Department of Agricultural Engineering, Delta State University of science and Technology, Ozoro, Nigeria.

Methods

Concrete production experimental plan

Seven sets of concrete (6 sets were modified, and 1 set was the control) were produced in this research, in variance to previous mixture ratio of Memon *et al.* (2022) and França *et al.* (2023). The modification is done through the addition of organic starch to the concretes to enhance their engineering properties. Table 1 showed the quantity of the primary and secondary constituents of the concrete. All the materials quantities were measured based on a mix ratio of 1:2:4. The SBA and cassava starch quantity were percentage weight of cement, while the rice husk volume was percentage weight of the fine aggregates.

Table 1. *The concrete production plans.*

Samples code	Cement volume (%)	SBA volume (%)	Fine aggregates volume (%)	Rice husk volume (%)	Coarse aggregates volume (%)	Cassava starch (%)
GC 0 (control)	100	0	100	0	100	0
GC 1	95	5	95	5	100	0
GC 2	90	10	90	10	100	0
GC 3	85	15	85	15	100	0
GC 4	94	5	95	5	100	1
GC 5	88	10	90	10	100	2
GC 6	82	15	85	15	100	3

Concrete mixture design

A concrete mixture design of ratio 1:2:4 was adopted for this research, while a water-cement ratio of 0.6 was implemented during the course of the concrete production. The mix ratio represents the proportions of different ingredients in the concrete mix, and batching my mass was used to measure the amount of the different constituents used for the concrete production. These mix ratios will have significant effect the strength properties and workability of the concrete (Uguru *et al.*, 2022).

Concrete production

The fresh concrete was poured into a pre-prepared (oiled) mould of dimensions 0.15 x 0.15 x 0.15 m in three equal layers. After each layer was poured into the mould, it was vigorously rammed 25 times using a 0.016 m ramming rod, to compact the concrete and remove any voids. Then the surface of the mould was smoothed and leveled by using a hand trowel (Uguru *et al.*, 2022).

Curing

The concrete was cured through the total immersion in water under environmental conditions (temperature 31±6°C and 82±9% relative humidity) as described by Uguru *et al.* (2022) in a curing tank at ambient environmental conditions.

Laboratory analysis

Particles size grading

The sharp sand particle size grading was conducted in harmony with ASTM C136 (2006) approved procedures. Thereafter, the calculation of the coefficient of uniformity (Cu) of the sand was done through the formula shown in Equation 1. Coefficient of uniformity is a factor that helps to evaluate the uniformly the soil particles distributed within soil mass, and how the soil can be graded (Eboibi *et al.*, 2022).

$$Cu = \frac{D_{60}}{D_{10}} \quad (1)$$

Where: D_{60} is the volume of 60% finer soil particles, and D_{10} is the volume of 10% finer soil particles.

Slump test

The slump test (workability) of the concrete was determined in accordance to the ASTM C143 (2017) approved procedures.

Concrete density

The concretes' density was determined at 28th curing day in accordance with ASTM C642 (2021) approved standard. An electronic weighing balance and caliper were used to measure the mass and dimensions of the concrete cube respectively. Thereafter, the density was calculated through the expression in Equation 2, as described by Suhad *et al.* (2016).

$$Density\ (kg\ m^{-3}) = \frac{Mass\ (kg)}{Volume\ (m^3)} \quad (2)$$

Concrete compressive strength test

The compressive strength-of the most essential mechanical behavior of a concrete was measured in accordance with ASTM C39M (2014) approved procedures, by using a Stye-2000 Ctm Digital Hydraulic Compression Testing Machine-Model NO: STYE-2000 manufacture in China (Figure 1). At the end of each concrete cube testing, to calculate the concretes' compressive strengths, the expression in presented Equation 3 as described by Akpokodje *et al.* (2021) was used. The test (for each concrete set) was done in triplicate and the average value recorded.

Figure 1. *The crushing of the concrete cube.*

$$Compressive\ strength = \frac{Force}{Area} \quad (3)$$

Statistical analysis

The results obtained from the all-laboratory tests were analyzed statistically through the use of appropriate charts and tables. Each test was conducted in triplicate, and the mean value recorded.

RESULTS AND DISCUSSION

Particle size grading (PSD)

The PSD result of riverbed sand used in this study is presented in Figure 2. Based on the Cu and Cc values (Cu= 5.46 and Cc= 1.25), the fine aggregates used for concrete production fall within the range for "Poorly graded" fine aggregates according to the Unified Soil Classification System (USCS) grading system. According to USCS (2015), any soil having Cu greater than 6 and the fine content

less than 5% is considered "Well Graded sand" (USCS, 2015). Generally, poorly graded soil tends to produce concrete of lower quality (poor mechanical strength) when compared to its counterparts made from well graded soil (Akpokodje *et al.*, 2021).

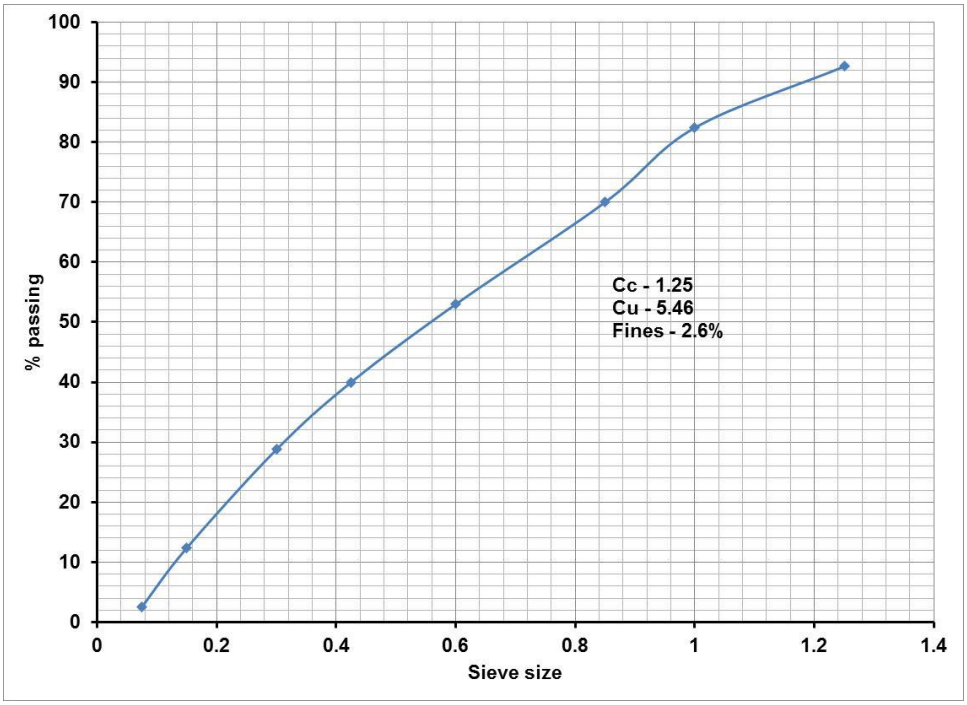

Figure 2. *A plot of sieve analysis.*

Concrete Slump

The result of the concrete slump is shown in Figure 3. Figure 3 revealed that the slump value of the seven concrete sets GS 0, GS 1, GS 2, GS 3, GS 4, GS 5 and GS 6- was 31, 38, 35, 30, 42, 45 and 51 mm, respectively. It can be observed from the slump result that the SBA and cassava starch tend to enhance the concrete's workability, which is comparable to the observations made by Memon *et al.* (2022). Likewise, this research finding depicted that the rice husk tends to retard the workability of the concrete. It was detected that the slump increased from 31-38 mm as the SBA and RH amount inclined from 0-5%, before it started to decline from 38-30 mm as the SBA and RH volume increased from 5-15%. This is an indication that a larger volume of RH hinders the workability of the concrete, which can be attributed to the textural characteristic (roughness) and high-water affinity of the rice husk. The roughness of the RH can interfere with the flow rate of the fresh concrete mixture, while the high RH water absorption rate will deprive the concrete of enough water for hydration and lubrication; hence, leading to the formation of concrete with poor workability (Sotiropoulou *et al.*, 2017).

Remarkably, the findings of the study depicted that the concrete's slump values increased in a non-linearly pattern, when the amount of the cassava starch integrated into the concrete increased from 0 to 3% (GC4, GC5 and GC6). This revealed that cassava starch is a potential green concrete workability booster, resulting in the formation of concrete with more uniform and compacted mixture. These results are in conformity with previous research findings as reported by Abalaka (2011) and Joseph and Xavier (2016). Slump is a vital parameter in concrete

technology, as it is an indicator for the fresh concrete consistency, workability, and compatibility. This study's findings revealed that starch and SBA are sustainable and environmentally friendly admixtures, which reduce the volume of water needed for the complete chemical reaction of the cement, thereby boosting the concrete mix design efficiency (Eboibi *et al.*, 2022).

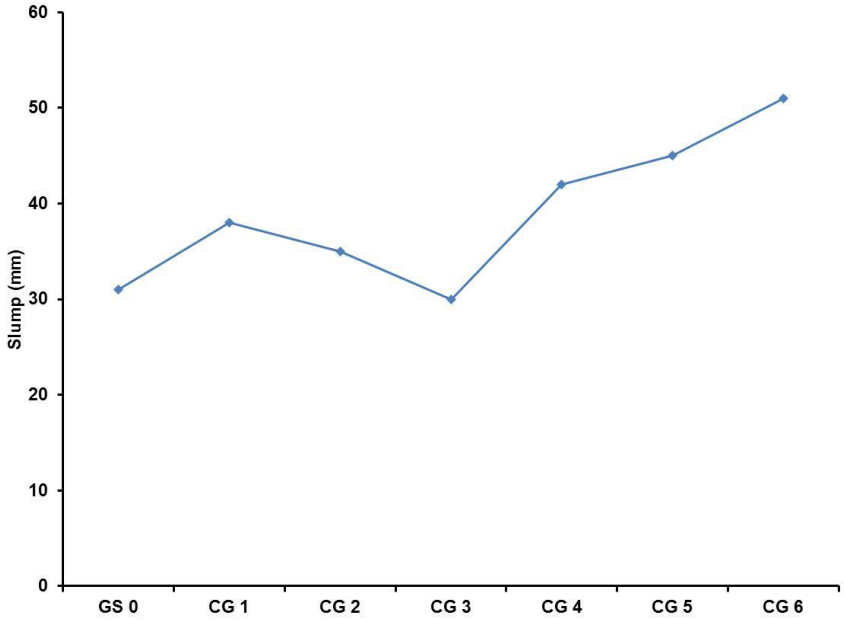

Figure 3. *The results of the concrete units' slump.*

Concrete Density

Figure 4 presents the calculated density of the concrete sets. At the 28th curing day, it was noted that the SBA and the cassava starch had substantial effect on the concrete density. As shown in Figure 4, the density of the control unit (GS 0), GS1, GS2, GS3, GS 4, GS5 and GS6 concrete units was 2470, 2350, 2190, 1970, 2410, 2250 and 2060 kg m^{-3} respectively. This is an indication that the admixture and the rice husk caused a significant reduction in the concrete weight. Memon *et al.* (2022) and França *et al.* (2023) made similar observations during their research into the impact of SBA on the mechanical properties and durability of concrete. The decline in the concrete density can be attributed to the lower specific gravity, porosity and density of the ash when to compared to these parameters' values of the cement (Rattanachu *et al.*, 2018).

Furthermore, the results revealed that the concrete density declined non-linearly as the volume of the rice husk in the concrete increased from 0 to 15% (by weight of the fine aggregates). This finding can be attributed to the lower bulk density of the rice rusk compared to fine aggregate bulk density, therefore increasing the quantity of the materials with lower bulk density in the concrete will translate to reduction in the concrete density (Akpokodje *et al.*, 2019). Additionally, the findings of this research revealed that the density of concrete produced with cassava starch (GC4, GC5 and GC6) as workability enhancer, developed higher density compared to the density of concrete sets produced without cassava starch (GS 1, GC 2 and GC3). This portrayed that cassava starch improves the distribution and dispersion of cementitious materials, leading to a more uniform and densification of the concrete

(Abd *et al.*, 2016; Monteiro *et al.*, 2019). This finding is similar to previous observations of Agbi and Uguru (2021), where cassava starch caused a significant increment in the density of concrete produced with sawdust as a partial replacement for fine aggregates.

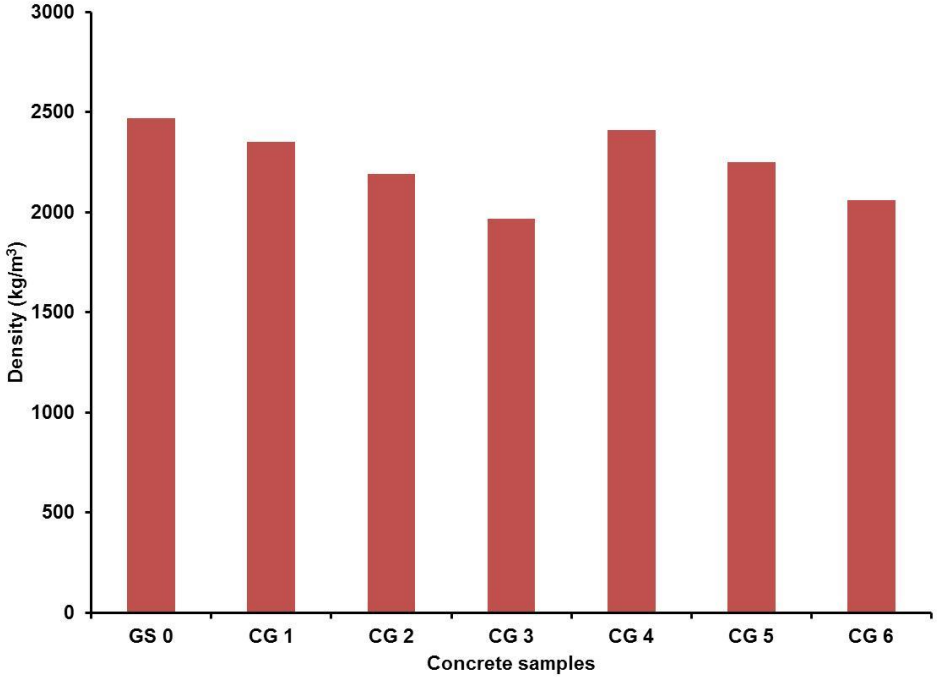

Figure 4. *The impact of admixtures on concrete density.*

Compressive strength

Results gotten for the various concrete units' compressive strength are presented in Figure 5. It can be comprehended from Figure 5 that the compressive strength of the GC0, GC1, GC2, GC3, GC4, GC5 and GC6 concrete units was 21.7, 22, 18.5, 15.4, 22.6, 23.7 and 19.8 N mm^{-2} respectively. It was observed from the results that despite the presence of RH as a partial replacement for fine aggregates, the strength developed by the concrete increased gradually with an increment in SBA volume from 0 to 5%, after which it started to decline as the ash volume increased to 15%; which is similar to the findings made by Memon *et al.* (2022) and Zareei *et al.* (2018) when SBA was used as supplementary cementing material during concrete production.

According to (França *et al.*, 2023) SBA is a prospective pozzolanic material which forms calcium silicate hydrate compound during chemical reaction, thereby contributing to the development of mechanical strengths of the concrete made with it. This trend is a frequent occurrence in green concrete technology. The differences observed in the compressive strength of the concrete experimentally produced in this research, when compared with observations reported by other authors (Zareei *et al.*, 2018; de Siqueira and Coreiro, 2022), can be attributed to the chemical composition of the SBA, particulate size and quality of the SBA employed to create the concrete, and the curing method adopted. Finer admixture particles have the ability of improving composite/concrete strength, when compared to coarse admixture particles, which can be attributed to their increased effective contact surface area, besides reactivity of the fine-grained particles admixture.

Furthermore, findings obtained from this experimental work indicated that the compressive strength of green concrete without cassava starch admixture (GS 1, GC 2, and GS 3) developed lower compressive strength of 19.3, 17.5 and 15.4 N mm^{-2} respectively, compared to green concrete made with different cassava starch content (GS 4, GS 5 and GS 6) that recorded compressive strength of 22.6, 23.7 and 19.8 N mm^{-2} respectively. Interestingly, it was noticed that the cassava starch led to a steady rise in the amount of compressive strength developed as its' amount increased from 0-3%, portraying that cassava starch is a suitable green admixture that has the capacity of augmenting the strength characteristics of concrete. These results are similar to the observations made by Okafor (2010) and Agbi and Uguru (2021), where the compressive strength of cement composite increased non-linearly when the amount of the cassava starch added into the concrete increased linearly.

Effectiveness of cassava starch as concrete mechanical properties enhancer is dependent on the biochemical properties of the cassava starch, the cassava varieties, the concrete mixture design, and the concrete production method (Akindahunsi and Uzoegbo, 2015). According to Akpokodje and Uguru (2019), cassava starch aids the cohesion between the cement matrix and primary aggregates in the fresh concrete, improving the concrete bonding strength in the process, which will lead to higher compressive strength formation at the end of the reaction. Furthermore, these results portrayed that replacing sand with rich husk (at lower volume) can produce concrete with reasonable strength above the 17 N mm^{-2} approved by NIS as minimal allowable compressive strength for concrete meant for residential buildings construction.

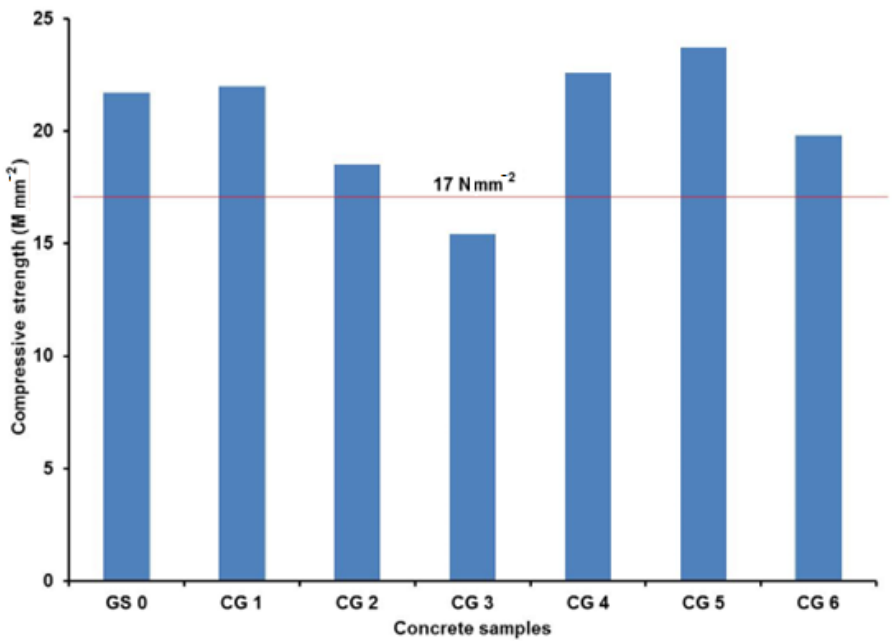

Figure 5. *Compressive strength of the concrete.*

CONCLUSION

This study was done to determine the probability of producing high strength concrete, through the substitution of concrete primary materials-cement and fine aggregates - with organic cementing materials. Six units of modified (green) concrete

were produced through the partial replacement of the cement volume with sugarcane bagasse ash (SBA), substituting the fine aggregates content with rice husk (RH), and cassava starch (CS) as organic concrete workability enhancer. Results obtained from the laboratory tests of the concrete indicated that both the SBA and cassava starch have a positive impact on the concrete's engineering properties. The density of the concrete tends to decline in an uneven order, the volume of the SBA (by percentage amount of the cement) and rice husk (by percentage volume of the fine aggregates) increases, which can be attributed to its lower bulk density of the two materials. Likewise, the green concrete's mechanical (compressive) strength inclines with an increment in the percentage of SBA and cassava starch incorporated into the concrete. The maximum compressive strength (23.7 N mm^{-2}) was recorded with substitution of 10% SBA, 10% rice rusk and 2% cassava starch. It was also noted from the observations that both the SBA and CS admixtures enhance the workability of the concrete produced, while the rice husk caused substantial retardation in workability and compressive strength development. Conclusively, this research depicted the substantial potential of SBA, RH and CS hybridization for sustainable high quality concrete production.

DECLARATION OF COMPETING INTEREST

The authors declare that they have no conflict of interest

CREDIT AUTHORSHIP CONTRIBUTION STATEMENT

The authors declared that the following contributions are correct.
Otaghogho Zion Tachere: Designed the research Methodology and writing of the original draft.
Onyekachukwu Nicklette Akpenyi-Aboh: Edited the manuscript.
Ovie Isaac Akpokodje: Data analysis and review of the original draft.
Oderhowho Nyorere: Designed the research and writing the original draft.

ETHICS COMMITTEE DECISION

This article does not require any ethical committee decision.

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Turkish Journal of Agricultural Engineering Research

Turk J Agr Eng Res *(TURKAGER)*

https://dergipark.org.tr/en/pub/turkager
https://doi.org/10.46592/turkager.1389808

ISSN: 2717-8420
2023, 4(2), 251-262

Research Article

Investigation into the Mechanical Properties of Commercial Sandcrete Blocks Produced in Nigeria: A Case Study of Warri Metropolis

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Article Info
Received: 12.11.2023 **Accepted:** 12.12.2023 **Published:** 31.12.2023

ABSTRACT

This study investigated the extent to which the mechanical strength of commercially produced sandcrete blocks in Delta State, Nigeria, conforms to recognized international standards. Fifty sandcrete blocks (28 curing days) were sampled from ten known sandcrete block manufacturers in Warri municipal area, five blocks from each manufacturer. The compressive strength of the blocks was determined in accordance with the American Society for Testing and Materials (ASTM) International guidelines. The results showed that the compressive strength of all the blocks failed to meet the Nigeria Industrial Standard (NIS) benchmark for load loading sandcrete block, while only 20% of the blocks attained NIS requirement for non-load bearing walls. Field observation revealed that poor mixing ratio of the sandcrete; inconsistencies in the batching method and sand used in the production of the sandcrete blocks were responsible for the poor quality (low compressive strength) of the sandcrete blocks manufactured in the region. The findings of this study underscore the importance for the Nigerian Institution of Structural Engineers, to rigorously monitor the strength of sandcrete blocks made in Nigeria to ensure that their quality meets internationally recognized standards. This will reduce the occurrence of structural damage in Nigeria, due to the use of low quality blocks for wall construction.

Keywords: *Agricultural structure, Housing shortage, Quackery, Quality control, Sandcrete blocks*

To cite: Nyorere O, Akwenuke M and Tachere OZ (2023). Investigation into the Mechanical Properties of Commercial Sandcrete Blocks Produced in Nigeria: A Case Study of Warri Metropolis. *Turkish Journal of Agricultural Engineering Research (TURKAGER), 4(2): 251-262.*
https://doi.org/10.46592/turkager.1389808

INTRODUCTION

Nigeria is currently facing a significant housing deficit. The housing shortage problem is mostly caused by the poor economic situation, urbanization/industrialization, increased in population growth, and inadequate investments in the real estate sector. The Federal Mortgage Bank of Nigeria (FMBN), an institution responsible for the provision of affordable housing in Nigeria, stated that Nigeria currently lacks about 21 million housing units, which may increase to 28 million by 2050 if appropriate actions are not taken (Adenikinju, 2019). Adequate safe, conducive, accessible and affordable housing is a fundamental human right as stated laws of the United Nations. Additionally, Article 11(1) of the International Covenant on Economic, Social and Cultural Rights (ICESCR), enshrines the Right of every person (individual) to an adequate standard of living without unsafe housing (ICESCR, 1996; UN Habitat, 2001). Similarly, Goal 11 of the Sustainable Development Goals encourages sustainable accommodation for people without discrimination.

Affordable but standard building materials will play an indispensable role in overcoming the accommodation problem in Nigeria. It is necessary to recognize that using counterfeit/fake composite parts during civil engineering structures construction tends only not to compromise their integrity and the safety of their occupants, but also has long-term economic and societal consequences. It is therefore imperative for the sustainability of infrastructural development in Nigeria to address this important issue (Uguru and Obukoeroro, 2020; Ihemegbulem *et al.*, 2022). Materials selection is one of the critical aspects in the construction industry, and this process requires serious attention to achieve the specific project requirements. Therefore, engineers need to consider this factor seriously, to ensure that sandcrete blocks and other concrete materials used for the construction of buildings comply with international and local building codes/standards (Erakpoweri and Onah, 2022). Sandcrete block which is a masonry unit is made from sand, cement and water; the cement acting as the binder from the composite material, while the water hydrates the cement which lead to chemical reaction that binds the sand and cement together (Sholanke *et al.*, 2015; Awolusi *et al.*, 2021). The percentage of the sand, cement and water used to produce the block can vary, and this variation is dependent on the specific requirements for the desired mechanical properties of the blocks (Akpokodje *et al.*, 2021). Sandcrete blocks have become popular building material in most African countries, due to their cost-effectiveness, availability, ease of production, and relatively good structural properties (Baidenand and Tuuli, 2004). Farm structures faced severe environmental conditions-moisture content, chemical reactions from agricultural chemicals, wide temperature fluctuations, and physical stress-in most cases. Most farm structures are built with various forms of the sandcrete blocks, making the quality of sandcrete blocks an issue of paramount interest, since building structures with poor quality materials have serious negative long-term effects (Agbi *et al.*, 2020). Since most farm structures are unframed structures built with poor quality wall materials (low load-bearing elements), the walls lack the required compressive strength and structural integrity, leading to cracks in the walls and eventually failure of the structure (Kashani *et al.*, 2023).

The preference for commercially (mass) produced sandcrete blocks in building works in Nigeria is really overwhelming, as developers seek to the bridge housing deficit in the country (Agbi *et al.*, 2020). Numerous scientific investigations have been conducted to appraise the engineering properties of sandcrete block that are mass-produced in the African continent (Ajao *et al.*, 2018; Akpokodje *et al.*, 2021; Ogunbayo and Aigbavboa, 2021). They noted that the engineering behaviors of these composite blocks were strongly influenced by the type and quantity of aggregates and cement used in the sandcrete blocks production. According to Esegbuyota *et al.* (2019), the sandcrete block mix ratio, curing methods and the presence of admixture significantly affect the mechanical properties and durability of the products produced.

Proper quality control and testing procedures are critical to achieving the desired performance and durability of these materials in construction (Rubaratuka, 2008; Schabowicz, 2021). Despite numerous investigation into the quality (in terms of mechanical strength) of blocks produced in Nigeria (Onwuka *et al.*, 2013; Odeyemi *et al.*, 2018; Ambrose *et al.*, 2019), literature search revealed no results on recent appraisal of the compressive strength of commercially produced sandcrete blocks within Warri metropolis. Therefore, this research was conducted to access the compressive strength of commercially manufactured sandcrete blocks in Warri metropolis of Delta State, Nigeria. Warri is one of major commercial cities in Nigeria with a lot of residential, industrial and farm structures. Hence, the information provided by this research will help to monitor the quality of building materials used in Nigeria.

MATERIALS and METHODS

Study area

This research was conducted with Warri metropolis of Delta State, Nigeria, as shown in Figure 1. Warri is the largest city in Delta state and also a major oil hub of Nigeria, with a population of approximately 400,000 people (DSG, 2015). Geographically, the study area is located between latitudes 5˚30′ and 5˚35′ North and longitudes 5˚29′ and 5˚48′ East. The area is located in the tropical region of Nigeria with moderate temperature and high annual rainfall (about 1800 mm per annual) that is widely distributed across the year (Efe and Ojoh, 2013; Uguru *et al.*, 2023). The Warri metropolitan area can be confidently classified as a commercial, industrial and educational center. The city has several tertiary institutions, medium and large-scale businesses, and urban markets; hence, there are lots of buildings constructions in new residential and industrial layouts.

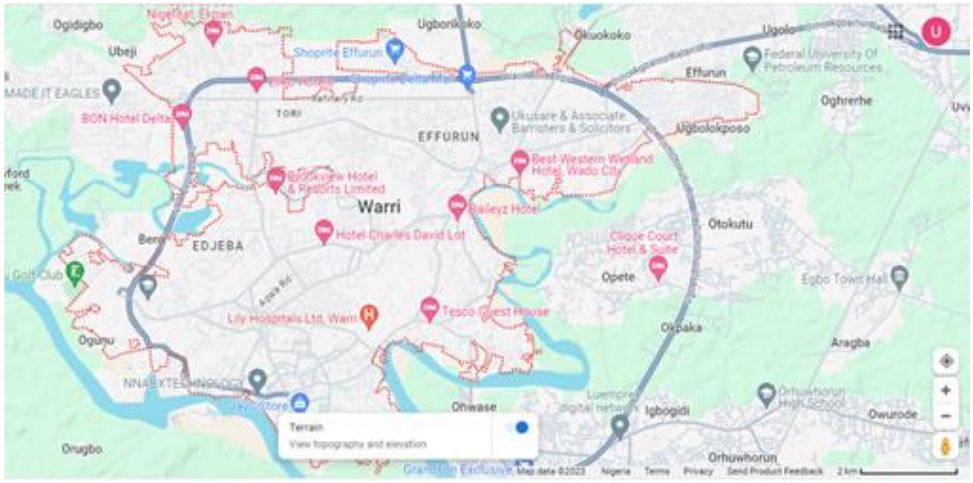

Figure 1. *Warri and its environs map (Goggle Map, 2023).*

Samples collection

A total of fifty books were sampled from 10 block producing industries (Figure 2) within the metropolis, 5 blocks per industry. Additionally at each block moulding industry, 2 kg of sand was taken for sieve analysis, to determine the suitability of the sand for sandcrete blocks production. The blocks were cured by watering twice a day.

Figure 2. *A sandcrete blocks producing industry.*

Block production and field observations

The observations made during the field survey are presented in Table 1. It was noted from the field observations that seven out of the ten industries visited used mechanical sandcrete mixers and vibrating block moulding machines for their sandcrete block production. This method increases the mechanical strength of the blocks, since vibrated blocks tend to have higher compressive strength than non-vibrated blocks (Akpokodje *et al.*, 2021).

In all the blocks industries visited within the study area, batching was done by volumetric methods with a lot of inconsistencies in dosing. An inconsistent mix ratio can lead to variations in the rate at which these blocks absorbed compression force, resulting in a reduction of the effective life span of the sandcrete blocks (Akpokodje *et al.*, 2021). Furthermore, it was noted during the on-the-spot assessment that all the blocks industry supervisors did not adhere to any water-cement ratio, as water was added to the mix arbitrarily based on the discretion of the sandcrete blocks moulders. This singular act will affect the quality of the blocks produced since water-cement ratio is an essential factor in sandcrete technology. It plays a vital part in determining the mechanical properties of blocks produced, irrespective of the batching or mixing method adopted.

Table 1. *Sandcrete blocks production method.*

Block industry	Cement-sand mix ratio	Water-cement mix ratio	Site manger	Mixing method	Batching method
1	1:10	N	Engineer	Mechanical	Volumetric
2	1:12	N	Mason	Manual	Volumetric
3	1:14	N	Mason	Mechanical	Volumetric
4	1:12	N	Mason	Mechanical	Volumetric
5	1:10	N	Mason	Mechanical	Volumetric
6	1:12	N	Mason	Manual	Volumetric
7	1:14	N	Mason	Manual	Volumetric
8	1:10	N	Mason	Mechanical	Volumetric
9	1:12	N	Mason	Mechanical	Volumetric
10	1:14	N	Mason	Mechanical	Volumetric

N = not determined

Laboratory analysis

Sieve analysis

The sieve analysis of the 10 soil samples collected from the various sandcrete blocks moulding centers, was carried out in harmony with the procedures recommended by ASTM C136 (2006) . Then the major coefficients-uniformity (C_U) and curvature (C_C) values of the sand based on USCS guidelines, were calculated through Equations 1 and 2 respectively. These two coefficients provide meaningful information about the particle size distribution pattern of the soil (Eboibi *et al.*, 2022).

$$Cu = \frac{D_{60}}{D_{10}} \quad (1)$$

$$Cc = \frac{(D_{30})^2}{D_{60} \times D_{30}} \quad (2)$$

Where: D_{60} is the volume of 60% finer soil particles, and D_{10} is the volume of 10% finer soil particles (USCS, 2015).

Compressive test

The compressive strength of the blocks on 28th day of curing was determined in agreement with techniques approved by ASTM C39 / C39M (2014), by using a digital concrete strength testing machine (manufactured in China, model: STYE 2000).

During the test, each block was clamped in the crushing chamber of the machine (Figure 3), and the blocks were compressed at a rate of 10 mm min^{-1} until failure of the block occurred. Thereafter, the sandcrete block compressive strength value was calculated through the formula presented in Equation 3 (Akpokodje and Uguru, 2019).

$$\text{Compressive strength (MPa)} = \frac{Force\ (N)}{Area\ (mm^2)} \quad (3)$$

Figure 3. *Sandcrete block undergoing compressive strength testing.*

Statistical analysis

The results were statistically analysis-using the mean as a statistical tool-with the aid of Microsoft for Excel-2019 version. Thereafter, mean compressive strength values were plotted using the appropriate bar chart.

RESULTS AND DISCUSSION

Soil particle size grading (PSD)

The PSD curves from the sieve analysis of the various sand samples collected from the blocks industry are displayed in Figure 4, and their coefficients of uniformity and curvature are presented in Table 2. Sieve analysis of one of the geotechnical tests carried out on sand to determine its suitability for various construction applications, including concrete and sandcrete blocks production. Table 2 shows that 70% of the fine aggregates used to make the blocks were poorly graded sand "PGS", while only 30% of the fine aggregates were well graded sand "WGS", using the Unified Soil Classification System (USCS) guidelines. Well-graded soils have a wide range of particle sizes and are considered more stable and less susceptible to settling or segregation (USCS, 2015). The Nigeria Industrial Standard (NIS) recommends WGS for concrete and sandcrete blocks production, as sandcrete blocks made from WGS

tend to have better (higher) compressive strength, compaction and resistance to settlement (NIS-87, 2005).

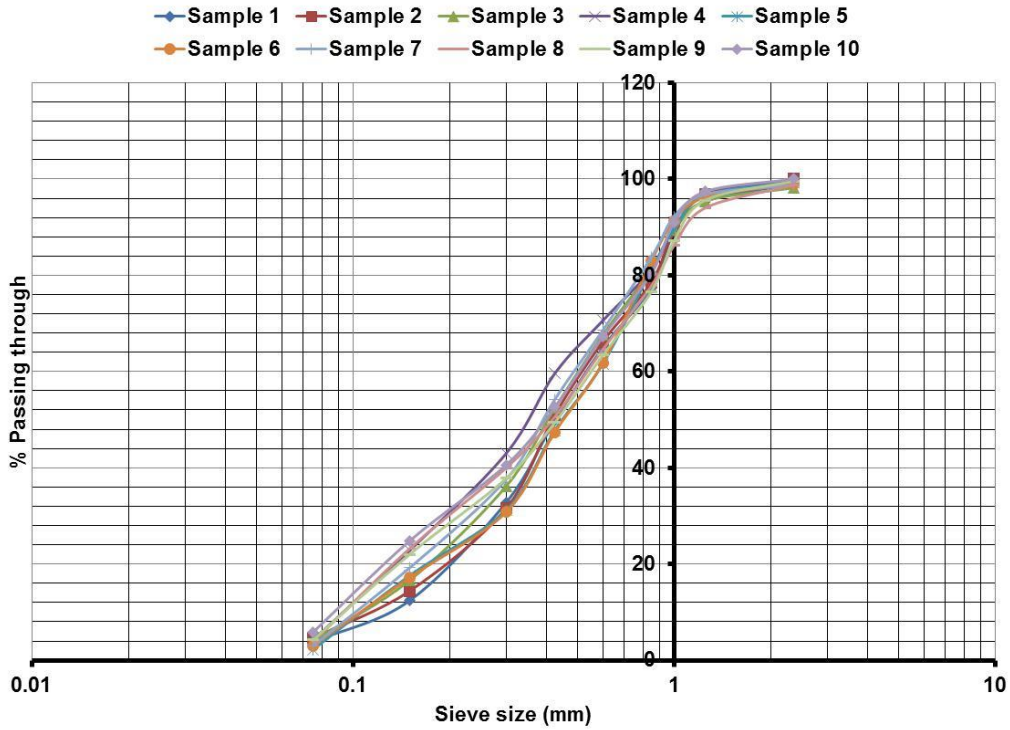

Figure 4. *Soil particle size distribution curves.*

Table 2. *Grading of the soil samples according to USCS.*

Soil sample	Cc	Cu	Fines	USCS grading
Sample 1	1.33	4.58	3.8	PGS
Sample 2	3.55	4.72	4.6	PGS
Sample 3	2.45	5.00	4	PGS
Sample 4	1	4.00	4.2	PGS
Sample 5	1.55	6.00	2.2	WGS
Sample 6	1.81	5.27	3	PGS
Sample 7	1.23	5.1	3	PGS
Sample 8	0.77	6.3	3.8	WGS
Sample 9	0.81	6.5	4.2	WGS
Sample 10	0.54	6.67	5.8	PGS

PGS = poorly graded soil, WGS = well graded soil

Compressive strength

Figure 5 shows the plot of the mean values of the sandcrete blocks' compressive strength at curing day 28. It was noted from Figure 5 that the blocks' compressive strength ranged from 0.76 to 3.42 N mm^{-2} across the 10 major sampling points. It was detected from the results that 100% of the blocks commercially produced within the Warri municipal area failed to meet the required NIS standard for load loading sandcrete block, while 80% of the sampled sandcrete blocks tested could not meet the international (NIS) condition for non-load bearing walls. The NIS and SON

recommendations for building materials state that, the lowest permissible compressive strength of sandcrete blocks for non-loading wall construction is 2.5 N mm^{-2}, while blocks for load bearing walls should have a minimum compressive strength of 3.5 N mm^{-2} (NIS-87, 2005). These results are similar to those obtained by Aiyewalehinmi and Tanimola (2013), Onwuka *et al.* (2013) and Yusuf *et al.* (2017), where the compressive strength of sandcrete blocks from other regions of Nigeria are consistently below the NIS/SON recommended values of 2.5 and 3.5 N mm^{-2} for load and non-load bearing walls respectively.

The poor quality of the blocks produced by these sandcrete blocks producers could be linked to the poor formation of these blocks manufacturers, the quality of the fine aggregates used, and blocks production method adopted. The poor quality of the blocks produced by most of the block's industry sampled could be partially attributed to the poorly graded soils that were used as a primary material during the sandcrete blocks production (Omoregie, 2013). The geotechnical properties of the sand used in the production of sandcrete blocks usually have a significant impact on the quality (mechanical properties) of the final product (blocks) produced. According to Akpokodje *et al.* (2021) reports, cement-composites (concrete or sandcrete) produced from poor quality fine aggregate tend to develop lower compressive strength, when compared to their counterpart produced with high quality fine aggregates.

Furthermore, the quantity of cement used in sandcrete block production plays a critical role in the final strength developed by block (Ewa and Ukpata, 2013; Alejo, 2020). Consequently, the poor compressive strength generally recorded in all the block moulding sites could be linked to the poor cement-sand mix ratio (1:10 and above) used by all those responsible for making their blocks. Sholanke *et al.* (2015) in their reports stated that, the mechanical behaviors of sandcrete block are inversely proportional to its cement content. It is very unfortunate that majority of the sandcrete block industry producer in Nigeria internationally altered the standard (NIS approved mix ratios of 1:6, 1:8 and 1:10) sandcrete block mix design ratios to maximize their profit, thereby exploiting their customers and lowering the integrity of the blocks produced. Therefore, the sand-cement and water-cement ratios should be strictly controlled to ensure that the blocks have the desired strength and durability.

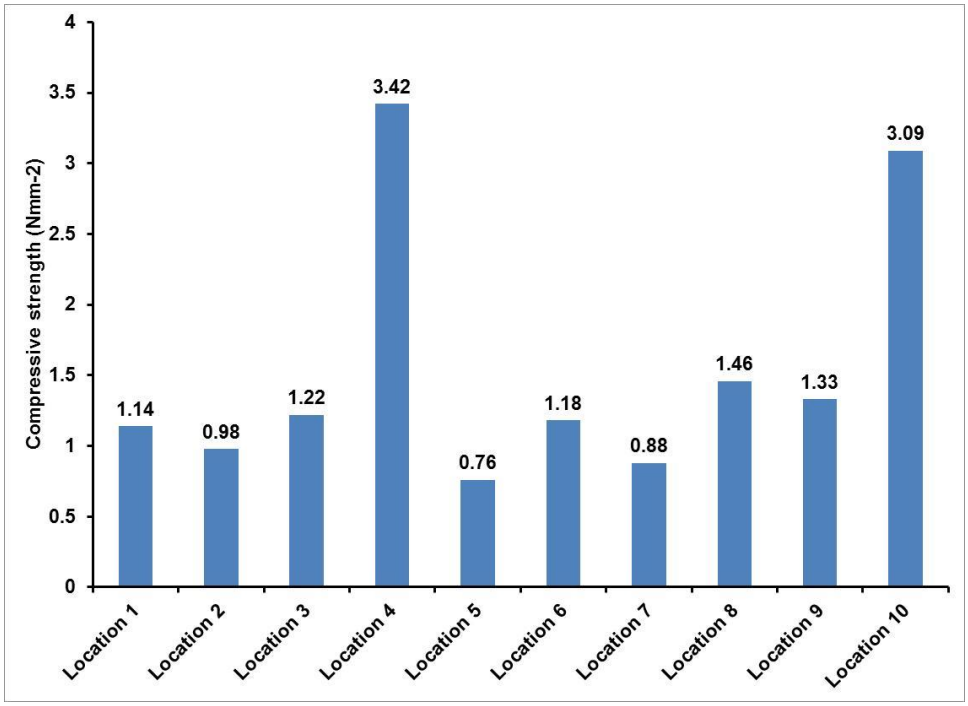

Figure 5. *The sandcrete blocks compressive strength results.*

The identification of poor sandcrete mix ratio, inconsistencies in the batching method, and the use of poorly graded sand as contributing factors to the low quality (low ability to absorb compression loading) of the sandcrete blocks is a very significant finding. These factors can have a substantial impact on the overall performance and structural integrity of the blocks. This study's findings emphasize the significance of consistence monitoring of the sandcrete blocks produced in the region, to check their compliance to international/local approved standards. Load-bearing blocks are vital components of an unframed structure, as they provide the structural support for the building. Therefore, the use of substandard blocks in the construction of unframed building raises potential issues regarding the integrity and reliability of the building.

CONCLUSION

This work was conducted to evaluate the compressive strength of sandcrete blocks manufactured in Warri metropolis of Delta State, Nigeria; and evaluate their compliance with international building materials standards. 50 sandcrete blocks were randomly sampled from the study area, and their compressive strength was determined in harmony with ASTM International approved methods. The findings obtained through the laboratory test indicated that 100% of the sandcrete blocks sampled failed to meet Nigeria Industrial Standard (NIS) requirement - compressive strength of 3.5 N mm^{-2} for load bearing walls, while only 20% of the sandcrete blocks complied with NIS recommendation -compressive strength of 2.5 N mm^{-2} for non-load bearing walls. Compressive strength is an essential material when selecting building wall materials, as it specifies the capacity of the wall building material to withstand axial loads.

The results of this study have highlighted the necessity of regular monitoring of sandcrete blocks produced in the region, to ensure that block producers prioritize quality over short-term profit maximization. Furthermore, more research should be conducted to explore sustainable alternative materials, which can produce sandcrete blocks with better compressive strength without compromising their standards and cost-efficiency.

DECLARATION OF COMPETING INTEREST

The authors declare that they have no conflict of interest

CREDIT AUTHORSHIP CONTRIBUTION STATEMENT

The authors declared that the following contributions are correct.
Oderhowho Nyorere: Designed the research and writing the original draft.
Moses Akwenuke: Edited the manuscript.
Otaghogho Zion Tachere: Designed the research Methodology and writing of the original draft.

ETHICS COMMITTEE DECISION

This article does not require any ethical committee decision.

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Turkish Journal of Agricultural Engineering Research

Turk J Agr Eng Res *(TURKAGER)*

https://dergipark.org.tr/en/pub/turkager
https://doi.org/10.46592/turkager.1365697

ISSN: 2717-8420
2023, 4(2), 263-277

Research Article

Design and Development of IoT based Smart System for Monitoring Laboratory Environment

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Article Info

Received: 25.11.2023 **Accepted:** 18.12.2023 **Published:** 31.12.2023

ABSTRACT

This study was conducted to address the critical issue of the poor safety management system in laboratories, through the design of a smart laboratory management facility based on the Internet of Things (IoT). In this design, three major safety parameters-fire, temperature and carbon (ii) oxide (CO) levels were monitored by appropriate sensors, which transmit data to the microcontroller (Arduino) for interpretation. The Arduino microprocessor processed the data received from the sensor(s), makes decisions based on the predefined algorithms. Based on the decisions made by the Arduino, the microprocessor sends instructions to a relay module triggered the necessary actions to be taken by the output hardware devices-fire extinguisher, air conditioning system and exhaust fan unit. The temperature monitoring system was designed at an operational range of 18°C to 25°C, the CO control unit was designed to maintain the CO concentration inside the laboratory at a level not exceeding 4 parts per million (ppm), as approved by the World Health Organization; while fire control unit was designed to detect the presence of smoke of naked fire inside the building. In the event that any of these parameters breach safety thresholds, the smart structure's safety system will trigger the appropriate responses. The designed structure was built in compliance with international safety standards. Results obtained through the testing and evaluation of the system revealed that the smart system had overall performance efficiency of 91% and false output of 9%. The system's failure rate of 9% can be reduced by employing advanced sensors and adjusting the delay rate. The findings of this study revealed that IoT and automation can successfully monitor and protect the working environment inside laboratories.

Keywords: *Arduino UNO, Automation, C++ Programming, Environmental control, Health hazards, Sensors and hardware*

To cite: Odoh FE, Akpomedaye O and Ekruyota OG (2023). Design and Development of IoT based Smart System for Monitoring Laboratory Environment. *Turkish Journal of Agricultural Engineering Research (TURKAGER), 4(2): 263-277. https://doi.org/10.46592/turkager.1365697*

INTRODUCTION

Laboratory is a specialized place equipped with various instruments/apparatus that enhanced research and developments, analyzed data and contribute immensely to knowledge and development of new technologies (Junwei *et al.*, 2022; Wang, 2022). Laboratory provides a conducive environment for methodical investigation and experimentation, enabling researchers to test hypotheses, validate theories, and make meaningful contributions to their respective fields (Shana and Abulibdeh, 2020). Laboratories which are integral spaces within colleges and universities play a pivotal role, in the education and professional development of the students. Apart from practical skills that students learn in laboratories, they are major source of internal generated revenue to higher institutions, as they carry out consultancy services for individuals and corporate organizations. Laboratories are hubs for research and modernization, as they enable individuals/students to conduct experiments, investigations, and research that will aid their practical knowledge in their respective areas of specialization (Liboreiro *et al.*, 2022).

There are several tasks required for an upkeep of any standard laboratory. Some of these tasks are environmental monitoring and control, attendance taking, materials inventory, waste management and other safety precautions. Uguru *et al.* (2023) reported that high temperature usually affects the results of most food items during laboratory analysis, hence temperature should be considered as a serious factor during mechanical and textural evaluation of most agricultural food products. According to Befekadu *et al.* (2020), appropriate inventory management minimized bottleneck laboratory operations, and by ensuring that there are adequate materials for the smooth running of the laboratory system, by ensuring timely replenishment of laboratory commodities. Proper inventory management and environmental monitoring greatly influence the overall efficiency of laboratory operations (Leung *et al.*, 2016; Restiana and Djukri, 2021).

Smart system is a new innovation where the system meets remote monitoring needs, hence reducing the time taken and risks involved in the system operation. Smart systems enable real-time monitoring of laboratory equipment and processes from a remote location. The integration of automaton and smart systems into machine operations brings about several advantages, particularly in the context of remote monitoring and quality control (Ekruyota *et al.*, 2021; Idama and Ekruyota, 2023). Well-furnished laboratories contribute immensely to the academic and socio-economic excellence of any institution of learning or research. Modernized laboratories are often equipped with sensitive apparatus and equipment that require specific environmental conditions (Timotheou *et al.*, 2023). Many smart systems come with user-friendly interfaces that make it easy for researchers and technicians to interact with and control laboratory equipment remotely.

Recently there are several innovations in agricultural productions that evolved from Internet of Things (IoT), automation, laboratory analysis, and biotechnology (Awad *et al.*, 2022; Dhanaraju *et al.*, 2022; Rejeb *et al.*, 2022). Research findings from the laboratory have led to the development plants and animals with anticipated traits, and production of numerous high quality food items with improved shelf life. This has enhances the state of food security and reduces the occurrence of malnutrition (Pawlak and Kołodziejczak, 2020; Lenaerts *et al.*, 2019;

Rajeev *et al.*, 2022). Standard laboratories play a crucial role in supporting and advancing improved agricultural practices; thus their automation and application of IoT have become paramount interest (Dhanaraju *et al.*, 2022). IoT is a new engineering innovation which allows hardware to be remotely activated and deactivated across the internet, as it has the ability to collect, share, and act on data, creating a network of interconnected systems (Nižetić *et al.*, 2020; Ehsan *et al.*, 2022). The (IoT) is a complex structure which involves the interconnectivity of various components (software and hardware) to create a network of interconnected devices. According to Sisinni *et al.* (2018), IoT has a lot of influence in the educational, agricultural, industrial and medical sectors, as it plays a pivot role in monitoring and controlling essential parameters in the workshop, laboratories and production unit operations.

Several smart systems have been developed and evaluated by numerous researchers, and each system having its own assets and liabilities (Wenwen *et al.*, 2016; Ma *et al.*, 2017; Zhichuang, 2018; Li *et al.*, 2020; Zhou, 2022; Zhang and Zhou, 2023). The resources and liabilities of smart systems are dependent on the specific context, goals, and requirements of the intended application of the smart structure (Reisinger *et al.*, 2022). The major liabilities of smart structures are high initial costs of the smart equipment, and non-compatibility of the system with most obsolete apparatus and machines, though retrofitting package have been developed to boost the compatibility of older tools and machines with modern advance smart technologies (Pandiyan *et al.*, 2023). Through numerous smart technologies has been developed and evaluated (Shazali Dauda and Toro, 2020; Tun and Myint, 2020), research into the development of hybridized smart university laboratory system is still scanty, mostly in the area of security and safety. Therefore, the goal of this research is to develop a smart technology for a modern laboratory of a university that will effectively monitor the temperature, fire and poisonous gas level. The monitoring of these crucial parameters will enhance the overall functionality and safety of the laboratory environment.

MATERIALS and METHODS

This smart structure design focused mainly on the implementation of intelligent control system in a laboratory to enhance the learning capability, and guarantee the safety of the occupants of the building-human beings and materials. Fatemi *et al.* (2022) during their investigation into laboratories safety, identified fire incidence and gas poison as some of leading cases of health hazards in major laboratories and workshops.

The methodology adopted in this study was design of the smart system (with the goals clearly stated), testing and data collection, evaluation and monitoring systems. Remarkably, the system will provide alerts and warnings for any abnormal situations encountered (fire and excess CO), allowing for quick responses and interventions. Furthermore, the IoT unit will help to facilitating seamless communication between the system and administrator. Designing a system to ensure that critical parameters within the laboratory align with international safety

standards reflects a commitment to maintaining a healthy and secure environment in the workshop.

The system software

The Arduino Compiler (Integrated Development Environment-"IDE"), Blynk application for Android, and MATLAB were the software packages/platforms used for developing the system. The Arduino Compiler IDE is a powerful software platform that provides a user-friendly interface for programming Arduino microcontroller, and it is compatible with C++ programming language.

Blynk Application for Android enables the development of more flexible Internet of Things (IoT) applications. Blynk Application has a strong potential of creating a graphical user interface (GUI) for IoT structures on mobile device. The MATLAB software was used to complement the capabilities of the Arduino in this smart laboratory facility. Remarkably, since Arduino which is compatible with C++ programming language was selected as the microprocessor, the C++ programming language was chosen as the programming language of the smart system.

The system hardware

Microcontroller

An Arduino UNO R3 (model-ATmega328P) as shown in Figure 1 was used as microcontroller for the design of the smart facility. The Arduino UNO have these specifications: voltage rating-6 V to 20 V, direct current-20 mA, main processor clock speed-16 MHZ, Memory-2KB SRAM and 32KB FLASH-, and operating voltage of 5 V was used as microcontroller for the design of the smart facility.

Figure 1. *An Arduino microprocessor.*

MQ-2 Gas Sensor

The MQ2 gas sensor which is commonly used for detecting carbon (ii) oxide and smoke was used to monitor the CO and smoke level inside the laboratory. It has these specifications: operating voltage of 5 V DC, heating resistance of 33Ω, power consumption of 800mw, and the sensing resistance ranges from 10 kΩ to 60 kΩ. The MQ2 gas sensor can be classically connected to an Arduino microcontroller to read the sensor's output.

DHT11 sensor

The DHT11 sensor is basically used for Temperature and Humidity monitoring, and has a resolution of 1oC and 1% humidity. It has an operating current of 2.5 mA and operating voltage of 5 V DC.

Arduino Buzzer

A buzzer for Arduino was used for the design and development of the smart system. The buzzer has a maximum sound output level of approximately 88 decibel, and operating voltage that ranged from 3 V to 24 V.

Wi-Fi module

The wireless router supports 2.4 GHz Wi-Fi with a transmission rate of 300 Mbps. It 3 ports, with each port supporting network speeds of approximately 100 Mbps and, CPU frequency of 650 MHZ.

Relay module

Various types of relay modules were used to develop the system. Relay modules are specifically designed to control high-power output devices with lower-power rating microprocessor (Tjandi and Kasim, 2019). Their functions are to activate "switch ON" and deactivate "switch OFF" the control hardware, based on the instruction that it received from the microcontroller.

Smart system architecture

Figure 2 shows the block diagram of the smart laboratory, with the various entities of the prototype IoT based control system. The system architecture is a closed-loop system where the microcontroller interprets sensor(s) data, makes decisions based on programmed logic, and then controls the appropriate hardware device(s) in the laboratory.

The various sensors are deployed in the laboratory to collect data from the system, and transmit them to the central processing unit (Arduino UNO R3). Thereafter, the microprocessor process and interprets the raw data received from the sensors, and activates the relay modules and Wi-Fi module in accordance with the interpreted data. The Wi-Fi module helps to facilitates basic communication between the Arduino UNO and the internet, and communicates wirelessly with to the designated mobile phone or personal computer. Interestingly, the system architecture depicted that the Arduino board is responsible for hardware control and interfacing, the Blynk app provides a user-friendly interface on a mobile device, and MATLAB may contribute additional analytical or computational capabilities.

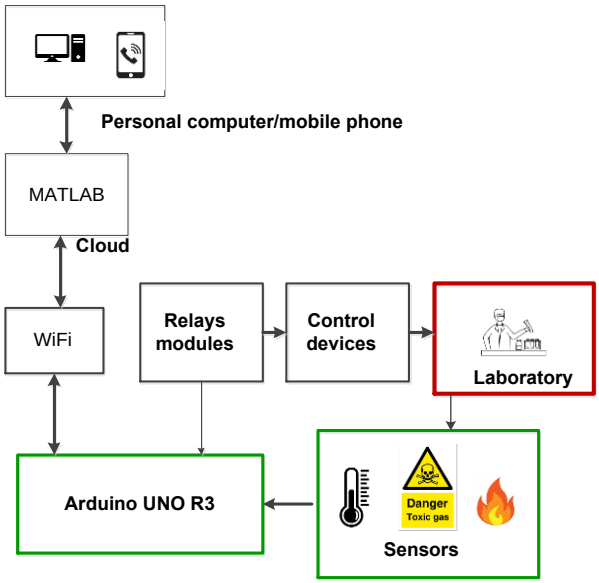

Figure 2. The system block diagram.

Hardware design

The schematic view of the smart system hardware layout is illustrated in Figure 3. In the development phase of the system, the DHT11 sensor was connected to one of the digital pins on the Arduino board. The DHT11 interacts with the microcontroller through this digital pin, where its reads the digital signals to determine the temperature and humidity values inside the smart facility, and transmits the results to the microcontroller (Arduino), to process and determine if to initiate the relay module controlling the air conditioning unit based on predefined temperature threshold. The temperature relay module, when activated, controls the air conditioning unit according to the temperature conditions detected by the DHT11 sensor.

Furthermore, the buzzer functions as the alarm system. The buzzer and relay modules were linked to a digital output pin on the Arduino. Once it received data, the microcontroller sends a signal to the relay module by setting the digital pin to "HIGH" or "LOW", which will translates if to activate or deactivate the appropriate hardware device after due interpretation of the signal. The hardware device relay module activates were air conditioning unit, fire extinguisher and exhaust fan for the temperate, fire and high CO presence signals, respectively. By combining these elements, the smart technology for the laboratory can create a dynamic, efficient, and secure learning environment for students while preparing them for the technological advancements in their studies.

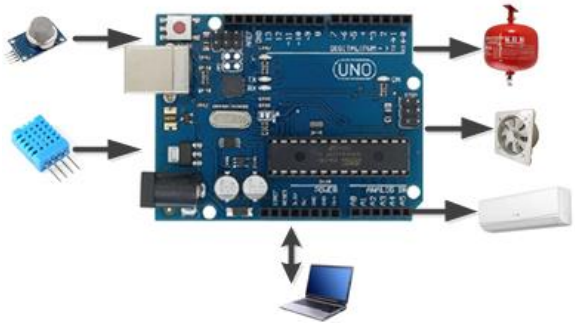

Figure 3. Diagram of the smart structure.

Targeted monitored parameters inside the laboratory

Temperature control

The system is designed to activate the air conditioning unit when the temperature rose above a specified threshold of 25°C, and deactivate the AC unit when the temperature falls below a specified threshold of 18°C. This is to maintain a comfortable and safe working environment. Figure 4 shows the flowchart of the temperature management inside the laboratory. Figure 4 depicted that the air conditioning unit will switched "ON" by a temperature relay module when the internal temperature exceeded the maximum predetermined level of 25°C; similarly, the flow chart revealed that the air conditioner will be switch "OFF" by the temperature relay module when the interior temperature of the laboratory falls below the minimum pre-set level of 18°C. Furthermore, the internet system will send alerts via email or SMS notifications to a selected administrator, indicating the interior temperature condition of the room.

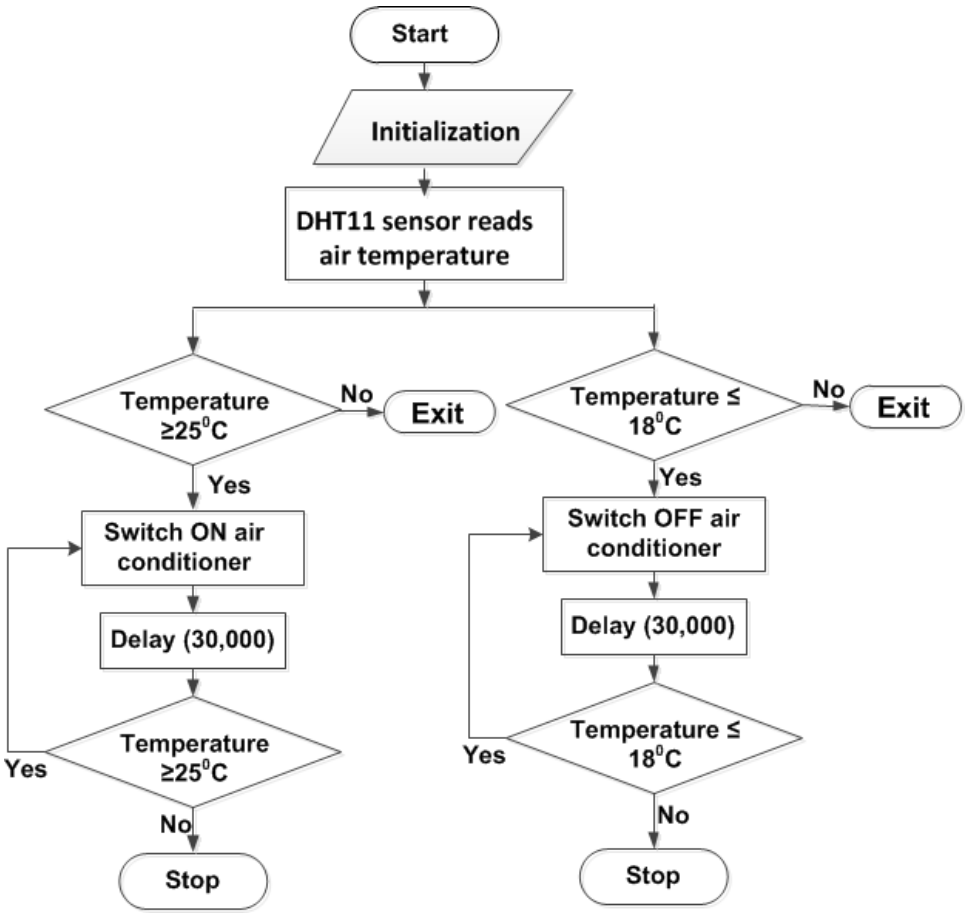

Figure 4. The temperature control flowchart.

Carbon (ii) oxide control

The CO concentration in the laboratory was constantly monitored to protect the lives of the students and other workers inside the structure. The flowchart in Figure 5 turns the exhaust fan "ON" when the CO level inside the laboratory exceeded the World Health Organization (WHO) maximum limit of 4 parts per million (ppm), the CO relay module switches its state, enabling power to flow to the exhaust fan. Furthermore, the flowchart will send a signal to the targeted administrator if the

high CO accumulation problem exceeded 10 minutes after the force ventilation. This is a common safety measure to ensure that the air quality in the laboratory remains within acceptable limits. The alert system will assist in promptly notifying responsible personnel, enabling them to investigate and address any potential issues contributing to prolonged high CO levels.

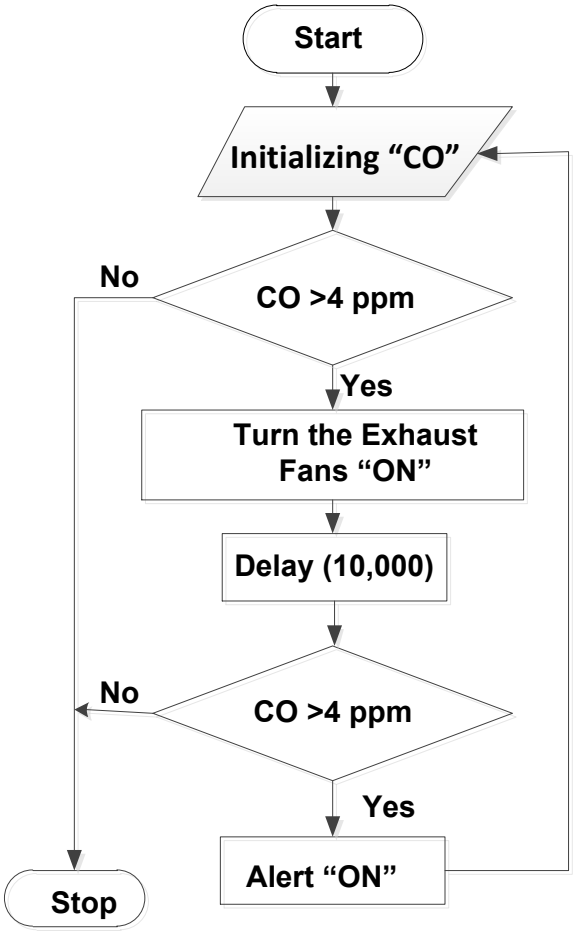

Figure 5. *The CO monitoring unit flowchart.*

Fire control

Fire control is a pivot factor of safety in any laboratory or workshop. As shown in Figure 6, the flowchart activates the alarm system once smoke or naked flame is detected inside the building. Additionally, there is an IoT (Internet of Things) component calibrated to notify the administrator instantly, and if the issue persists after a set delay period of 10 minutes, the fire extinguisher unit is activated through the aid of the fire relay module. This will initiates the release of fire suppressant agents into the enclosed environment. This is a crucial step in attempting to control or extinguish the fire before it can spread further.

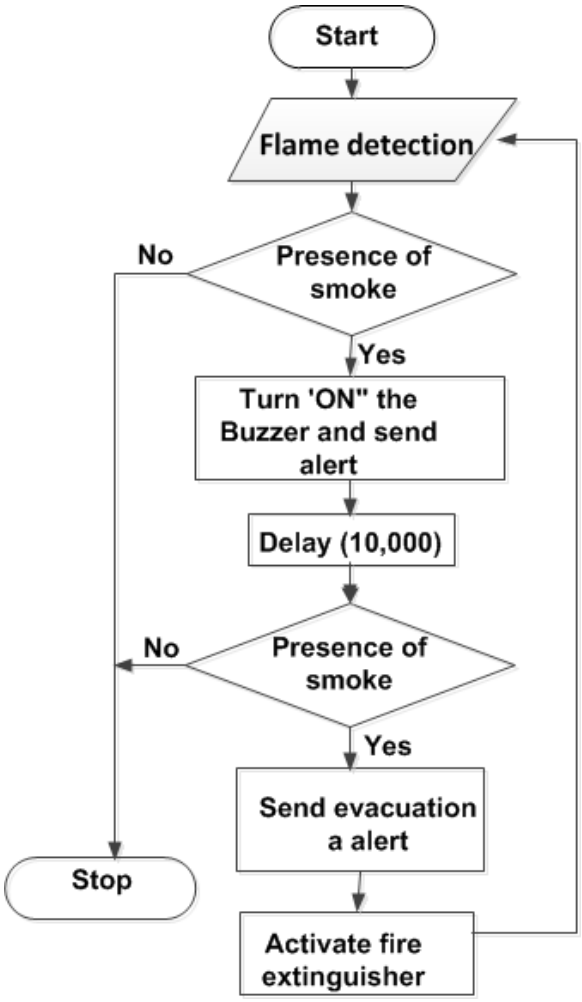

Figure 6. The fire control flowchart.

Testing of the system

The laboratory was tested for duration of 15 hours, during which the temperature, smoke and gas level inside the laboratory open space randomly varied through the aids of coal stove and electric heater. Incomplete combustion of coal produce carbon (ii) oxide (National Cancer Institute, 2022), which is the targeted poisonous gas designed for in this study. The internal temperature of the laboratory was preset a temperature ranged of 18°C to 25°C.

The Wi-Fi module was responsible for connecting all the activities within the workroom to a cloud server, and the cloud server then relays this information to a designated administrator. Additionally, the buzzer helps in providing the necessary sound signal to alert the occupant of the building of the impeding danger. According to Tun and Myint (2020) and Ehsan *et al.* (2022), buzzer, an essential component of the IoT-based safety system (Arduino alarm system), provides audible alerts to notify a building occupants about potential environmental disasters. Similarly, the cloud server incorporated into this system acts as an intermediary and a central hub for processing and storing the data (Tariq *et al.*, 2023).

The performance of each hardware device in the smart structure, and the overall performance of the structure were calculated through expressions shown Equations 1 and 2.

$$P = \frac{T_0}{T_o + F_o} \times 100 \quad (1)$$

$$\sum P = \frac{P_1 + P_2 + P_3}{3} \quad (2)$$

Where: T_o = True outcomes,
F_o= False outcomes,
P_1= Performance of the temperature regulation unit
P_2= Performance of the fire control unit
P_3= Performance of the CO monitoring unit.

RESULTS AND DISCUSSION

The results of the testing of smart facility are presented in Figures 7, 8 and 9. The findings of the study revealed that the temperature, fire and CO monitoring units exhibited a commendable efficiency 87%, 93% and 93% respectively. These findings depicted that temperature control unit recorded the poorest (lowest) performance, while the fire and CO control units had the highest performance results. This reflects the system's robust performance in detecting smoke/fire and carbon monoxide levels, and fairly good performance in regulating the room temperature. The fire protection results obtained in this study are in conformity with those previously recorded by Ehsan *et al.* (2022). The poor results recorded for the temperature monitoring unit could be attributed to poor delay setting (timing) and communication gap between the temperature monitoring unit and other components of the system (Fang *et al.*, 2021).

Early fire and poisonous gases detection and containment are critical for the safety of the occupants of any structure, as it allows timely evacuation of human beings and reducing the risk of injury or loss of life (Firesafety, 2023). These goals were achieved by this system, as fire and CO detection recorded 93% success rate. Additionally, it was noted that the total performance efficiency of the smart scheme was 91%. Similar results were reported by Li *et al.* (2020) where they used ZigBee and RFID technologies to monitor the performance of some instruments and equipment in a smart laboratory. In the work of Poongothai *et al.* (2018), they developed a smart system using an Internet of Things (IoT) and mobile application technologies to control the environmental condition and energy consumption in a laboratory.

This study finding highlights the positive synergies between different control subunits and how their collective performance contributes immensely to the overall success of the smart system. Damaševičius *et al.* (2023) stated that applying a robust smart system helps significantly in timely addressing of any anomalies; therefore, ensuring the overall safety of human beings and the environment. The failures (9%) observed during the testing of the scheme could be attributed to system of program errors, and partial compatibility of the software with the hardware, probably caused by coding issues and algorithmic shortcomings. These problems can be reduced through thorough examinations and optimization of the sensors and algorithms used

in the software system. According to Ruskin *et al.* (2021), modifying the delay rate and sensors in a smart system is crucial for balancing responsiveness and avoiding false results.

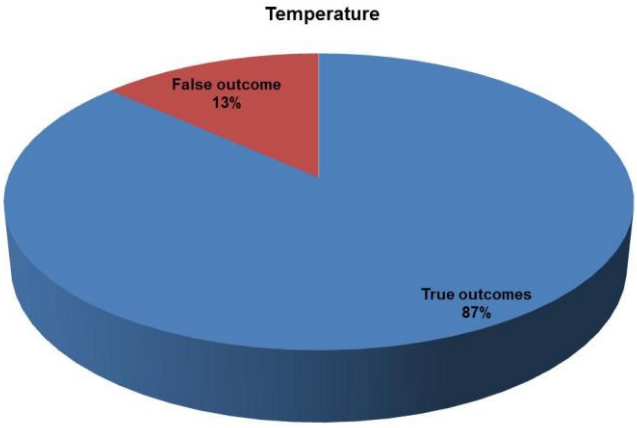

Figure 7. *The result of the temperature monitoring unit.*

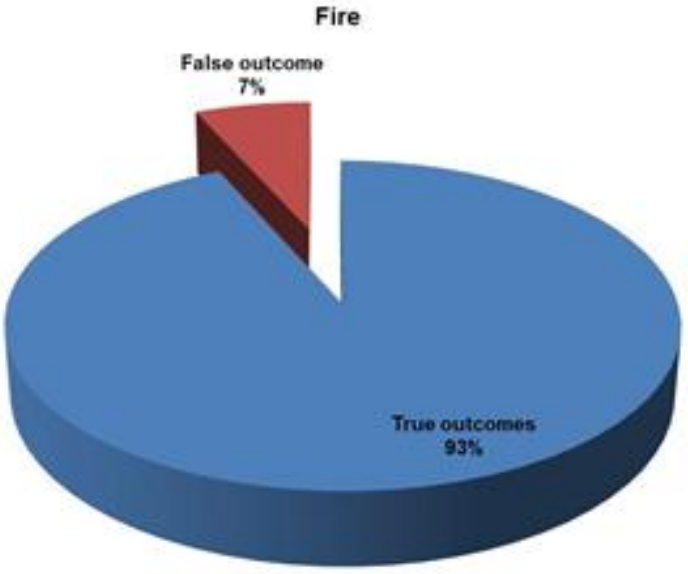

Figure 8. *The performance of the fire control unit.*

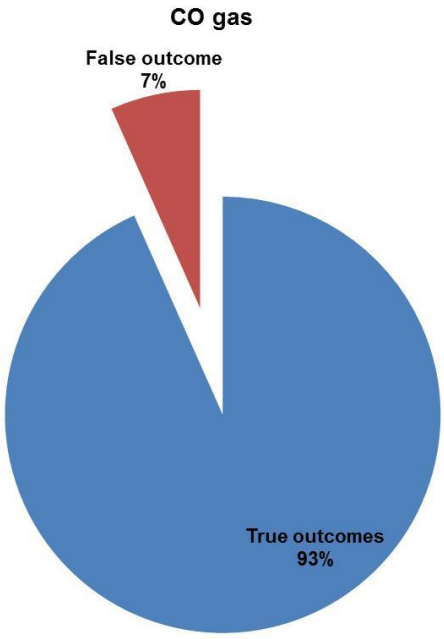

Figure 9. *Performance rating of the CO monitoring unit.*

The overall performance of the smart system = $\frac{87+93+93}{3}$
= 91%

CONCLUSION

The study focused on developing a smart system that can monitor and control the temperature, poisonous gas (carbon monoxide - CO) level, and fire incidence inside a laboratory environment. These three parameters were designed to ensure a comfortable and operational environment for individuals working inside the laboratory. The fire detection and control unit was designed for effective fire extinguishing and evacuation of individuals and materials from the laboratory in case of fire incidence. Similarly, the system was programmed to maintain the laboratory temperature within the range of 18°C to 25°C. Simultaneously, the system will ensure that the CO level inside the laboratory is maintained below 4 ppm. Following the device's construction, the system underwent successful testing. Results obtained from the system testing revealed that: the fire detection and control unit successfully suppressed instances of fire within the laboratory, the temperature control unit successfully kept the room temperature within the desired comfort range, and the CO monitoring unit effectively prevented the buildup of the toxic gas within the laboratory environment. Summarily, the smart system indicated a 91% operational efficiency, earning it a performance rating that is generally considered above average.

Considering the system's reliability and robustness in various scenarios, an automated monitoring system was developed by integrating three sensors, a microcontroller, and relay modules. This system responds to specific conditions inside the laboratory, contributing to both comfort and energy efficiency. Utilizing of advanced sensors and careful adjustment of delay rates can indeed be effective strategies for addressing and reducing the shortcomings (9% failure rate) identified in the system. Regular maintenance, testing and documentation are essential tools

in ensuring the reliability and effectiveness of the smart structure. Additionally, information obtained from this study will contribute to the advancement of smart agricultural production structures; thereby, improving food productivity and strengthening the prospects of achieving adequate food security.

DECLARATION OF COMPETING INTEREST

The authors declare that they have no conflict of interest.

CREDIT AUTHORSHIP CONTRIBUTION STATEMENT

The authors declared that the following contributions are correct.
Friday Elohor Odoh: Designed the research Methodology and writing of the original draft.
Ogaga Akpomedaye: Edited the manuscript.
Ovuakporaye Godwin Ekruyota: Data analysis and review of the original draft.

ETHICS COMMITTEE DECISION

This article does not require any ethical committee decision.

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Turkish Journal of Agricultural Engineering Research

Turk J Agr Eng Res
(TURKAGER)

https://dergipark.org.tr/en/pub/turkager
https://doi.org/10.46592/turkager.1392828

ISSN: 2717-8420
2023, 4(2), 278-288

Research Article

Influence of Treatments on the Mechanical Properties of Epoxy Resin Hybrid Composites Reinforced with Pineapple Fiber and Snail Shell Particulates

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Article Info
Received: 18.11.2023 **Accepted:** 20.12.2023 **Published:** 31.12.2023

ABSTRACT

The growing environmental concern regarding synthetic materials in various engineering applications is driving increased research into the production of green composites. In this study, pineapple leaf fiber (PLF) and snail shell powder amended with sodium hydroxide (NaOH) solution, at concentration levels of 0, 2, 4, 6 and 8% for 30, 60 and 90 minutes, respectively, were used to produce various composite samples; and their mechanical properties tested in agreement with American Society for Testing and Materials (ASTM) International approved procedures. The laboratory test results revealed that both the NaOH concentration and treatment period considerably influenced the tensile and flexural strengths of the composite samples. It was observed that the composite samples, made with reinforcement materials modified with NaOH concentrations of 0%, 2%, 4%, 6%, and 8% for durations of 30, 60, and 90 minutes, exhibited tensile strengths of 8.12, 9.88, 11.04, 14.11, and 16.74 MPa; 10.93, 14.22, 17.04, and 15.71 MPa; and 12.27, 15.19, 14.06, and 13.84 MPa, respectively. Similarly, the results portrayed that the composite samples produced with reinforcement materials treated with 2%, 4%, 6% and 8% sodium hydroxide concentrations for durations of 30, 60 and 90 minutes, developed flexural strength of 31.98, 38.82, 43.97 and 49.03 MPa; 36.55, 44.17, 53.38 and 47.93 MPa; and 39.62, 46.08, 48.17 and 43.66 MPa, respectively. It was also interesting to observe that 6% NaOH treatment for 60 minutes yields the optimum tensile and bending strengths of 17.04 and 53.38 MPa respectively. This finding revealed the potential of using bio-composites for engineering applications, mostly where moderate tensile and flexural strengths characteristics are sought after.

Keywords: *Biodegradability, Composites, Hybridization, Organic materials, Strength optimization*

To cite: Akpenyi-Aboh ON, Akwenuke MO, Edafiadhe ED (2023). Influence of Treatments on the Mechanical Properties of Epoxy Resin Hybrid Composites Reinforced with Pineapple Fiber and Snail Shell Particulates. *Turkish Journal of Agricultural Engineering Research (TURKAGER), 4(2): 278-288.* https://doi.org/10.46592/turkager.1392828

INTRODUCTION

There is a growing recognition of the environmental impact of traditional inorganic materials, especially those derived from petroleum sources. The production and disposal of these synthetic (inorganic) materials contribute significantly to pollution, resource depletion, and climate change. David and Niculescu (2021) reported that the production of synthetic materials often leads to the emission of harmful pollutants, including volatile organic compounds into the environment. Similarly, Rádis-Baptista (2023) expresses great concern about using synthetic materials in making household items, as most of these materials contain toxic chemicals that adversely affect human beings. Neurotoxicity and other hypersensitive reactions which can results in the downregulation of gene expression in human beings are some of the negative health effects of synthetic compounds (Pinkas *et al.*, 2017). The toxicity of harmful compounds depends on the duration, volume and concentration of exposure (Uguru *et al.*, 2022). Therefore, there is a global push toward developing and adopting sustainable organic alternatives for the producing and utilizing materials for both domestic and industrial applications.

Intensive research into plant-based organic materials, known for their renewability, biodegradability, and lower environmental impact, is underway for the production of composites in diverse engineering applications (Liu *et al.*, 2017; Asim *et al.*, 2018). Composites manufactured from natural fibers and fillers are being rigorously researched as substantial alternatives to synthetic composite reinforcement materials. Bio-based composites are gaining industrial attention, as these materials are widely used in a variety of industrial applications (Sivakumar *et al.*, 2017; Asim *et al.*, 2018; Edafiadhe *et al.*, 2019; Obukoeroro and Uguru, 2021; Cionita *et al.*, 2022). One of the significant advantages of natural materials is their biodegradable nature; which contrasts with synthetic materials, as they persist in the environment for much longer durations. Natural materials used for composites production-particulates, fibers and resin-offer numerous advantages such as renewability, low environmental impact, energy efficiency, local availability and biodegradability, compared to synthetic materials hence, making them sustainable composite for numerous applications in the industries (Koronis *et al.*, 2013; Fiore *et al.*, 2015; Edafeadhe *et al.*, 2020).

The design and production of green composite with natural fillers, fibers or hybridization of both primary materials to produce highly efficient engineering materials have garnered significant attention from numerous researchers (Usman *et al.*, 2016; Adeyanju *et al.*, 2017; Tepsila and Suksri, 2018; Obukoeroro and Uguru, 2021). The interfacial adhesion between organic reinforcement materials and the matrices is essential in determining the overall mechanical properties, of natural fiber-reinforced composite produced. A strong

interfacial adhesion correlation between the fibers/fillers and matrix help to improve the tensile strength of the composite, due to the effective transfer of tensile loads from the filler to the matrix. (Edafiadhe *et al.*, 2019). A strong interface between the reinforcement and matrix also encourages the primary elements (fibers and matrix) to work together, resulting in the composite absorbing more tensile and flexural forces/energies. This will lead to a more gradual failure rate of the composite and prevent sudden and catastrophic failure during field applications (Edafeadhe *et al.*, 2020).

Some inherent components-hemicelluloses, cellulose, pectin, lignin, waxes and water-soluble substances-of natural materials tend to limit their utilization level in the composite industry, as they cause strength reduction in the composite produced (Ahmad *et al.*, 2019; Hamidon *et al.*, 2019). These limitations caused high hydrophilic behavior and smooth surface topography. The poor surface roughness of most natural fibers and particulates tends to hinder the mechanical interlocking between the fibers/fillers and the matrix; therefore leading to a decline in the overall mechanical strength and performance of the composite (Abiola, 2017; Ekwueme *et al.*, 2019). An adequate understanding of overcoming these limitations is essential for producing composite materials with better engineering properties. Some solutions to the problems associated with poor bonding of natural fibers are: surface/mechanical treatment, chemical modifications, and applying hydrophobic agents to the composite during production.

The engineering properties of agricultural materials depend on the crop variety, cropping system, processing and storage methods. Different crop varieties have distinct physical and mechanical behaviors that affect the engineering properties of any material produced from them, mainly in the construction industry. Additionally, improper drying, seasoning and other processing techniques can result in severe issues related to mechanical defects-cracks, brittleness or lowered strength-of the agricultural material (Ijabo *et al.*, 2019; Nwanze and Uguru, 2020). Several chemicals are being used to modify the engineering properties of organic materials and improve the mechanical attributes (Owen *et al.*, 2018; Baarimah *et al.*, 2021; Mohd Ghaztar *et al.*, 2022). These amendments are frequently embarked upon to improve the bio-materials engineering characteristics-strength, durability, flame resistance, and dimensional stability. A major goal achieved through alkaline treatment/modification of agricultural materials is the alteration in their hydrogen bonding structure. Hydrogen bonding plays an essential part in the structure and properties of materials; therefore, its alteration can increase the roughness of the material's effective surface area, and enhance its mechanical properties in the process (Mohanty *et al.*, 2000; Ray *et al.*, 2001; Farahani *et al.*, 2012).

Recently, there have been several researches on the production of hybridized pineapple leaf fibre PLF and other organic fillers to produce a sustainable material (Siregar *et al.*, 2010; Tepsila and Suksri, 2018; Nnodu *et al.*, 2020). Findings from related literature search revealed very little information on the production of high quality composite from the hybridization of alkaline modified pineapple leaf fiber and snail shell fillers (Igwe, 2007; Onuegbu and Igwe, 2011). Therefore, the aim of this research was to achieve an optimum alkaline (sodium hydroxide) treatment for snail shell fibers and pineapple leaf fiber, and its effect on the mechanical properties of the bio-composite produced.

MATERIALS and METHODS

Materials

The epoxy resin (LY556), hardener (HY951) and sodium hydroxide used for this study were all purchased from a chemical shop at Onitsha, Anambra State of Nigeria. Likewise, the pulverized snail shell and pineapple fibers were obtained from the farm structure and materials laboratory of the Delta State University of Science and Technology, Ozoro, Nigeria.

Methods

Preparation of the snail shell

The milled snail shells were sized with a 150 mm sieve to obtain fine snail shell particulate.

Alkali modification of the organic materials

The snail shell fillers and pineapple leaf fiber (PALF) were treated with sodium hydroxide (NaOH) with varying concentrations of 0%, 2%, 4%, 6% and 8%, for 30, 60 and 90 minutes at ambient room temperature (29±2°C). The NaOH concentration was expressed in w/v%.

This wide range of chemical concentrations was adopted in order to optimize the treatment conditions, therefore achieving the best desired behaviors of the natural reinforcement materials. Reaction duration and temperature conditions are vital factors that influence the chemical reactions, suitability and compatibility of the product produced.

Composite samples mix ratio design

The non-metallic matrix used for the composite production was prepared by mixing the epoxy resin and hardener in a ratio of 8:2. Then the green composite was prepared by reinforcing 80 wt% of the epoxy matrix with 15 wt% PLF and 5 wt % snail shell fillers. In summary, the bio-composite was prepared by mixing the matrix and reinforcement materials at a ratio of 80:15:5. The entire weight percentage was calculated based on the weight of the matrix. For easy identification of the samples, the sample codes are presented in Table 1.

Table 1. Treatment codes.

Sample code	Treatment concentration	Treatment duration
Control	0%	0 minutes
S1	2%	30 minutes
S2	4%	30 minutes
S3	6%	30minutes
S4	8%	30 minutes
W1	2%	60 minutes
W2	4%	60 minutes
W3	6%	60 minutes
W4	8%	60 minutes
T1	2%	90 minutes
T2	4%	90 minutes
T3	6%	90 minutes
T4	8%	90 minutes

Composite preparation

The hand lay-up method was used to fabricate the composite material, using the ASTM International approved mold size of 200×150×5 mm^3. Adopting the ASTM standards will ensure that the composite is in accordance with internationally established procedures and dimensions.

During the production, the filler (snail shell particulates) was mixed thoroughly with the resin for 20 minutes to obtain a near consistent mixture. After that, the hardener was added to the mixture and stirred vigorously and carefully for 5 minutes, before it was poured into the already prepared (oiled) mold. But before the mixture of the matrix and filler was poured into the mold, the required amount of the PLF was manually placed into the already prepared mold, as described by Edafeadhe *et al.* (2020).

Each composite sample was subjected to a dead load of 10 kg at ambient environmental conditions (temperature 30±5°C, 80±5% relative humidity) for 24 hours to expel any entrapped air from it, before it was demolded and taken to the material laboratory for mechanical properties analysis. Expelling air from the materials (reducing the porosity) helps to produce a composite with better consolidation, leading to materials with improved mechanical properties (Edafiadhe *et al.*, 2019).

Mechanical properties

Tensile strength test

The tensile strength test of the composite was conducted with the Universal Testing Machine (UTM) with 1000 kg loading capacity (Testometric model, series 500-532), in harmony with the ASTM D3039/D3039M (2008) procedures. The sample was tensile by the machine at 1 mm/min speed until rupture occurred (as shown in Figure 1), as explained by Edafeadhe *et al.* (2020). At the end of each testing, the tensile strength of each sample was calculated through Equation 1.

$$Tensile\ strength, \sigma = \frac{Force_{Max}}{Area} \quad (1)$$

Figure 1. *A composite sample undergoing tensile strength test.*

Flexural strength test

The flexural strength test of the samples was performed using the UTM in accordance with ASTM D790 (2017) guidelines, and employing the 3-points bending fixture method. At the end of the test, the flexural/bending strength was calculated using the expression shown in Equation 2.

$$Bending\ Strength, \sigma = \frac{3FL}{2bd^2} \quad (2)$$

Where; F= load (force) at the fracture point (N), L= length of the support span, b= sample width, and d= sample thickness.

Statistical Analysis

The results obtained from this work were thoroughly analyzed through the use of appropriate charts with the aid of MS-Excel for Windows. All the tests were carried out in four replicates, and the mean value was recorded for the plotting of the charts.

RESULTS AND DISCUSSION

Tensile strength

The plot presented in Figure 2 shows the tensile strength of all the composite samples prepared in this research. The results revealed that the composite samples prepared with 0%, 2%, 4%, 6% and 8% reinforcement materials treated for 30 minutes, developed tensile strength of 8.12, 9.88, 11.04, 14.11 and 16.74 MPa respectively. Also, the composite made with reinforcement materials treated with the various NaOH concentrations for 60 minutes (1 hour) had tensile strengths of 10.93, 14.22, 17.04 and 15.71 MPa, respectively. Furthermore, the findings indicated that composite samples, created from green materials modified with four different NaOH concentration levels (2%, 4%, 6% and 8%) for 90 minutes, exhibited tensile strengths

of 12.27, 15.19, 14.06, and 13.84 MPa, respectively. These findings clearly showed that the composite tensile strength increased unevenly with increasing NaOH concentration used to modify the fillers and fibers, and the duration of treatment. Among the treatment options, the composite produced with organic materials treated with 4% NaOH for one hour showed the maximum tensile strength (17.04 MPa).

These results comply with the findings of Siregar *et al.* (2010), when the tensile strength of polystyrene composite strengthened with pineapple leaf fiber increased from 22.64 to 29.95 MPa, as the NaOH treatment concentration increased from 0 to 4%. Furthermore, the results of this study are similar to those reported by Wijianto *et al.* (2019) and Meon *et al.* (2012). In Wijianto *et al.* (2019) investigation into the alkaline modification of organic fibers, they noted that the optimal tensile strength was recorded in 5% NaOH treatment for 60 minutes. Similarly, Meon *et al.* (2012) reported that 6% NaOH treatment of kenaf fibers for 24 hours gave the optimum mechanical properties values. The superior tensile strength observed in alkaline-treated organic materials can be linked to the improved adhesive characteristics of the materials surface (Mohanty *et al.*, 2000). Alkaline treatment often removes impurities from the materials. It modifies the surface of the materials hence, improving the adhesion capacity and compatibility of the bio-materials with matrices during composite production. This will increase the mechanical properties of the composite produced in most cases (Meon *et al.*, 2012).

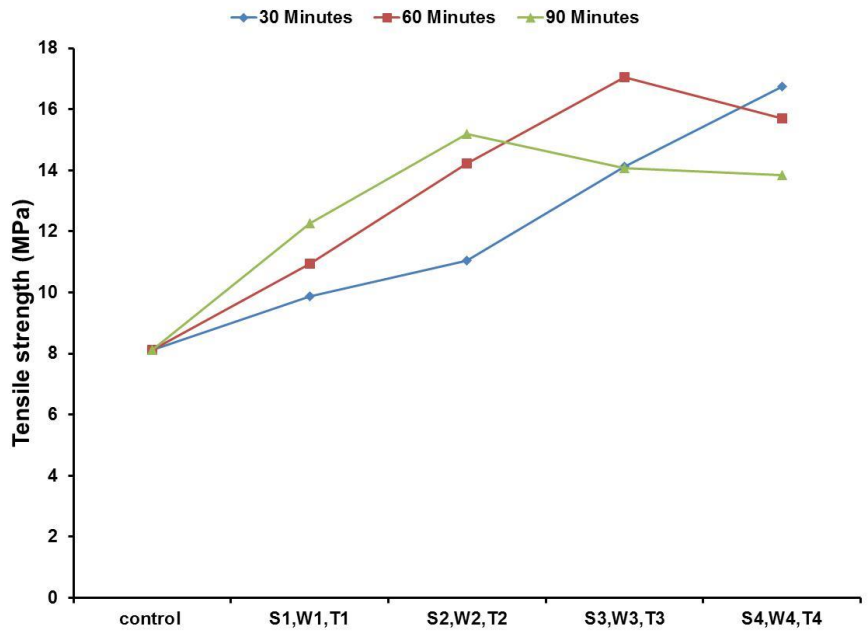

Figure 2. *The tensile strength of the composite materials.*

Flexural strength

The results of the flexural strength of the composite samples are presented in Figure 3. It was revealed that the composites, made with reinforcement items treated with 2%, 4%, 6% and 8% sodium hydroxide concentrations for 30, 60 and 90 minutes, developed flexural strength of 31.98, 38.82, 43.97 and 49.03 MPa; 36.55, 44.17, 53.38 and 47.93 MPa; and 39.62, 46.08, 48.17 and 43.66 MPa, respectively. Similar to what was obtained under the tensile strength, the flexural strength of the composites was highly influenced by the treatment concentration and duration. It is also interesting

to highlight those 60 minutes treatment duration yields the optimum flexural strength, irrespective of the alkaline concentration level. The impact of treatment options on the flexural strength of the materials obtained in this work is similar to those obtained by Siregar *et al.* (2010), where the bending strength of PLF-fortified polystyrene composite increased from 31.66 to 40.79 MPa as the alkali concentration increased from 0 to 4%. Similarly, Cao *et al.* (2006) reported flexural strength and modulus of biodegradable composite tend to increase non-linearly after chemical treatment of the bio-fibers, which they accredited to the deletion of impurities from the surfaces of the fibers, leading to the creation of higher bonding strength.

The findings of this study emphasize the importance of treatment options (concentration and duration) in optimizing the tensile and flexural parameters of composite materials. Mukhlis *et al.* (2021) in their research into the mechanical properties of natural fibers reinforced composite observed that treatment duration had noteworthy impacts on the mechanical properties of all composite specimens produced. Remarkably, these results revealed that concentration and treatment time influenced the composite materials' mechanical parameters. Therefore, by carefully manipulating the treatment concentration and duration, composite materials with enhanced mechanical properties can be produced. Exposure of bio-materials to extreme alkaline or acid environment could lead to more aggressive chemical reactions with the fibers or fillers. This might weaken the strength of the fibers/fillers; lowering the composite's mechanical properties. Zin *et al.* (2018) stated that exposure of organic fibers to high alkali concentrations cause extreme delignification and deterioration of the fiber, reducing its strength properties.

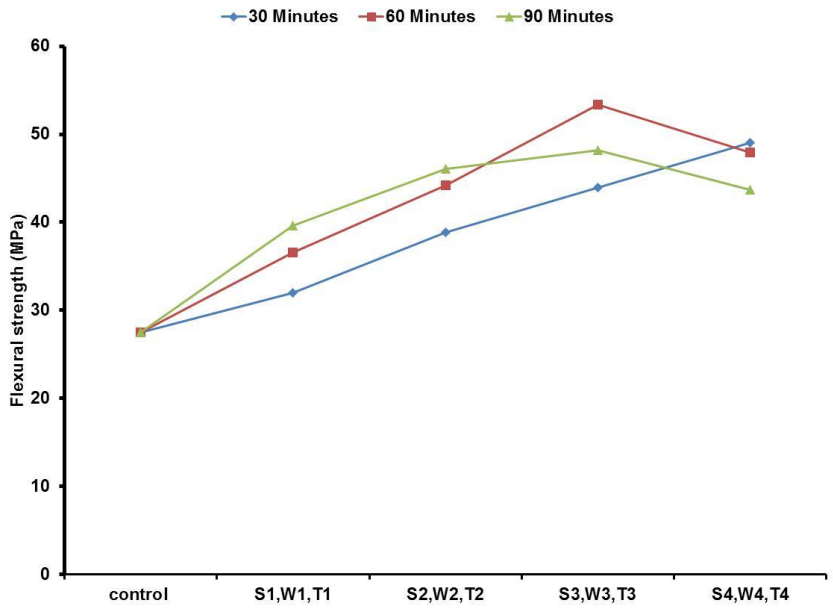

Figure 3. *The composite samples flexural strength.*

CONCLUSION

There is an increase in use of bio-composite, as light-weight biodegradable material for industrial and domestic applications. This research was conducted to optimize

the strength behavior of green composite, through chemical modification of the organic fillers and fibers. The pineapple leaf fiber and snail shell fillers underwent treatment with sodium hydroxide (NaOH) at concentrations of 0, 2, 4, 6, and 8%, each for durations of 30, 60, and 90 minutes. In each treatment scenario, a green composite was formulated by reinforcing 80 wt% of the epoxy matrix with 15 wt% pineapple leaf fiber (PLF) and 5 wt% snail shell fillers. The mechanical and strength behaviors of these composites were subsequently assessed in accordance with ASTM guidelines. Results of the mechanical test depicted that the treatment concentration and duration, significantly affected mechanical parameters of the composite samples. The ductile and bending behaviors of the prepared composite increased non-linearly at the alkaline concentration, and the treatment period increased linearly. This study's findings indicated that 6% NaOH treatment for one hour duration was the optimum condition to achieve the maximum tensile and flexural strengths of 17.04 and 53.38 MPa, respectively. High alkali concentration and treatment duration tends to weaken the strength of the fibers/fillers; hence lowering the strength properties of the composite produced. This study's findings revealed the potential of using alkaline-modified bio-composites for engineering applications, where moderate tensile and flexural strength characteristics are desirable.

DECLARATION OF COMPETING INTEREST

The authors declare that they have no conflict of interest

CREDIT AUTHORSHIP CONTRIBUTION STATEMENT

The authors declared that the following contributions are correct.
Onyekachukwu Nicklette Akpenyi-Aboh: Designed the research Methodology and writing of the original draft.
Moses Akwenuke: Edited the manuscript.
Donatus Edafiadhe: Designed the research and writing the original draft.

ETHICS COMMITTEE DECISION

This article does not require any ethical committee decision.

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Turk J Agr Eng Res *(TURKAGER)*

https://dergipark.org.tr/en/pub/turkager
https://doi.org/10.46592/turkager.1384004

ISSN: 2717-8420
2023, 4(2), 289-300

Research Article

Evaluating the Effects of Drying Temperatures on the Nutritional and Bioactive Quality of Ackee Aril Apples

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Article Info

Received: 01.11.2023 **Accepted:** 22.12.2023 **Published:** 31.12.2023

ABSTRACT

This study examines the effects of varying drying temperatures on the bioactive and nutritional characteristics of ackee aril apples (Blighia sapida), The study showed how drying temperatures affect ackee aril apples' nutritional and bioactive qualities, emphasizing the fruit's potential as a useful dietary ingredient with both financial and health advantages. The harvested fresh ackee aril apples were cleaned, dried in an oven at different temperatures (40°C, 50°C, 60°C, 65°C, and 70°C), and then dried under the sun. Proximate techniques to examined nutritional qualities such as moisture, fat, protein, ash, fiber, and carbohydrate content. Vitamin C, flavonoid content, and total phenolic content were among the ascertained bioactive quality characteristics. The lowest moisture content of 2.997% was reached at 70°C which is safer for storage. Higher drying temperatures resulted in a lower moisture content and a faster reduction in moisture. Significant differences in nutritional components were found during drying, including a rise in crude fiber and protein content and a decrease in ash content. To evaluate the energy potential, metabolic energy was computed as the drying temperature rose and the amount of carbohydrates increased. Dried ackee aril apples may have potential as a nutraceutical because bioactive quality parameters like flavonoids, total phenolic content, and vitamin C rise with drying temperature. The findings highlight the value of drying as a preservation method to increase this perishable fruit's shelf life.

Keywords: *Ackee aril, Drying temperature, Nutritional quality, Bioactive properties, Drying, Perishable fruit.*

To cite: Olabinjo OO and Sama MO (2023). Evaluating the Effects of Drying Temperatures on the Nutritional and Bioactive Quality of Ackee Aril Apples. *Turkish Journal of Agricultural Engineering Research (TURKAGER), 4(2): 289-300. https://doi.org/10.46592/turkager.1384004*

INTRODUCTION

Crops can be classified into food and cash crops, with the latter serving both commercial and consumption purposes (Sawicka, 2019). Agriculture is vital to Nigeria's economy, with over 70% of the country's extensive land suitable for cultivation (Maxwell, 2018). While Nigeria has a growing population, agriculture's contribution to GDP has decreased over the years due to various factors, leading to food insecurity (Ekué *et al.*, 2010; Otaha, 2013; Dossou *et al.*, 2014a). Diversifying food sources, such as conserving indigenous crops like ackee, is crucial for addressing this challenge.

Ackee aril apples, a West African tree crop and Jamaica's national fruit hold immense economic and nutritional potential. The ackee tree belongs to the *Sapindaceae* family and thrives in well-drained soil (Sanford *et al.*, 2018; Kakpo *et al.*, 2020). It produces small, hermaphroditic flowers during warm months and can reach heights of 7-25 m. The fruit changes color as it ripens and splits into three sections, revealing the arillus/aril, a creamy fleshy part with a nutty flavor. Aril is a versatile food that can be eaten raw, dry, fried, roasted, or blended into a sauce. However, caution is advised as the raphe (Figure 1), a thin lining membrane, should be removed before consumption due to its hypoglycin A content (Anupama and Sunilkumar, 2019).

The ackee fruit contains two amino acid components responsible for the toxic hypoglycaemic syndrome, also known as Jamaican vomiting sickness (Kakpo *et al.*, 2020). They are called hypoglycin A and B, and according to Sanford *et al.* (2018), hypoglycin A is more water soluble and hazardous than hypoglycin B. Symptoms of toxicity, including nausea, vomiting, and hypoglycemia, occur within 6-48 hours of ingestion, which can be fatal, particularly in young children (Aubry, 2012; Kakpo *et al.*, 2020). Early administration of sugar and glucose is recommended to relieve symptoms. The cooking of the arils of unripe ackee fruit does not reduce toxicity, but cooking ripe arils eliminates toxicity by leaching hypoglycin A (Emanuel and Benkeblia, 2011). Research has shown that hypoglycin A transfers from the arils to the seeds as the fruit matures, reducing its toxicity to about one-tenth of the original level. Additionally, when the pods of the fruit open at full maturity, sunlight dispels toxicity (Emanuel and Benkeblia, 2011).

Drying is a crucial preservation method to extend the shelf life of food goods. To determine the effects of varying drying temperatures on ackee aril apples' nutritional value and bioactive characteristics, we concentrated on Ackee aril apples (*Blighia sapida*). Canned ackee arils have generated significant revenue in Jamaica, highlighting the economic potential of this fruit (Emanuel and Benkeblia, 2011; JIS, 2018). Nevertheless, the ackee's status as a highly perishable seasonal fruit in its land of origin presents a challenge. This study specifically focuses on how drying affects the nutritional quality of the ackee aril apple, excluding other parts of the ackee fruit. The study involves sun drying and oven drying at varying temperatures (40°C, 50°C, 60°C, 65°C, and 70°C) to enhance preservation.

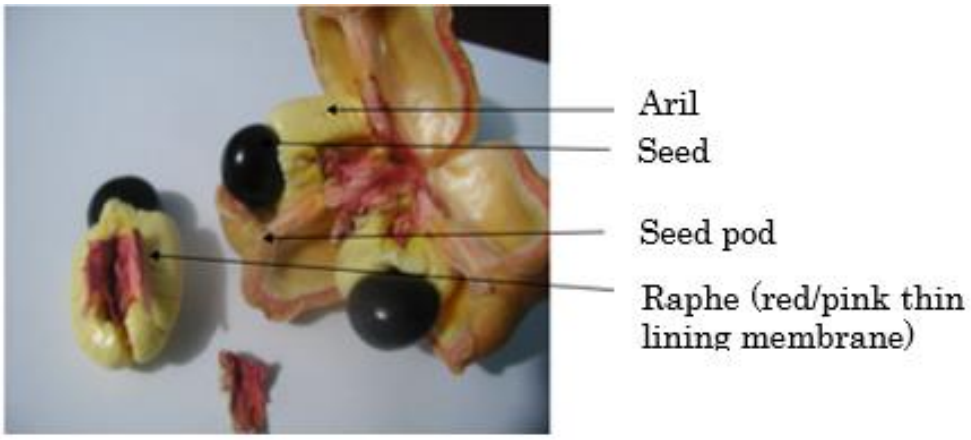

Figure 1. *Parts of the Ackee Fruit* (Wray *et al.*, 2020)

MATERIALS and METHODS

Materials

The fresh ackee aril apple used in this study was subjected to drying using the following materials and equipment:

i. Oven dryer (DHG-9053A) with a fixed air velocity of 1.4 m s^{-1}. The oven operates at a voltage of 220V and 50Hz.
ii. Electronic weighing scale (Golden-Mettler, model-20002) with a measurement precision of ±0.01 g and a maximum capacity of 2000 g.
iii. Trays wrapped with foil paper for arranging the samples before placing them in the oven and sun.

Raw Material and Sample Preparation:

Fresh and mature ackee aril apple fruits were harvested from a tree in Akure, Ondo State, Nigeria. To get rid of damaged fruits, ripe ackee apples were sorted, washed, and cleaned. The seeds and raphe were manually removed, and the samples were grouped and placed in trays for further processing (Figure 2a and 2b).

Figure 2a. *Freshly harvested acked apple fruits.* ***Figure 2b.*** *Clenaed ackee aril apple.*

Experimental Site

The research was conducted in the Crop Processing Laboratory, located within the Department of Agricultural and Environmental Engineering, School of Engineering and Engineering Technology, Federal University of Technology, Akure (FUTA), Ondo State, Nigeria.

Methods

The methods employed in this study are described as follows:

Drying:

The Ackee aril apples were subjected to drying using two methods:

a. Sun Drying: Ackee aril apples were spread out in the sun until a constant weight was achieved.
b. Oven Drying: The drying was conducted in an oven dryer (DHG-9053A) with a fixed air velocity of 1.4 m s^{-1}. The oven operates at a voltage of 220V and 50Hz. Samples were arranged on trays wrapped with foil paper and placed in the oven dryer (at various temperatures of 40, 50, 60, 65, and 70°C). The drying process was continued until a constant weight was achieved.

Nutritional Quality:

The nutritional quality of the ackee aril fruit was determined, including moisture content, fat, protein, ash, fiber, and carbohydrate content. The following standard methods were used for analysis:

a. Moisture Content: Analyzed using the standard AOAC (2012) method. It involved weighing an empty evaporating dish (W1), adding 10g of the sample to the dish (W2), drying the sample at 105°C, and calculating the moisture content using Equation 1.

$$\%MC = \frac{W2 - W3}{W2 - W1} 100 \quad (1)$$

Where W_1 is the weight of the empty evaporating dish;
W_2 is the weight of the sample + evaporating dish
W_3 is weight of sample + evaporating dish after drying at 105°C.

b. Crude Fat Content: Determined by saponifying the extracted fat content of the sample and then analyzed by gas chromatography described by Olagunju and Nwachukwu, (2019).
c. Protein Content: Measured by the micro-Kjeldahl method, where the percentage nitrogen content was calculated and multiplied by a factor of 6.25 to determine the protein content (Equation 2).

$$\%Protein = \frac{N.F \times M \times V_1 \times T \times PF \times 100}{V_2 \times W} \quad (2)$$

Where N.F *is* the nitrogen factor (0.014); M is the morality of HCl (0.01);
V_1 is the final volume of digest (50 ml); V_2 is the volume of digest used (10 ml);
Tis the titre volume of distillate; W is the Weight of sample used;

PF is the protein multiplication factor (6.25)

d. Ash Content: Ash content was determined by ashing the sample in a muffle furnace at 600°C. The final weight of the sample was taken, and the percentage ash content was calculated using Equation 3 stated by Oguntola *et al.* (2019):

$$\%Ash = \frac{(weight of empty crucible + ash) - weight of empty crucible}{Weight\ of\ sample\ taken} \times 100 \quad (3)$$

e. Crude Fiber Content: Crude fiber was obtained through hydrolysis and filtration methods. The percentage crude fibre was calculated using the Equation 4 as stated by Oparaku *et al.* (2010):

$$\%crude fibre = \frac{loss \in weight after drying}{weight of sample} \times 100 \quad (4)$$

f. Carbohydrate Content: Calculated by subtracting the sum of ash, protein, fat, moisture, and crude fiber from 100, using Equation 5 as stated by Olabinjo and Adeniyan (2020) and Oparaku *et al.* (2010):

$$\%Carbohydrate = 100 - (\%ash + \%protein + \%moisture + \%crude fibre) \quad (5)$$

g. Calculated Metabolic Energy: it was estimated using Equation 6 stated by Akalu and Geleta (2019). The metabolic energy is measured in kcal 100 g^{-1}.

$$CME = (9 \times crude fat) + (4 \times protein content) + (4 \times carbohydrate content) \quad (6)$$

Bioactive Quality:

Bioactive quality parameters, including total phenolic content, vitamin C, and flavonoid content, were determined using relevant methods.

a. Total Phenolic Content (TPC): Analyzed using the Folin-Ciocalteu reagent reducing substance method. Gallic acid corrosive was used as standard and results were expressed as Gallic acid equivalents (mg GAE) (Batista *et al.*, 2016).
b. Vitamin C: It was determined through titration with 2,6-dichlorophenol indophenol using the standard AOAC (2005) method.
c. Flavonoid Content: Calculated using the method described by Mudoi and Das (2019).

RESULTS AND DISCUSSION

Effect of temperature on the moisture content of the ackee aril apple

Figure 3 demonstrates that higher drying air temperatures lead to shorter drying times and a more rapid decrease in moisture content. The moisture's movement from the center of the biomaterial to the surface can be attributed to its diffusion, which explains this pattern (Nguyen *et al.*, 2019).

Before drying, the ackee aril apple's initial moisture content was approximately 54.814% wet basis (wb). At drying temperatures of 70°C, 60°C, 50°C, 40°C, and open sun drying, respectively, the moisture content decreased to 2.997%, 4.530%, 7.097%, 7.520%, and 7.725%. When the drying process started, the moisture movement was shown to decrease gradually; however, when the temperature rose during drying, it accelerated until it reached the equilibrium moisture content (EMC).

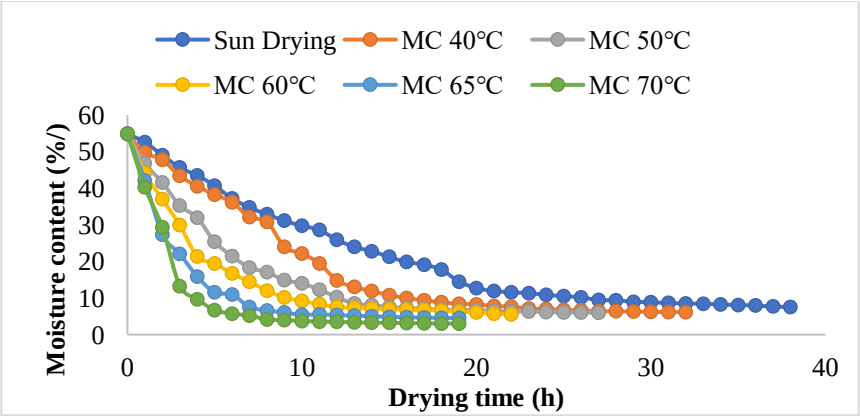

Figure 3. *Moisture content against drying time (hour) at different drying temperature.*

Effect of temperature on the nutritional composition of ackee aril apple

Proximate analysis revealed significant variations in nutritional components during drying. Sun-dried and oven-dried ackee aril apple at 40°C showed similar results. The different impact of drying temperatures on the retention of nutritional components can be attributed to their varying stabilities (Joshi *et al.*, 2011).

Ash Content

Ash content reflects mineral presence, quality, and safety. Increasing oven drying temperature led to decreased ash content from 5.010% at 40°C to 2.856 % at 70°C. Compared to other foods such as palmyra palm, cashew kernels, taro, and yam, ackee aril apple contains a notable amount of minerals, making it a valuable dietary component (Abe-Inge *et al.*, 2018; Akalu and Geleta, 2019; Olalekan-Adeniran and Ogunwolu, 2018).

Moisture Content

Initial moisture content was 54.814%, highlighting its perishability. The lowest moisture content of 2.997% was achieved at 70°C and lowered than the moisture content reported by Dossou *et al.*, (2014b) with 4.83% which can have negative effect on nutritional and bioactive composition of the sample. Compared to taro, yam, and cashew kernels oven-dried at 50-70°C, ackee aril apple displayed higher moisture content (Akalu and Geleta, 2019; Olalekan-Adeniran and Ogunwolu, 2018).

Crude Fat Content

Ackee aril apple is rich in fat and suitable for commercial soap and oil production. Dietary fat promotes fat-soluble vitamin absorption (Dossou *et al.*, 2014b; Oyeleke *et al.*, 2013). Drying temperatures decreased fat content, with the lowest fat content

(7.910%) observed at 50°C oven drying temperature. Ackee aril apples were found to contain more crude fat than taro (0.77% - 1.26%) and yam (0.71% - 1.30%) oven-dried at 50-70°C (Akalu and Geleta, 2019). The high-fat content in ackee aril apples with Oleic acid can contribute to reducing the risk of prostate cancer when incorporated into a diet (Goldson *et al.*, 2014).

Crude Fibre Content

Ackee aril apples have been identified as a rich source of dietary fibre, which is beneficial for digestion and offers numerous health advantages. These include lowering cholesterol levels and reducing the risk of cardiovascular diseases, obesity, colon diseases, and type 2 diabetes (Anupama and Sunilkumar, 2019; Ouattara *et al.*, 2010).

The study results indicated a notable rise in the crude fibre content in dried ackee aril apples as compared to their fresh counterparts. The process of oven drying at 60°C led to the maximum percentage increase (31.997%) in crude fibre content, suggesting that the drying process significantly enhances the fibre content. When compared to other food items such as cashew kernels, yam, and taro, the crude fibre content of ackee aril apples was found to be considerably higher (Akalu and Geleta, 2019; Olalekan-Adeniran and Ogunwolu, 2018).

Protein Content

The protein content of ackee aril apple, initially low at 5.335%, can be increased through drying (Anupama and Sunilkumar, 2019; Dossou *et al.*, 2014b; Ouattara *et al.*, 2010). Sun drying yields the highest protein content (23.068%), while oven drying at 50℃ gives the lowest (10.987%). A balance of protein content (22.797%) and safe moisture levels is achieved at 60℃. This method produces higher protein content than in cashew kernels, taro, and yam dried similarly (Olalekan-Adeniran and Ogunwolu, 2018).

Carbohydrate content

An increase in drying temperature led to a rise in carbohydrate content. Samples dried at 70℃ had the highest carbohydrate value of 43.022%, a 72.93% increase from fresh ones. The ackee aril apple had less carbohydrate content than taro and yam. However, it's still a good source of carbohydrates, which are crucial for energy production (Akalu and Geleta, 2019).

Calculated metabolic energy (CME)

Fresh ackee aril apples had the lowest metabolic energy (213.365 kcal 100 g^{-1}), while those dried at 70°C had the highest (341.528 kcal 100 g^{-1}), attributed to their high moisture content (Abe-Inge *et al.*, 2018). These values differed from those reported by Dossou *et al.* (2014b). Among comparable foods, ackee aril apples exceeded the metabolic energy of palmyra palm but were lower than cashew kernels (Abe-Inge *et al.*, 2018; Olalekan-Adeniran and Ogunwolu, 2018; Akalu and Geleta, 2019). Ackee aril apples exhibit high metabolic energy potential.

Table 1. Result of proximate analysis of ackee aril apple.

S/N	Parameters (%)	Fresh Samples	Oven Dried Samples				
			70°C	60°C	50°C	40°C	Sun Dried
1	Ash Content	1.737	2.856	4.566	5.240	5.010	4.565
2	Moisture Content	54.814	2.997	4.530	7.097	7.520	7.725
3	Crude Fat Content	16.161	13.108	13.137	7.910	12.546	13.546
4	Crude Fibre Content	10.309	25.150	31.997	30.497	28.329	25.802
5	Protein Content	5.335	12.867	22.797	10.987	20.816	23.068
6	Carbohydrate Content	11.644	43.022	22.973	38.269	25.744	25.294
7	Calculated Metabolic Energy (kcal 100 g^{-1})	213.365	341.528	301.313	268.214	299.154	315.362

Effect of temperature on the bioactive composition of ackee aril apple

The presence of natural antioxidants in ackee aril apple, including flavonoids, total phenolic compounds, and ascorbic acid, holds significant implications for health maintenance and the prevention of chronic and degenerative diseases (Anupama and Sunilkumar, 2019). Previous research has underscored the medicinal and disease-preventive potential of bioactive and nutritional components in food materials (Anupama and Sunilkumar, 2019). Notably, oven-dried ackee aril apple exhibited higher concentrations of total phenols, vitamin C, and flavonoids than the fresh counterpart, suggesting its suitability as a nutraceutical (Table 2).

Flavonoids

Drying air temperatures significantly increased the flavonoid content in ackee aril apples. Sun drying yielded the highest flavonoid content at approximately 23.588 mg 100 g^{-1}, while oven-drying at 50°C resulted in the lowest at 12.989 mg 100 g^{-1}. Interestingly, drying at 70°C for 19 hours and at 60°C for 22 hours led to nearly identical flavonoid content, approximately 19.801 mg 100 g^{-1}, representing a substantial increase from the fresh state. This fluctuation may be attributed to operational factors during sample weight measurements. Flavonoids offer various bioactive benefits, including antiviral, antibacterial, anti-inflammatory, cardio-protective, antidiabetic, anticancer, anti-aging properties, and the ability to modulate the body's response to allergies, viruses, and carcinogens (Wang *et al.*, 2018).

Total Phenolic Content

Fresh ackee aril apples possessed a total phenolic content of approximately 11.545 mg 100 g^{-1}, signifying its rich source of phenolic compounds, known for their potential in reducing blood pressure and offering anticancer and antibacterial properties, as well as the ability to adsorb and neutralize free radicals (Anupama and Sunilkumar, 2019). Anupama and Sunilkumar (2019) recommended a daily intake of 100g of ackee aril apple to meet the body's daily phenolic requirement. Notably, higher temperature significantly affected total phenolic content positively, with highest and lowest values observed at 70°C (26.185 mg 100 g^{-1}) and 40°C (15.993 mg 100 g^{-1}). Samples dried at higher temperature exhibited higher total phenolic but 50°C exhibited higher values (22.055 mg 100 g-1) than those dried at 60°C (21.383 mg 100

g^{-1}), which could be influenced by external factors. While the total phenolic content in this study was lower than that of red apple slices (71.26 mg 100 g^{-1}) oven-dried at 70°C, as reported by Joshi *et al.* (2011), it exceeded the value for fresh ackee aril apple (9.9 mg 100 g^{-1}) reported by Anupama and Sunilkumar (2019). Notably, the results revealed a direct relationship between drying temperature and total phenolic content.

Vitamin C

Fresh ackee aril apple contained approximately 3.887 mg 100 g^{-1} of vitamin C, which increased by about 79% during open-sun drying (18.536 mg 100 g^{-1}) over 38 hours. Samples subjected to oven drying at different temperatures displayed higher vitamin C levels than the fresh sample. Specifically, ackee aril apple dried at 70°C, 60°C, 50°C, and 40°C exhibited vitamin C contents of 12.258 mg 100 g^{-1}, 17.750 mg 100 g^{-1}, 14.152 mg 100 g^{-1}, and 13.038 mg 100 g^{-1}, respectively. Although the vitamin C content reported in this study was lower than that of red apple slices (78.14 mg 100 g^{-1}) oven-dried at 70°C according to Joshi *et al.* (2011), it was notably higher than the value for fresh ackee aril apple (1.15 mg g^{-1}) reported by Anupama and Sunilkumar (2019). Vitamin C is crucial in stabilizing folate and aiding metabolism, such as tyrosine metabolism. Ackee aril apple, with its considerable vitamin C content, can serve as an antioxidant, commonly called ascorbic acid.

Table 2. *Bioactive Composition of Ackee Aril Apple.*

S/N	Parameters (mg 100 g^{-1})	Fresh Samples	Oven Dried Samples				Open Sun
			70°C	60°C	50°C	40°C	
1	Vitamin C	3.887	12.258	17.750	14.152	13.038	18.536
2	Flavonoids	9.542	19.801	19.801	12.989	19.241	23.588
3	TPC	11.545	26.185	21.383	22.055	15.993	20.661

CONCLUSION

The research findings on the impact of different drying temperatures on ackee aril apples (*Blighia sapida*) provide valuable insights into this tropical fruit's potential for both economic and nutritional purposes. Higher temperatures during the drying process significantly reduced the moisture content, which decreased the chance of spoiling and increased shelf life. When they were dried, Ackee aril apples showed significant differences in their nutritional composition. A decrease in ash content indicates reduced mineral content. On the other hand, there was a noticeable rise in the amount of protein and crude fiber. Improved digestion and a lower risk of multiple illnesses are just two of the many health advantages of dietary fiber. The carbohydrate content of dried ackee aril apples also increased with drying temperature, making them a potential energy source. Ackee aril apples displayed a rich fat content, making them suitable for commercial soap and oil production. High-fat content can also aid in the absorption of fat-soluble vitamins. Drying at elevated temperatures increased bioactive properties. Flavonoids, total phenolic content, and vitamin C were all enhanced. Ackee aril apples, especially those dried at higher

temperatures, showed significant potential as a source of natural antioxidants. These bioactive compounds have various health benefits, including antiviral, antibacterial, anti-inflammatory, cardio-protective, antidiabetic, anticancer, and anti-aging properties. The research findings highlight the economic potential of ackee aril apples, particularly in regions like Jamaica, where canned ackee arils have generated significant revenue. The study underscores the fruit's potential as a nutraceutical, providing economic and health benefits. In conclusion, drying ackee aril apples at different temperatures extends their shelf life and enhances their nutritional and bioactive properties.

DECLARATION OF COMPETING INTEREST

We certify that there is no conflict of interest with any financial organization regarding the material discussed in the manuscript.

CREDIT AUTHORSHIP CONTRIBUTION STATEMENT

The authors confirm contribution to the papers as follows:
Oyebola Odunayo Olabinjo: Methodology, conceptualization, formal analysis, data curation, validation, Editing.
Mercy Omowunmi Sama: Investigation, Writing (original draft, Review, Visualization).

ETHICS COMMITTEE DECISION

This article does not require any ethical committee decision.

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Turkish Journal of Agricultural Engineering Research

Turk J Agr Eng Res (TURKAGER)

https://dergipark.org.tr/en/pub/turkager
https://doi.org/10.46592/turkager.1322425

ISSN: 2717-8420
2023, 4(2), 301-316

Review Article

Uplands Rural Development Programme and Investigation of the Program Process in Kastamonu Province

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Article Info

Received: 04.07.2023 **Accepted:** 17.08.2023 **Published:** 31.12.2023

ABSTRACT

There are significant threats to the security of agricultural supply from people migrating from rural areas to urban areas due to economic difficulties and disadvantages arising from a lack of extension. However, agricultural production is strategically important for Türkiye and the most important economic activity for rural areas. People who migrate to cities prefer to stay in output if agricultural subsidies are provided to encourage production. In addition to the support of the Turkish government, it is important to benefit from the work of international organizations such as the International Fund for Agricultural Development (IFAD), which works in rural areas and supports the agricultural sector. IFAD is well aware of the needs of Türkiye's rural areas with 11 projects implemented with a total cost of USD 697.91 million and IFAD contribution of USD 251.84 million. In Türkiye, Uplands Rural Development Programme (URDP), financed by IFAD, supports the disadvantaged people living in rural areas. In this study, information about IFAD and its activities in Türkiye is given the ongoing URDP of the organization in Türkiye, the studies carried out in the process of including Kastamonu province in the programme, the project acceptance process in Kastamonu province and the results of the programme in Kastamonu province in 2020 when the programme was implemented for the first time in Türkiye, are examined in detail. As a result of the research, the utilisation of the fund by taking into account the needs of rural areas and the monitoring process were found to be positive.

Keywords: *Agricultural policies, Agricultural supports, Rural development, International organizations, The International Fund for Agricultural Development, Uplands Rural Development Programme*

To cite: Inan O, Gürel F (2023). Uplands Rural Development Programme and Investigation of the Program Process in Kastamonu Province. *Turkish Journal of Agricultural Engineering Research (TURKAGER), 4(2), 301-316. https://doi.org/10.46592/turkager.1322425*

INTRODUCTION

The International Fund for Agricultural Development is an international financial institution of the United Nations, established on 30 November 1977 following the World Food Conference in 1974. The aim of the IFAD is to increase food production in developing countries to combat hunger and rural poverty, to provide new job and income opportunities, and to provide low-interest and long-term loans to rural development projects, especially to help poor people (Aras and Arısoy, 2021).

The fund finances projects specifically designed to develop and expand food production systems. The fund contributes to agricultural development projects in developing countries through donations and loans with favourable conditions. The development projects to be supported must have features that increase food production, prevent poverty and improve nutrition. IFAD implements agricultural development programmes aimed to increase food production in the most vulnerable developing countries. Today, 177 countries are IFAD members, headquartered in Rome/Italy. IFAD carries out its activities with the resources provided as contributions from various countries. There are industrialised countries in the first category, oil producing developing countries in the second category and developing countries in the third category (Aytekin, 2012).

Türkiye became a member of IFAD in 1982. Türkiye aims to participate in the activities of IFAD actively. In this framework, the activities of the Governing Council and the Executive Board, the decision-making and executive bodies of IFAD, are followed. For IFAD's 11th Resource Renewal Period (2019-2021), Türkiye contributes USD 5 million.

"Host Country Agreement between the Government of the Republic of Türkiye and the IFAD on establishing an IFAD Country Office - Eastern Europe and Central Asia Hub" was signed in Ankara on 5 November 2018. After that, the work between IFAD and the Government of Türkiye has gained a more advanced dimension. It is important to analyze IFAD's activities in rural areas, pave the way for more effective activities, and make the best use of financing resources.

MATERIALS and METHODS

The study is a compilation of secondary data, primarily obtained from IFAD and the Ministry of Agriculture and Forestry of the Republic of Türkiye, publications that examine the assistance of international organizations in Türkiye, especially IFAD. General information on the Rural Disadvantaged Areas Project (2018-2026) was obtained from IFAD's international website documents and records of Provincial Directorates of Agriculture and Forestry in Türkiye where the programme is implemented. The data on the implementation of the URDP project in the Kastamonu province were compiled from the records obtained from the Kastamonu Provincial Directorate of Agriculture and Forestry.

PREVIOUS AND ONGOING IFAD PROJECTS IN TÜRKİYE

IFAD projects implemented in Türkiye aim to increase rural people's income and living standards. From the past to the present, 11 projects have been implemented

by IFAD in Türkiye. The total cost of these projects is estimated at USD 697.91 million and the contribution provided by IFAD is USD 251.84 million.

It is calculated that 1,486,238 households are affected by the IFAD projects implemented. Eight of these projects have been completed and, three are still ongoing (IFAD, 2021). Figure 1 shows, the completed and ongoing IFAD projects in Türkiye by indicating the regions where they are implemented.

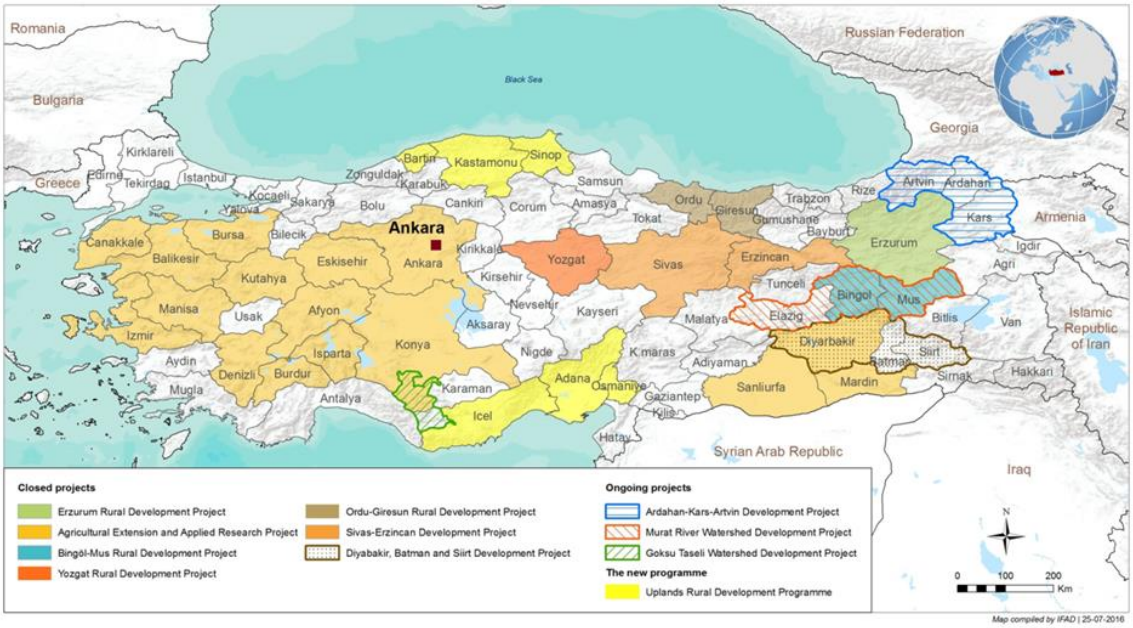

Figure 1. *IFAD projects implemented in Türkiye from past to present (IFAD, 2021).*

IFAD Projects Completed in Türkiye

1) Erzurum Rural Development Project (1982-1989): The project was implemented between 1982-1989 as a rural development project in the region. The total project cost was estimated at USD 104.80 million. Of this, USD 58.50 million was contributed by the Government of the Republic of Türkiye, USD 15.20 million by IFAD and USD 31.10 million by external financing. 36.200 households were affected by the project.

2) Agricultural Extension and Applied Research Project (1984-1993): The project was carried out for research, extension and training purposes. Total project cost: USD 164.90 million. Of this, USD 94.40 million was contributed by the Government of the Republic of Türkiye, USD 6.50 million by IFAD and USD 64 million by external financing. 1.20 million households were affected by the project.

3) Bingöl-Muş Rural Development Project (1989-1999): The project was implemented as a rural development project in the region. The total project cost was calculated as USD 52.20 million. Of this, USD 13.80 million was contributed by the Government of the Republic of Türkiye, USD 19.90 million by IFAD, USD 9.40 million by local financial institutions and USD 9 million by external financing. 35.000 households were affected by the project.

4) Yozgat Rural Development Project (1990-2001): The project was implemented as a rural development project in the region. Total cost of the project: USD 40.50 million. Of this, USD 24.10 million was contributed by the Government of the

Republic of Türkiye and USD 16.40 million was IFAD financed. 30.000 households were affected by the project.

5) Ordu-Giresun Rural Development Project (1995-2005): The project was implemented as an agricultural development project in the region. Total cost of the project: USD 51.20 million. Of this, USD 18.20 million was provided as Turkish Government contribution, USD 20.00 million as IFAD financing, USD 4.80 million as beneficiary contribution and USD 8.20 million as external financing. 44.000 households were directly affected by the project.

6) Sivas-Erzincan Development Project (2003-2013): The project was implemented as a rural development project in the region. The total cost of the project was calculated as USD 30.20 million. Of this, USD 4.40 million was contributed by the Government of the Republic of Türkiye, USD 13.10 million by IFAD, USD 2.60 million by beneficiary contributions and USD 10.10 million by external financing. 10.000 households directly benefited from the project.

7) Diyarbakır, Batman and Siirt Development Project (2006-2014): The project was implemented in the field of credit and financial services in the region. The total cost of the project was calculated as USD 36.90 million. Of this, USD 4.40 million was contributed by the Government of the Republic of Türkiye, USD 24.10 million by IFAD and USD 7.60 million by beneficiaries. 5,000 households were directly affected by the project.

8) Ardahan-Kars-Artvin Development Project (2009-2017): The project was implemented as an agricultural development project in the region. The total cost of the project was calculated as USD 26.30 million. Of this, USD 3.20 million was contributed by the Government of the Republic of Türkiye, USD 19.20 million was IFAD financed and USD 3.90 million was beneficiary contribution.

IFAD Projects Ongoing in Türkiye

9) Göksu-Taşeli Basin Development Project (2015-2023): The project is being implemented as a rural development project in the region. The total cost of the project was calculated as USD 25 million. Of this, USD 3.80 million was planned as the contribution of the Government of the Republic of Türkiye, USD 18.30 million as IFAD financing, and USD 2.90 million as a beneficiary contribution (Aras and Arısoy, 2021).

10) Murat River Basin Rehabilitation Project (2012-2021): The project is being implemented as an agricultural development project in the region. The total cost of the project is calculated as USD 61.50 million. Of this, USD 7.40 million will be provided through the contribution of the Government of the Republic of Türkiye, USD 36.30 million through IFAD financing, USD 2.60 million through local financing sources and USD 25.20 million through external financing. Twelve thousand five hundred households will directly benefit from the project.

11) Uplands Rural Development Programme (2018-2026)

- Eastern Mediterranean Rural Development Programme (2018-2026)
- Western Black Sea Rural Development Programme (2018-2026)

The programme is calculated as a rural development programme to be implemented in disadvantaged rural areas. The total cost of the project is calculated as USD 98.50 million. Of this, USD 23.60 million will be provided by the Government of the Republic of Türkiye, USD 56.90 million by IFAD, USD 2.90 million by the

Credit Guarantee Fund (CGF), and USD 15.10 million by the beneficiary (IFAD&GTHB, 2018).

UPLANDS RURAL DEVELOPMENT PROGRAMME (2018-2026)

The difference between these supports of IFAD from other IFAD activities is that they are prepared as projects, while this type of support is planned as a programme. The programme was initially planned to cover the years 2017-2023 under the name 'Uplands Rural Development Programme (URDP)'. The final draft of the programme was prepared in 2017. The subsequent process delayed the implementation period of the programme. The programme was extended until 2026 and planned as an 8-year project covering the years 2018-2026, with the revisions made in the programme through negotiations between IFAD delegations and Turkish government officials.

The programme was launched in 2020 under the name of Uplands Rural Development Programme (URDP) with an agreement between the Ministry of Agriculture and Forestry and the International Fund for Agricultural Development (IFAD) to increase the welfare and resilience of small-scale farmers living in disadvantaged areas, to ensure rural transformation, and to facilitate access to rural finance through the clustering method. With mutual negotiations, clarification of the application conditions, review of the processes, and preparation of the implementation procedures, the programme's first beneficiaries in Türkiye could benefit from the programme in 2020. In the programme's first phase, the budget was determined as USD 52.50 million and USD 98.50 million in total.

In the first phase, the programme will be implemented in six provinces and two regions, namely Eastern Mediterranean (Adana, Mersin, Osmaniye) and Western Black Sea (Bartın, Kastamonu, Sinop), covering 35 districts and targeting 30,000 households. The programme is implemented in 35 villages in 6 provinces in first phase.

In the second phase, the programme will assess the feasibility of covering two more provinces: Kahramanmaraş (Eastern Mediterranean) and Çankırı (Western Black Sea), with a total of 45 districts, 2,132 villages and 30,000 households in 8 provinces.

The programme is intended to benefit investors concentrated or clustered in upland and transitional areas in the programme provinces, where agricultural and pasture lands are mostly at altitudes above 600 m and where most of the forest villages and villages adjacent to the forest are located. The individuals and groups targeted by the programme are defined as follows (IFAD, 2017).

- People with low income, living on subsistence or semi-subsistence, suffering from poverty,
- Especially people living in high areas above 600 altitude,
- Especially those living in forest villages or villages close to forests,
- Regions considered to be more backward,
- Aimed at young people,
- Regions with relatively good agricultural potential in a particular area,
- People or regions with migration forecasts.

New Approaches in Rural Areas with URDP

1) Creation of Economic Development Clusters: In general terms, clustering is the tendency of firms carrying out similar activities to establish close to each other in a particular area without any obligation (Crouch *et al.*, 2001). In the URDP approach, people engaged in the same agricultural activities in the rural areas of the provinces were brought together and benefited from the support. For example, if a region of the province is divided into several districts and the intensive economic activity is livestock breeding, 10-15 people engaged in livestock breeding in this region are brought together, and allowed to collectively apply for support. The benefits of the clustering approach can be listed as marketing advantages, information sharing, and increasing the effectiveness of extension services (Tutar *et al.*, 2011).

2) Establishment of Multi-Stakeholder Platforms: Under the programme, MSPs are established to regularly exchange information on practices and skills, and as a result, take a common stance to influence decision-making within the economic development cluster. These MSPs are intended to work on the bases of the strategic investment plan of each cluster, such as determining the primarily agricultural production in the Economic Development Clusters (EDC), prioritising the infrastructure, individual investment issues, etc., during the establishment process. These platforms have effectively in prioritised the needs in the provinces and districts where the programme has been implemented and in forming several EDCs. It is calculated that the decisions of the MSPs will be important in the works to be carried out in the future processes of the programme.

3) Establishment of a Rural Credit Guarantee System: The programme is aimed at small farmers who are disadvantaged in the upland areas and it is foreseen that the beneficiaries will have problems with collateral. For this reason, it is planned that farmers who have difficulties in providing collateral will be able to obtain the credit they need under the rural disadvantaged areas project together with the CGF and will not have to worry about providing collateral. In this context, Turkish government allocated a budget of 5 million € to overcome the difficulties in providing collateral. The CGF is aimed to utilise a credit volume of 300 million ₺ with the grants to be given to those living in the provinces within the scope of the URDP projects.

Distribution of Supports Provided with URDP by Category

URDP provides subsidies in the categories of cluster investment partnerships, young entrepreneur start-up packages, improvement of livelihoods of nomads, privately shared economic infrastructure, public economic infrastructure and rural roads. Table 1. shows the amounts of the subsidies distributed according to the categories provided by the URDP.

Table 1. *Distribution of the support provided by the URDP according to categories (IFAD, 2017).*

Category	Indicative Ceiling (€)	Contribution of URDP	Beneficiary Contribution	Tax	Investor Type	Secondary Beneficiaries
Clustering Investment partnership	14.500	%70	%30	Investor Individuals	Individual, groups	Individual, group members
Young Entrepreneur Start-up Package	5.000	%70	30% in kind or in cash	Investor Individuals	Educated young entrepreneur	Young people
Improving the Livelihoods of Nomads	5.000	%80	%20 kind	Republic of Türkiye	Yoruk households	Members of the nomadic community
Privately Shared Economic Infrastructure	25.000	%75	%25	Investor Individuals	Cooperative, Union	EDC Stakeholders
Public Economy Infrastructure	150.000	%100	-	Republic of Türkiye	Local Government	EDC Stakeholders
Rural Roads	-	%60	%40	Republic of Türkiye	Local Government	EDC Stakeholders

Examples of the forms of support can be given as follows:

- Support for Cluster Investment Partnership; it can be plant production and livestock farming grant investments.
- Supports Young Entrepreneurs; can be planted production and livestock farming grant investments.
- Small farmers and/or men and women processing small-scale products: barn repairs, tents, greenhouses, greenhouses, animal drinking water structures, living conditions improvement investments, etc.
- Supports Economic Infrastructure Investments: storage, cold air unit, milk collection centres, product processing facilities, and geographical indication related activities.
- Public Investment Support can be in small-scale fruit and vegetable wholesale markets, animal markets, rural road construction for the market, animal drinking water structures, and irrigation facilities investments.

Subjects and Rates of Support Allocated to Rural Areas with URDP

- The project support plant and animal production.
- Production in these areas is supported at 70 per cent.
- The grant rates for farmers under 40 years of age are between 70% and 100%.
- Grants of 75% are given for economic infrastructure works by unions, co-operatives and KOBİs.
- The grant rates for nomads engaged in animal husbandry activities in the Taurus Mountains are 100%.
- Small-scale vegetable and fruit markets, animal markets, slaughterhouses, pressurised irrigation systems, pasture and market roads, animal drinking water structures and pasture infrastructures etc. 100% of the investments made for use in the public sphere are covered by the Ministry of Agriculture and Forestry.

- Not only real persons but also agricultural enterprises, unions and cooperatives can benefit from grants.

Documents Required for URDP Application Process

Project applications are made in consultation with the Directorates of Agriculture and Forestry in the provinces and districts, taking into account that the documents may differ. Common documents that may be requested in each province and group can be counted as follows:

- Photocopy of the Republic of Türkiye identity card
- Income certificate
- Current Farmer Registration Certificate and/or Animal Information System record
- Residence certificate
- Documents showing land information
- Documents encouraging agricultural production

Support Subjects Provided to Rural Areas with URDP

The topics of support provided by the programme may vary according to the province-district and EDC. Table 2 and Table 3 show the components, sub-components and the distribution of support according to the subjects of the components within the scope of URDP.

Table 2. *Supports under the sub-component of supporting individual investments for the development of the URDP value chain (Anonymous, 2020).*

Main Component	**Promoting Economic Development Clusters**	
Subcomponent	Supporting Individual Investments for the Development of Value Chain	
	BARN AND CORRAL REHABILITATION - Barn Rehabilitation- Corral Rehabilitation	
	MODERN TENT BARN AND CORRAL CONSTRUCTION - - New Barn Construction (Tent), - New Corral Construction (Tent)	
	PURCHASE OF MACHINERY AND EQUIPMENT - Purchase of Baler Machine, - Purchase of Mower Machine - Purchase of pneumatic grain seeding seeder machine - Silage Machine Purchase, - Feed Mixer Purchase - Feed Crushing Machine Purchase	
	ELECTRIC FENCE FOR BEEKEEPERS	MUSHROOM GREENHOUSE INSTALLATION
	BEEKEEPING TOOL AND EQUIPMENT PACKAGE	WALNUT CULTIVATION
	GREENHOUSE INSTALLATION	

Table 3. *Subsidies under the sub-component on skills and organization of farmers in the URDP (Anonymous, 2020).*

Main Component	**Promoting Economic Development Clusters**
Subcomponent	Farmers' Skills and Organization
	DEMONSTRATIONS - Calf Care and Feeding Demonstration - Walnut Garden Demonstration - Linen Demonstration - Mushroom Greenhouse Demonstration - Greenhouse Demonstration - Soilless Agriculture Strawberry Greenhouse Demonstration - Forage Crops Cultivation Demonstration

Other Transactions Performed by Provincial Directorates of Agriculture
- List of villages: The list of villages that can benefit from the programme is announced.
- Application Call Announcement: Information is given about the application time and investment periods.
- Cluster Project Distributions: EDC and the support to be provided in these clusters are announced.
- Letter of Undertaking: The required letters of undertaking regarding the support issues are announced.

WORKS CARRIED OUT IN KASTAMONU PROVINCE WITHIN THE SCOPE OF UPLANDS RURAL DEVELOPMENT PROGRAMME

The rural development platform (Multi-Stakeholder Platform) was established on 27 October 2014 with the participation of 13 Civil Society Organizations (CSOs) in the Kastamonu province. Afterwards, RDP notified the Provincial Directorate of Agriculture and Forestry of their request for the implementation of the IFAD Project (KİTOM, 2015).

Based on the request of RDP, Kastamonu Provincial Directorate of Agriculture and Forestry prepared Kastamonu Province Rural Situation Report on 18 March 2015 (KİTOM, 2016).

Kastamonu Province Rural Situation Report was sent to the Ministry of Agriculture and Forestry on 19.03.2015, and an external project (IFAD) was requested (KİTOM, 2016).

On 15.04.2015, the Ministry of Agriculture and Forestry stated that the request of the Kastamonu Directorate of Agriculture and Forestry would be evaluated (KİTOM, 2016; IFAD&GTBH, 2018).

In March 2016, a team of experts from the Ministry of Agriculture and Forestry, Foreign Funded Projects and IFAD carried out inspections and visits in İnebolu, Devrekani and Taşköprü districts. Kastamonu province was included in the scope of 'Western Black Sea Rural Development Project' together with Bartın and Sinop provinces (KİTOM, 2017).

A mission delegation consisting of IFAD and Ministry of Agriculture and Forestry General Directorate of Agricultural Reform experts visited Kastamonu province between 27 February-01 March 2017 to carry out the necessary studies in the project area and carried out the First Feasibility Field Study (KİTOM, 2018).

On 27 February 2017, the project stakeholders, Kastamonu Chamber of Commerce and Industry, Kastamonu Commodity Exchange, Kastamonu Chamber of Agriculture, Kastamonu Village Development and Other Agricultural Purpose Cooperatives Union, Kastamonu Breeding Sheep and Goat Breeders Union, Kastamonu Breeding Cattle Breeders Union, Kastamonu Bee Breeders Union, Kastamonu Red Meat Producers Union, Representatives of Kastamonu Milk Producers Association, Kastamonu Chamber of Agricultural Engineers, Turkish Agriculturalists Association, Kastamonu Chamber of Veterinary Doctors, Kastamonu Special Provincial Administration General Secretariat, ARDSI Kastamonu Provincial Coordination Office, North Anatolia Development Agency (KUZKA) General Secretariat, DSI Regional Directorate, Forestry Regional

Directorate, Kastamonu Handicraft Training Centre Directorate and Kastamonu Governorship Project Coordination Centre (KİTOM, 2018).

On 28 February 2017, the IFAD delegation went to Afşar Village of Taşköprü District and Çaybaşı Village of Hanönü District and met with farmers and conducted a feasibility study. On 01 March 2017 Wednesday, the IFAD delegation visited Kızacık Village of Devrekani District, Çatalyazı Village of İhsangazi District and Avlacık Village of Araç District and met with farmers including women and young people. Their problems and needs in the village were identified and observed on site (KİTOM, 2018).

A Feasibility Report was prepared in March 2017 and submitted to the Ministry of Development in April 2017. The Ministry, IFAD, Undersecretariat of Treasury and Ministry of Development agreed in principle to implement the project (KİTOM, 2018).

A delegation consisting of experts from the Ministry of Agriculture and Forestry of the Republic of Türkiye and the International Fund for Agricultural Development (IFAD) carried out detailed field studies in Kastamonu Province between 19-22 May 2017 for the preparation of the project's main report (KİTOM, 2018).

The delegation first visited the village in Ağlı District, interviewed the villages's residents, and examined the livestock enterprises in the village. On 20 May 2017, the delegation went to İnebolu district and visited the town there (KİTOM, 2018).

Afterwards, a large-scale stakeholder meeting was held at the Kastamonu Provincial Directorate of Agriculture and Forestry Güray KOÇAK meeting hall with the participation of representatives of Public Institutions and Organizations and Non-Governmental Organizations in Kastamonu Province, and mutual opinions were exchanged with all stakeholders attending the meeting (KİTOM, 2018).

In addition, some experts from the delegation visited the milk collection centre and feed preparation facility of S.S. Kastamonu Village Development and Other Agricultural Purpose Cooperatives Union in Çetmi village in Taşköprü district. During the visit, interviews were made especially with female co-operative members. Observations were made for the details of the main report of the project (KİTOM, 2018).

On 11 August 2017, before noon, the delegation visited the market place in Taşköprü district, and after this visit, the delegation paid a visit to the Taşköprü District Directorate of Agriculture. In the afternoon, a stakeholder meeting was held in the meeting hall of Kastamonu Provincial Directorate of Agriculture and Forestry with the participation of representatives of the Chamber of Commerce and Industry, Commodity Exchange, Agricultural Credit Cooperatives, Producer and Breeder Organizations, Cooperative Supreme Unions and Chambers of Agriculture (KİTOM, 2018).

On Saturday, 12 August 2017, visits were made to the Kastamonu marketplace, input suppliers, and local markets. Finally, the IFAD Delegation visited and exchanged information at S.S. Kastamonu Village Development and Other Agricultural Purpose Cooperatives Union and left Kastamonu on the same day (KİTOM, 2018).

On 16 August 2017, the Project was submitted to the Ministry of Development for inclusion in the 2018 Investment Programme and a positive opinion was given (KİTOM, 2018).

The project was published in the Repeated Issue of the Official Gazette no. 30302 dated 15 January 2018 and included in the 2018 Investment Programme (Anonymous, 2018). The final programme and grant guidelines have been prepeared (IFAD, 2017; IFAD, 2020). The start of the project is planned for the end of 2018 (KİTOM, 2019). The project is envisaged to be completed in two phases in a total of 8 years, and Çankırı and Kahramanmaraş provinces are planned to be added to the programme in the second phase (IFAD, 2017).

In Kastamonu, there are ten districts and a total of 676 villages belonging to the districts within the scope of the project. There are differences between these districts regarding agriculture, agriculture-based industry, climate and marketing.

Considering the 2004 Kastamonu Provincial Agricultural Master Plan and the similarities and differences between the districts, the study area of Kastamonu was divided into 3 Economic Development Clusters (EDC). These Economic Development Clusters are shown below as follows;

Figure 2. *Kastamonu Province Economic Development Clusters (EDC) (KİTOM, 2021).*

It is calculated that these 3 EDCs are supported in their own regions in the following subjects;

- EDC 1: Support is provided to clusters in the fields of dairy farming, fruit growing, viticulture, cut flowers, garlic, paddy, and greenhouse cultivation.
- EDC 2: Support is provided to clusters in Dairy and Livestock Breeding, Field Crops (Siyez Wheat), and Fruit Growing (Uryani plum).
- EDC 3: Support is provided to clusters on Livestock Breeding (Specialised Organised Industrial Zones Based on Agriculture (TDİOSB)), Tuberous Crops, Sugar Beet, Potato, Fodder Crops.

Following the URDP opening and promotion meeting held in Ankara on 05 March 2019 with the slogan "The Future will be Shaped in the Countryside", a URDP kick-off workshop for Regional Project Management Unit (RPMU), Provincial Project Management Unit (IPMU) and Farmer Support Teams (FSA) were held in Ankara Haymana District on 05-08 March 2020 (KİTOM, 2020).

Training and preparatory work was carried out by the Ministry of Agriculture and Forestry Department of Studies and Projects, G&G Consultancy firm at Ilgaz Mountain Biological Diversity and Natural Resources Research and Training Centre on 2-3 May 2019 for Kastamonu, Bartın and Sinop IPMU and FSA staff who will conduct the baseline survey before the start of the project (KİTOM, 2020).

In May-June 2019, 264 questionnaires were completed in a total of 33 villages, 31 in-scope villages and two out-of-scope villages in 9 districts in Kastamonu province and sent to the G&G consultancy firm (KİTOM, 2020).

Bilateral and Multiple Interviews, Farmer Meetings, Institution and Stakeholder Visits, ESP Meetings, Data Collection and Literature Review, Geographical, Demographic and Economic Structure Situation Analysis, Infrastructure Analysis, Current Situation Analysis, Value Chain Analysis, SWOT Analysis, Vision and Strategic Objectives Determination studies were carried out.

A Training and Workshop on the Preparation of Strategic Investment Plans was held in Afyon Sandıklı on 26-29 August 2019, and in September - October 2019, Strategic Investment Plans of 3 EDCs were prepared and sent to the Ministry of Agriculture and Forestry (KİTOM, 2020).

The memorandum of understanding of the existing Multi-Stakeholder Platform was harmonised with the Working Procedures and Principles of the URDP RDP (KİTOM, 2020).

Taking into account the selection criteria and representation rates of the RDP members, 12 new members were included in the existing platform to cover Economic Development Clusters. Thus, the number of RDP members was increased to 25.

A total of 7 RDP meetings were held, including 1 meeting in 2018, 4 in 2019 and 2 in 2020 (KİTOM, 2021).

At the widespread farmer program (YÇBP) workshop held in Antalya on 12-13 December 2019, the investment plans of the provinces for the activities within the scope of the project were reviewed. In March 2020, the budgets for 2020 were revised and sent to the Ministry of Agriculture and Forestry. In June 2020, the 2020 budget was updated and sent to the Ministry and the preparation of Implementation Plans started.

On 21 July 2020, Bartın, on 22 July 2020, Kastamonu and 23 July 2020, Sinop provinces were visited by the Head of Studies and Projects Department of the

Ministry of Agriculture and Forestry and other technical staff and one-to-one work was carried out on implementation plans (KİTOM, 2021).

In June- August 2020, Grant Implementation Plans were prepared in coordination with the Ministry of Agriculture and Forestry for the activities included in the 2020 budget (Anonymous, 2020).

Participation was ensured in the information meeting organised by the Head of Studies and Projects Department of the Ministry on Zoom for the IPMU personnel in June 2020 regarding the works and procedures to be carried out within the scope of the budget studies for URDP 2020 (KİTOM, 2021).

2020 Work Construction Agreements were signed for the infrastructure activities included in the budget of the year 2020 (KİTOM, 2021).

From August to September 2020, applications for Infrastructure Investments Supporting Clustering, CIP Individual Grants and Demonstration were received;
- 2,000 units for Fodder Crops Demonstration (133 K, 1,988 E, 465 G),
- 121 units for Paddy Demonstration (2 K, 119 E, 4 G),
- 71 units for Calf Care and Feeding Demonstration (14 K, 57 E, 28 G),
- 214 units (16 K, 198 E, 53 G) for the purchase of a Feed Mixer Machine within the scope of CIP
- 4 for Privately Shared Economic Infrastructure projects,
- 7 units for Public Economic Infrastructure Investments,

2,417 applications were received, evaluated and sent to the Ministry of Agriculture and Forestry (KİTOM, 2021).

In November 2020, grant agreements were signed with 50 investors for the purchase of feed mixer machines within the scope of CIP Individual Grants, the purchase procedures were completed and the grant amount of 633,773.82 ₺ (70%) was transferred to the accounts of the beneficiaries (total project amount excluding vat is 909,418.30 ₺) (KİTOM, 2021).

Uplands Rural Development Programme (URDP), which is included in the Cross Expertise sub-component of the Cross Expertise sub-component in the 2020 budget, the Ministry of Agriculture and Forestry and UNDP provided the rental vehicles needed by the RPMU and IPMUs, and six service vehicles were allocated to Kastamonu province and delivered to Kastamonu Directorate of Agriculture and Forestry with a ceremony held on 14 January 2021.

Work and transactions within the scope of the 2021 budget of the Rural Disadvantaged Areas Development Project continue. The works are carried out in line with the National Rural Development Strategy (UKKS, 2021), which states that "Integrated development projects carried out with international resources are determined to improve the socio-economic structure of the population living in rural areas, employment opportunities in rural areas and to encourage small farmers to take initiatives in groups or individually, to improve social infrastructure, production and the capacities of institutions directly linked to the poor in rural areas. In addition, it is aimed to reduce rural poverty by improving the agricultural value chain in the project area and ensuring economic diversification through sustainable natural resource management. In this respect, implementation priority will be given to regions where such activities have not yet been carried out. Expenditures from the 2021 budget will be compiled in November 2021.

CONCLUSION

For the continuity of food production, it is important to ensure that the people who produce food gain economically from this work, to ensure that they can continue production willingly and to improve their living conditions. When this situation is taken into account, the situation of the rural areas where the producers live should be reviewed and the people living in these areas, which are considered less developed than the cities, should be supported economically and should be informed and strengthened in the light of current scientific developments in technical issues.

Policies for ensuring the sustainability of food production and agricultural policies should not be evaluated separately from each other. It is known that the interest in cities is high, and the population of cities is increasing day by day. This population increase in the cities is due to the effect of people who have to migrate to the cities due to economic difficulties and disadvantages arising from lack of extension. This detachment from rural areas decreases agricultural production. Agricultural production is still the most important activity in rural areas. Production should be increased according to the increasing number of people and their needs, and agricultural policies encouraging production should be developed.

Rural and/or agricultural production can be supported by governments within the country, cooperatives, non-governmental organizations or affiliated international organizations. One example of an international organization that supports agriculture is IFAD. IFAD, of which Türkiye is a member, is an organization with many activities in rural areas and agriculture in the world. The experience and financing opportunities that this organization can bring to the country should be well evaluated.

The co-operation between IFAD and the government of Türkiye in rural development has a long history. When the ongoing projects are taken into consideration, it is seen that mutual relations have been successfully maintained despite the positive and negative effects and setbacks of 11 projects in total. This process has provided IFAD officials with an understanding of the needs of Türkiye's rural areas and Turkish governments with experience in relations with IFAD. At this point, programmes that are more aware of the needs of rural areas and that can be better implemented in rural areas of Türkiye have been developed.

URDP is important in that it is implemented in the form of a programme and specifically targets the development of people living in high altitude areas, who are more disadvantaged in the agricultural sector. In addition, it should be seen as a model that should be monitored, studied and its outputs should be evaluated with its recent important rural development approaches such as EDC, Multi-Stakeholder Platforms and the establishment of a rural credit guarantee system.

It is seen that the adaptation to the programme in Kastamonu province went through a long process. IFAD officials and Turkish representatives struggled for a long time to ensure mutual adaptation, held many meetings, and expected participation in order to bring relations to solid foundations. It was calculated that the total project amount excluding vat in Kastamonu province in 2020 was 909,418.30 ₺, of which 633,773.82 ₺ was transferred to the accounts of the beneficiaries in the form of grants (70%). It should be seen that it is too early to see the reflections of URDP on rural areas. The programme was implemented and

supported for the first time in 2020. In 2021, applications were evaluated, but programme outputs were not received as the process was not completed yet. It should be well known that the positive effects of the programme on rural areas can be better seen in the medium term.

DECLARATION OF COMPETING INTEREST

The authors declare that there has no conflict of interest.

CREDIT AUTHORSHIP CONTRIBUTION STATEMENT

Osman İnan conceptualised and developed the format of the study, ensured the acquisition of data from IFAD and checked the accuracy of the information, contributed equally to the drafting of the manuscript and carried out the writing and visualisation of the final version of the manuscript.
Fatih Gürel created the research idea, conducted the research process, collected and checked the accuracy of the data obtained from Kastamonu province, contributed equally to the drafting of the research, reviewed and checked the final text of the article.

ETHICS COMMITTEE DECISION

This article does not require any ethical committee decision.

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Turkish Journal of Agricultural Engineering Research

Turk J Agr Eng Res *(TURKAGER)*

https://dergipark.org.tr/en/pub/turkager

https://doi.org/10.46592/turkager.13438187

ISSN: 2717-8420

2023, 4(2), 317-326

Review Article

Agriculture: A Pathway to Create a Sustainable Economy in Nigeria

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Article Info

Received: 22.08.2023 **Accepted:** 13.11.2023 **Published:** 31.12.2023

ABSTRACT

Agriculture has emerged as a critical sector for constructing a long-term economy that balances economic growth, social well-being, and environmental stewardship. This report examines the relationship between sustainable agricultural practices, economic development, and environmental protection to create a sustainable economy through agriculture. It emphasizes the critical significance of sustainable agriculture in generating economic prosperity. It explores how organic farming, agroecology, and precision agriculture improve production, maximize resource usage, and minimize input costs. These approaches not only promote agricultural output but also help to improve food security, farmer income, and rural livelihoods. It explains how sustainable agricultural techniques safeguard natural resources, soil fertility, water quality, and biodiversity. Sustainable agriculture guarantees the long-term sustainability of farming systems by protecting the environment, mitigating the effects of climate change, and lowering the risk of environmental damage. It explores how sustainable agriculture fosters entrepreneurship, value chain development, and market connections, resulting in job creation, income production, and rural economic regeneration. It emphasizes the significance of supportive policies, financial access, and market-oriented initiatives in unlocking the economic potential of sustainable agriculture.

Keywords: *Agroecology, Precision agriculture, Value chain development, Biodiversity*

To cite: Olabinjo OO and Opatola SB (2023). Agriculture: A pathway to create a sustainable economy in Nigeria. *Turkish Journal of Agricultural Engineering Research (TURKAGER), 4(2): 317-326. https://doi.org/10.46592/turkager.13438187*

INTRODUCTION

Agriculture is a multifaceted field encompassing various activities such as soil cultivation, crop production, and livestock rearing. Additionally, it includes the

subsequent processes of product preparation and marketing (Foley *et al.*, 2011). Agriculture is critical to providing the fundamental demands of the world's rising population and guaranteeing food security. According to the World Bank (2021), agriculture employs around 26% of the global workforce and supports the livelihoods of billions of people globally. Agriculture entails various, such as land preparation, planting, irrigation, fertilization, pest control, harvesting, and post-harvest processing.

Agriculture plays a vital role in the global economy, supplying millions of people with food, raw materials, and employment. However, traditional agricultural techniques have resulted in environmental degradation, resource depletion, and social issues. As a result, there is a rising awareness of the need to develop a sustainable economy through agriculture that incorporates environmental stewardship, economic viability, and social well-being. Creating a sustainable economy through agriculture is a vital component of attaining global sustainability, according to the United Nations' Sustainable Development Goals (SDGs). SDG 2, "Zero Hunger," encourages sustainable agriculture techniques to provide food security; SDG 8, "Decent Work and Economic Growth," on the other hand, highlights agriculture's role in promoting inclusive and sustainable economic growth. In addition, SDG 12, "Responsible Consumption and Production," emphasizes the importance of transforming agricultural systems into more sustainable and efficient practices. Agricultural sustainability refers to the capacity of farming techniques and strategies to fulfil current and future societal demands while retaining economic viability. It entails the responsible management of agricultural resources, the reduction of negative environmental consequences, and the long-term profitability and resilience of agricultural companies. This paper is therefore aimed at the investigation and analysis of the potentials of sustainable agriculture practices and its contribution to the creation of a resilient and prosperous economy.

Economy

The economy refers to the comprehensive framework involving producing, distributing, and consuming goods and services within a designated geographical area. This encompasses endeavors related to the generation of revenue and the establishment of financial prosperity. Economies can be classified into traditional, command, market, or mixed systems based on their respective approaches to producing and distributing goods and services. The economy also indicates a particular region's fiscal well-being and stability (Samuelson and Nordhaus, 2010). It involves the production of goods and services, the allocation of resources, the distribution of income, and the exchange of goods and services through various markets. An economy's key elements include production factors such as labor, capital, land, and entrepreneurship. These factors are combined in different ways to produce goods and services. Economic activities are often categorized into sectors, such as agriculture, manufacturing, services, and finance, each contributing to the overall functioning of the economy.

A sustainable economy is an economic system that aims to meet the needs of the present generation without compromising the ability of future generations to meet their own needs (WCED, 1987). It entails striking a balance between economic

growth, social well-being, and environmental stewardship to ensure long-term prosperity and resilience.

Economy of Nigeria

Nigeria's economy is a middle-income, diversified economy with rising industrial, finance, service, communications, technology, and entertainment industries. In terms of nominal GDP (gross domestic product), it is the world's 31st largest economy, the largest in Africa, and the 27th largest in purchasing power parity. Nigeria's economy primarily relies on oil, which provides for around 90% of exports and 25% of government revenue. On the other hand, the Government has been attempting to diversify the economy by encouraging other industries like agriculture, manufacturing, and tourism. The Nigerian economy has been gradually rising with real GDP growth averaging 6% per year between 2005 and 2014. However, due to a drop in oil prices, growth slowed to 2.3% in 2015 (World Bank, 2021). The Nigerian economy is confronted with several challenges, including, a high unemployment rate (23.1% in 2022), Poverty (40% of the population live below the national poverty line), Corruption, infrastructure deficit and Insecurity. Despite these challenges, Nigeria's economy can expand significantly in the following years. The country boasts a vast and growing population, a young labor force, and a variety of natural resources. Nigeria GDP annual growth rate for July 2020 till July 2023 is as shown in Figure 1.

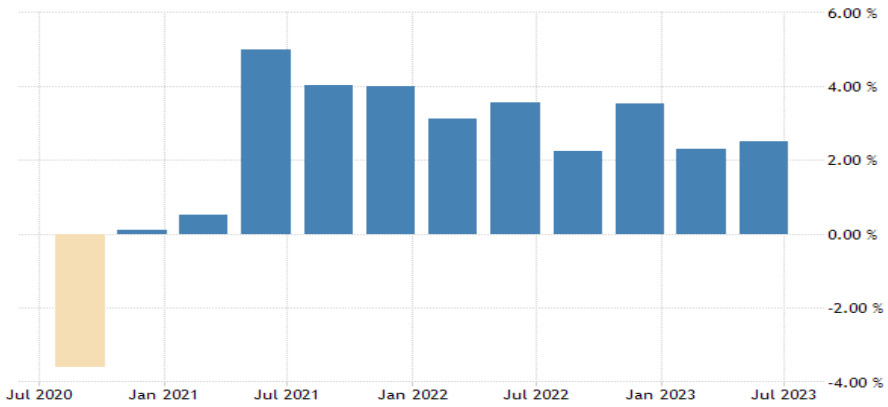

Figure 1. *Nigeria's GDP annual growth rate.*

Challenges in the Current Agricultural System of Nigeria

The current agricultural system faces several challenges that threaten its sustainability and long-term viability. The challenges facing the current agricultural system, including soil degradation, water pollution, deforestation, loss of biodiversity, climate change, and market distortions (Foley *et al.*, 2011). These issues have led to decreased crop productivity and overall instability in the agricultural economy. It was also highlighted that agricultural practices contribute significantly to global greenhouse gas emissions (Tilman *et al.*, 2017).

Sustainable Agriculture and Economic Development

Sustainable agriculture is critical to economic growth because it promotes ecologically responsible practices, increases production, and fosters long-term economic viability. Incorporating sustainable farming practices into economic development initiatives can have far-reaching consequences for rural and urban

communities (UNEP, 2019). In addition, sustainable agriculture encourages environmental responsibility and the conservation of natural resources. Soil conservation, water management, and biodiversity protection protect natural ecosystems and aid agriculture in the long run. Sustainable agriculture promotes the long-term viability of agricultural production systems by keeping soil fertility, conserving water resources, and protecting biodiversity.

The adoption of sustainable agriculture methods also helps to improve rural economies. Sustainable agriculture creates job possibilities and encourages rural entrepreneurship by diversifying agricultural operations and boosting value addition along the agricultural value chain. For example, establishing processing facilities, farmer cooperatives, and local marketplaces promotes revenue creation and economic activity in rural regions (World Bank, 2021).

Also, sustainable agriculture corresponds with customer demands for environmentally friendly and ethically produced food. Farmers and agribusinesses may benefit from the increased demand for organic and ecologically friendly products. Farmers may reach premium markets and obtain better prices for their goods by adhering to sustainable practices and satisfying market demands, resulting in improved revenue and profitability (FAO, 2020). Sustainable agriculture also helps local economies to be more resilient in the face of climate change and market changes. Crop diversification and climate-resilient strategies, for example, assist farmers in adapting to changing climatic circumstances, lowering their exposure to crop failures and revenue shocks. This resilience enhances local economies and promotes rural communities' overall stability and sustainability (IFAD, 2019). Effective policy and institutional frameworks are required to realize the promise of sustainable agriculture for economic growth. Through favorable regulations, access to funding, research and extension services, and market connections, governments must establish an enabling environment that promotes sustainable agriculture practices. Strengthening agricultural institutions and encouraging knowledge exchange among stakeholders helps to further integrate sustainable agriculture into economic development initiatives (World Bank, 2021).

Furthermore, agricultural sustainability highlights the necessity of market-oriented techniques and the development of value chains. It entails strengthening ties between producers, processors, distributors, and consumers to provide fair prices, market access, and income stability for farmers. Agricultural sustainability can contribute to poverty reduction, job creation, and general economic growth by expanding market possibilities and encouraging rural entrepreneurship (FAO, 2019).

Case Studies: Sustainable Agriculture Initiatives Driving Economic Development

1. Ogun State Anchor Borrowers' Program (ABP): The Ogun State Government launched the ABP to support small-scale farmers in the state. Farmers receive access to credit, improved seeds, fertilizers, and technical support through this program. It has helped increase agricultural productivity, enhance food security, and improve the livelihoods of farmers in the state.

2. Songhai Farm, Rivers State: The Songhai Farm in Rivers State is a model for sustainable agriculture and entrepreneurship. It integrates multiple agricultural activities, including organic farming, aquaculture, livestock rearing, and waste

recycling. The farm provides training and mentorship to farmers and agripreneurs, promoting sustainable practices and economic development in the region.

3. Lafiagi Fish Farm, Kwara State: The Lafiagi Fish Farm is a successful sustainable aquaculture project in Kwara State. It focuses on fish production using environmentally friendly and economically viable methods. The farm utilizes integrated fish farming systems, such as fishponds and vegetable cultivation, creating a sustainable and profitable enterprise.

4. Niji Farms, Oyo State: Niji Farms is an agribusiness enterprise specializing in poultry production in Oyo State. The farm implements sustainable practices, including organic feed production, waste management, and energy conservation. It has created employment opportunities, improved rural livelihoods, and contributed to the local economy.

5. Jos Green Centre, Plateau State: The Jos Green Centre is an agroecology training and demonstration farm in Plateau State. It focuses on promoting sustainable agriculture practices among smallholder farmers. The center provides training on agroecology principles, organic farming techniques, and value chain development, enabling farmers to adopt sustainable practices and access better markets.

Policy and Institutional Frameworks for Promoting Sustainable Agriculture and Economic Growth in Nigeria

Policy and institutional frameworks are critical in promoting sustainable agriculture and accelerating economic growth. They foster an atmosphere conducive to adopting sustainable practices, allow market access, and ensure the efficient execution of agricultural policy. Here are a few examples of policy and institutional frameworks that support sustainable agricultural and economic growth:

1. National Agriculture Policy: Many nations, including Nigeria, have adopted national agriculture policies that promote sustainable agriculture and give a road map for its implementation. These policies establish goals, objectives, and action plans for long-term agricultural growth, including research and extension services, market access, input supply, and environmental protection.

2. Ministry of Agriculture and Rural Development: The Ministry of Agriculture and Rural Development, or its equivalent, is responsible for developing and enforcing agricultural policy. It oversees agricultural operations, especially sustainable agriculture programs, by providing leadership, coordination, and monitoring. The ministry works with other government agencies, research institutions, and stakeholders to promote sustainable practices, assist farmers, and assure agricultural sector growth.

3. Research and Extension Services: Agricultural research institutions and extension services are important in promoting sustainable agriculture. They do research to create new agricultural techniques, better varieties, and long-term production systems. Extension services communicate this information to farmers by offering training, technical advice, ‘and assistance in implementing sustainable practices.

4. Financial Institutions and Access to Finance: Collaboration between financial institutions and agricultural stakeholders is critical for sustainable agriculture. Credit, grants, and other financial services are customized to the unique needs of

farmers and agribusinesses involved in sustainable agriculture. Farmers may use this financing to invest in sustainable methods, buy inputs, and expand their enterprises.

5. Market Linkages and Value Chain Development: Effective market connections and value chain development are critical for the economic viability of sustainable agricultural efforts. Governments and agricultural agencies collaborate to build market infrastructure, promote fair trade practices, and foster the growth of value-added processing and marketing businesses. Farmers will be able to access markets, command fair prices for their goods, and capture greater value along the agricultural value chain.

6. Environmental Regulations and Standards: Strong environmental laws and standards are essential for sustainable agriculture. Government enact and enforce regulations to conserve natural resources, prevent pollution, and encourage ecologically friendly farming methods. Compliance with these standards supports soil, water, and biodiversity protection, resulting in long-term sustainability and economic growth.

7. Farmer Organizations and Cooperatives: Farmer groups and cooperatives are important in advocating for farmers' interests in sustainable agriculture. They give farmers a unified voice, enable access to inputs, markets, and financial services, and encourage information exchange and capacity building among its members.

These policy and institutional frameworks offer the essential support, coordination, and resources to promote sustainable agricultural and economic success. Collaboration between government agencies, research institutions, financial institutions, farmer groups, and other stakeholders is essential for successful implementation. These frameworks contribute to adopting sustainable practices, increased productivity, and overall expansion of the agriculture sector by establishing an enabling environment.

Sustainable Agriculture: A pathway towards a Sustainable Economy

Sustainable agriculture is a holistic approach to farming that addresses the environmental, social, and economic challenges of conventional agriculture. It recognizes the interdependence between agriculture and the broader ecosystem, seeking to promote long-term sustainability and resilience. We can pave the way towards a sustainable economy that balances economic growth with environmental stewardship and social well-being by adopting sustainable agricultural practices.

Technological innovations used for Sustainable Agriculture in Nigeria

Using technologies such as precision agriculture, which involves using advanced technologies to optimize crop yields and efficiency (Zhang *et al,.* 2016), can minimize environmental impacts while maximizing productivity and profitability. The following are some of the innovations:

1. Precision Agriculture: Precision agriculture involves the use of technologies such as Global Positioning System (GPS), Geographic Information System (GIS), and remote sensing to optimize farm management practices. It enables farmers to precisely apply inputs like fertilizers, water, and pesticides, reducing wastage and environmental impact while maximizing crop yields (Fountas *et al.,* 2015; Zhang *et al.,* 2018). Precision agriculture also allows for real-time monitoring of crop

health and growth, facilitating early detection of diseases or nutrient deficiencies. Adopting precision farming practices that maximize resource usage, decrease waste, and boost output is also part of sustainable agriculture. This method allows farmers to increase efficiency, reduce environmental impact, and increase economic returns.

2. Controlled Environment Agriculture: Controlled environment agriculture (CEA) involves growing crops in controlled environments such as greenhouses, vertical farms, or aquaponics systems. These systems precisely control temperature, humidity, light, and nutrient levels, optimizing crop growth and reducing the need for chemical inputs (Jensen and Malter, 2019). CEA allows for year-round production, conserves water, and minimizes the use of pesticides, making it an environmentally sustainable approach.

3. Vertical Farming: Vertical farming is a form of CEA that involves growing crops in vertically stacked layers or towers, often indoors. Vertical farming maximizes land productivity by utilizing vertical space while reducing the need for extensive land use (Despommier, 2013). It can be integrated into urban areas, minimizing transportation distances and promoting local food production. Vertical farming enables efficient resource use, such as water recirculation and energy-efficient LED lighting systems.

4. Robotics and Automation: Robotics and automation technologies are revolutionizing various aspects of sustainable agriculture. Automated systems can perform tasks like planting, harvesting, and crop monitoring with precision and efficiency (Kusumaningtyas *et al.,* 2019). This reduces labor requirements and enhances productivity while minimizing human error. Drones equipped with sensors and cameras are also used for crop monitoring, disease detection, and pesticide application, providing real-time data for informed decision-making.

5. Internet of Things (IoT): IoT technology connects devices, sensors, and equipment on the farm, enabling real-time data collection and analysis. IoT-based systems can monitor soil moisture, temperature, and nutrient levels, allowing farmers to optimize irrigation and nutrient management (Zhang *et al.,* 2020). This promotes resource efficiency, reduces water and fertilizer waste, and improves crop health. IoT technology also facilitates remote monitoring and control of farm operations, enhancing productivity and reducing operational costs.

6. Genetic Engineering and Biotechnology: Genetic engineering and biotechnology contribute to sustainable agriculture by developing crop varieties with improved traits, such as pest resistance, drought tolerance, and enhanced nutritional content (Tester and Langridge, 2010). Biotechnology techniques like genetic modification and genome editing can reduce reliance on chemical pesticides and fertilizers, reducing environmental impact and improving resource efficiency.

7. Agroecological techniques that highlight the incorporation of ecological principles into farming systems must be promoted. Agroecology focuses on crop diversification, reducing external inputs, and improving ecosystem services to increase production while avoiding negative environmental consequences (Pretty *et al.,* 2018). Agroecology emphasizes incorporating ecological concepts and social factors into agricultural operations to improve economic viability, rural livelihoods, and food security. Agroecological methods attempt to maximize resource utilization, minimize dependency on external inputs, and increase production in a sustainable and economically feasible way by implementing ecological concepts such

as biodiversity protection, nutrient cycling, and natural pest management. Organic farming, agroforestry, and integrated crop-livestock systems have demonstrated the potential for increased yields, lower production costs, and increased market value for organic and sustainably produced goods (De Ponti *et al.*, 2012).

8. Adopting climate-smart strategies to meet the problems brought by climate change is part of sustainable agriculture. These activities include drought-tolerant crop varieties, water-efficient irrigation systems, and soil management approaches that boost carbon sequestration and resistance to extreme weather events (Lobell *et al.*, 2014).

9. Sustainable value chains encompass the entire manufacturing process, from inputs and production methods to processing, distribution, and consumption. It entails encouraging fair trade, assisting local and small-scale farmers, and building transparent and equitable market systems that pay farmers a reasonable price for their products (Gustafson *et al.*, 2020).

CONCLUSION

A sustainable economy built on agriculture promotes environmental sustainability by reducing the negative impacts of farming practices on ecosystems. It focuses on soil conservation, water management, biodiversity preservation, and the responsible use of resources. By protecting natural resources and minimizing pollution, sustainable agriculture contributes to the long-term viability of our ecosystems and the resilience of agricultural systems. Economically, sustainable agriculture offers numerous benefits. It improves the profitability and resilience of farmers by reducing input costs, enhancing market opportunities, and tapping into growing consumer demand for sustainably produced food. Sustainable practices also contribute to stable food prices, reduce the risk of market shocks, and promote economic stability in the agricultural sector. Transition to a sustainable economy through agriculture requires collective efforts from various stakeholders. Governments, international organizations, farmers, consumers, and the private sector must collaborate to promote sustainable agricultural policies, provide financial support, and invest in research and innovation. Education and awareness programs are also essential to foster a culture of sustainability and promote the adoption of sustainable practices. Through the collective commitment to sustainability, we can create a resilient and prosperous economy that benefits both people and the planet. Finally, developing a sustainable economy via agriculture is critical for solving the complex difficulties that our world faces. We can promote environmental sustainability, economic viability, and social well-being in agriculture using agro ecological concepts, precision farming techniques, climate-smart practices, and sustainable value chains. We can strive toward a future in which agriculture contributes to a sustainable and resilient global economy by integrating policy support, stakeholder engagement, and technology developments.

The following are recommendations to ensure the creation of sustainable economy through agriculture

1. Sustainable Farming Practices: Encouraging and supporting sustainable farming practices is essential for the long-term viability of agriculture. This includes

promoting organic farming, agroforestry, and permaculture techniques that minimize the use of synthetic inputs, conserve natural resources, and promote biodiversity. Governments and agricultural organizations can provide incentives and technical support to farmers who adopt sustainable practices.

2. Investment in Agricultural Technology: Embracing technological innovations in agriculture can significantly enhance productivity and sustainability. This includes the adoption of precision farming techniques, use of advanced machinery and equipment, and leveraging data-driven insights for efficient resource management. Additionally, investment in research and development for biotechnology and genetic engineering can lead to the development of resilient crop varieties that are better adapted to changing environmental conditions.

3. Market Diversification and Value-Added Products: Encouraging diversification of agricultural products and promoting value addition can contribute to a more resilient and sustainable agricultural economy. Farmers can be supported in diversifying their crops or livestock to reduce dependency on a single commodity. Furthermore, promoting the development of value-added products such as organic food products, herbal supplements, or bio-based materials can create new economic opportunities within the agricultural sector.

4. Access to Finance and Infrastructure: Ensuring that farmers have access to affordable credit, insurance services, and modern infrastructure such as irrigation systems, storage facilities, and transportation networks is crucial for building a sustainable agricultural economy. Financial institutions and governments can design tailored financial products for smallholder farmers and invest in rural infrastructure development to improve market access and reduce post-harvest losses.

5. Education and Training: Investing in education and training programs for farmers is essential for enhancing their skills, knowledge, and capacity to adopt sustainable agricultural practices. This includes providing extension services, vocational training, and educational resources on topics such as soil health management, water conservation, integrated pest management, and climate-smart agriculture.

DECLARATION OF COMPETING INTEREST

The authors declare that they have no conflict of interest.

CREDIT AUTHORSHIP CONTRIBUTION STATEMENT

The authors confirm contribution to the papers as follows:
Oyebola Odunayo Olabinjo: Writing (original draft, Review, Editing, Visualization):
Stephen Boluwatife Opatola: Investigation.

ETHICS COMMITTEE DECISION

This article does not require any ethical committee decision.

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TURKISH JOURNAL OF AGRICULTURAL ENGINEERING RESEARCH

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2023

e-ISSN:2717 - 8420

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