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Techno-Economic Analysis of the Statistically Optimized Whiteboard Marker Ink Production Process using Municipal Waste Materials Sourced in Ikot Abasi L.G.A.

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Abstract: This work investigated the economic viability and optimization of whiteboard marker ink using central composite design (CCD) of response surface methodology (RSM). The production was achieved using biochar, bioethanol, and natural resin at the range of 10 - 50 g, glycerol from 100 - 500 mL, and 10g – 50g, respectively. The Ink produced was characterize to check the viscosity, drying time, erasability and density. The ink at optimal condition has a drying time of 3.39s, viscosity of 1.47mPa.s at 30g of biochar, 300 mL of glycerol, and 30g resin. The results were compared to those of commercial inks. The results showed that the viscosity of commercial ink was 2.1mPa·s. and analysis revealed that the commercial marker ink had the fastest drying rate than the ink produced. Fourier transform infrared spectroscopy confirmed the presence of functional groups associated with the whiteboard marker ink produced. The techno-economic analysis carried out shows that it is viable and promising to invest on whiteboard marker with the raw materials understudied. The overall results show that natural sourced materials are viable and innovative material for whiteboard ink production.

Keywords*: Agricultural Waste, Whiteboard Marker Ink, Optimization, Response Surface Methodology, Techno-Economic Analysis.*

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I. INTRODUCTION

Municipal solid waste has become a highlight among the many waste found in Akwa Ibom particularly in Ikot Abasi. During academic activities when students are in session the municipal waste generated is high, which has generated serious concern especially on waste disposal and management. Over the past few years, many studies have been carried out on the recycling of waste to useful product. Agriculture waste has been converted to bioethanol, waste plastic bottle has been converted to bioethanol (Afia *et al.*,2025). Waste are classified into biodegradable and non-biodegradable waste. Biodegradable waste is waste that microorganism act on reducing the micronutrient and chemical composition of the waste while non-biodegradable is waste that microorganisms are unable to alter the chemical composition of the waste. It is on this background that the study on production of whiteboard marker ink wish to adopt waste materials.

Whiteboard marker ink (WMI) on the other hand is specifically used as writing tool. WMI has been recognize for

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its unique benefit over chalk. WMI has been utilized in institution, churches, conferences, workshop and by individual. WMI serve a variety of purposes, including coloring, and writing. The production of marker ink has garnered significant interest from scientists and researchers. This is because WMI can be produced from a variety of agricultural products and waste, such as berry seed (Nwafulugo *et al.*, 2019), mangosteen leaves (Basri *et al.*, (2021), and neem trunk (Sounjanya *et al.*, 2021). To the best of our knowledge, no research has been conducted on using renewable agricultural waste and non-biodegradable waste (plastic bottle).

Conventional whiteboard marker inks are produced mainly from non-renewable synthetic resources and chemicals, including solvents such as 2-pyrrolidone, propanediol, glycols, and phthalates, all derived from petroleum and petrochemicals (Thakker AM, & Sun D, 2022; Prasanna et. al., 2023). Conventional inks though have high drying time and are durable, they release volatile organic compounds (Saidina *et al.*, 2019) and are harmful to one's heath and the environmental. It could cause fatigue, irritability, and memory impairment (Valen *et al.*, 2018). These impediments provide the following insights for future research in producing ink from naturally sourced renewable materials.

Many researchers have utilized agricultural products to manufacture whiteboard marker ink. Hamzah *et al.*, 2025 produced ink from dabai pulp-based; Nwafulugo et al (2019) produce Marker ink from berry seed extract, Basri *et al.* (2021) produced mangosteen-leaves-based marker ink, Soujanya & Harish (2021) synthesized easily erasable whiteboard ink using locally available *Azadiracta indica* (neem) gum. Dagde *et al.*, (2019); Thakker & Sun (2024); synthesized inks from naturally sourced biomaterials

Raw materials formulation which includes solvents, pigments, and binders in WMI production is essential for excellent writing quality as evidenced by their favorable drying time, pH, viscosity, and density. Among the ink formulations tested, one containing carboxymethyl cellulose (CMC) was found to be the most effective viscosity modifier for the enzyme (Biswas *et al.*, 2022). Ding *et al*. (2020) demonstrated that CMC-based edible inks exhibited excellent printing quality and chromatic values on coated paper. Several reports have been published to date regarding the use of carboxymethyl cellulose (CMC) and glycerol as binding agents or additives

The approach on the use of waste materials addresses environmental concerns and promotes an eco-friendly formulation of WMI by replacing commercial marker ink. Understanding the formulation process of WMI and their effects on WMI has gain serious attention globally. Various materials and methods have been adopted to produce WMI, focusing on essential properties such as viscosity, color and drying time. However, due to the differences in physicochemical properties of the materials, different pigments have been studied to have different effects on WMI properties. According to Nwafulugo *et al.*, (2019), berry-based marker inks properties show that viscosity and drying time are keys for proper application and usability. Meanwhile, herbal inks from plant sources like bio-indigo and quebracho red were tested for viscosity, drying time, and density (Thakker & Sun 2022). Other studies affirm to this assertion that viscosity and drying time are keys to whiteboard ink performance (Soujanya and Harish 2021). At a very high or low viscosity WMI can clog and cause uneven application, while drying time shows the adhesive properties of WMI.

These properties, along with color and texture, are keys to evaluating the ink's performance and printability. Therefore, this study aims to explore the potential of MSW as an alternative, sustainable resource for developing ecofriendly and cost-effective WMI by optimizing its formulation using response surface methodology (RSM) and evaluating its Techno-economic analysis in comparison with conventional ink.

II. MATERIALS AND METHOD

➢ *Materials*

Solid wastes including wood and plastic bottle were sourced from federal university of technology, and its environs. The chemical reagents were bought from Uyo main market and Enugu Ogbete market. The chemical reagents include sulfuric Acid (H_2SO_4), sodium Hydroxide (NaOH), Engineered E. Coli Strain, calcium hydroxide ($Ca(OH)_2$), detergent solution, luria-bertani (LB) medium, and distilled water.

➢ *Sample Preparation*

- *Pigment Preparation*

First, the woods were washed and sundried for fourteen days. Following that, the dried woods were crushed with a jaw crusher FZSP6503GT model and converted to charcoal by burning. The pieces of charcoal were further crushed into smaller size and sieve with 700µm sieve prior for use for the experiment.

- *Bioethanol Preparation and Production*

The collected plastic bottles composed of edible drinks and water were manually sorted and contaminants/dirts were removed while residual liquid was removed with detergent solution for 1 hour and rinsed with clean tap water. The washed plastic bottles were sundried for ten days prior to processing it to bioethanol. The clean bottles were crunched into 5-10mm sizes flakes using the same jaw crusher (model: FZSP 6503GT). Afia *et al*. (2025) bioethanol production process was adopted. The flakes were depolymerized through acid-catalyzed glycolysis to monomers. Thereafter reacted with ethylene glycol and in the presence of a catalyst (concentrated H_2SO_4). The reaction was carried in a reactor equipped with a magnetic stirrer and reflux condenser at 190^{o}C for 8 hours. The products which are primarily bis (2-hydroxy ethyl) terephthalate (BHET) and oligomers, was then hydrolyzed in an aqueous solution at 90^{o}C for 4 hours to yield terephthalic acid (TPA) and ethylene glycol (EG), and were separated with filter paper. The pH of EG-rich filtrate

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was neutralized to 7.0 with NaOH. Then, Fermentation was conducted in a 2L bioreactor with a working volume of 5L, containing the neutralized EG solution and engineered strain of Escherichia (E. Coli Strain K-11 which expresses genes for EG assimilation and ethanol production) was used. Conversion conditions were maintained at 30°C at a pH 6.8 and 200rpm agitation for 96hours. Anaerobic conditions were induced after an initial aerobic growth phase to promote ethanol production. The fermentation broth was centrifuged for 40minutes to separate cells and particles. The supernatant containing ethanol was distilled at 78.3°C.

- *Gum Preparation*

Gum was extracted from neem trees and dissolve in distilled water prior to use for WMI production.

➢ *Characterization of Feedstock*

- *Properties of Biochar*

The charcoal was characterized to determine the physiochemical properties adopting ASTM standard. The morphological structure and elemental composition were determined using scanning electron microscope (SEM), Fourier transformed infrared (FTIR) Spectroscopy and X ray diffraction (XRD) as adopted by Umeagukwu *et al.* (2023).

- *Properties of Bioethanol*

The physiochemical properties of bioethanol produced was determined by proximate analysis and ASTM standard. The functional group was determined with Fourier transformed infrared (FTIR).

➢ *Production of Whiteboard Marker Ink*

The whiteboard marker ink was prepared by mixing 20g of pigment with 200ml of bioethanol to form charcoal-bioethanol solution and thereafter the 20g of gum in 50cm^3 was added to the solution and thoroughly mixed at 1500rpm for 30mins for homogeneity. The mixture was boiled together on a hot plate at a temperature of 30°C for 30 min to improve homogeneity. Thereafter, the mixture was collected in a container using a sieve to remove the pigment powder. Prior to testing, the WMI was stored in air tight transparent plastic container for 24hr at room temperature.

➢ *Characterization of WMI*

The physiochemical properties of whiteboard marker ink (WMI) produced was determined by proximate analysis and ASTM standard as adopted by Umeagukwu *et al.* (2024).

➢ *Effect of Process Parameters*

The effect of three process variables on the viscosity on WMI produced was studied. In this study, five values were assigned to each variable. As one variable is tested across the five values, the other two variables are kept constant. The same process was adopted for the other two variables.

➢ *Response Surface Methodology (RSM) Study on WMI Production*

The Design Expert 13 software was used to design experiments to determine the optimal conditions of the three variables on WMI production and its viscosity. Pigments, solvent and binder are the independent variables while viscosity is the dependent variable on the marker ink production. The interaction results and optimum parameters were obtained. Table 1 presents the RSM model experimental data values and their encoded levels. The process parameters' actual levels and ranges were expressed as − 1 (low), 0 (center), + 1 (high), + α (maximum), and − α (minimum). The WMI ink production was produced at pigment ranging from 20 to 40 g, bioethanol of 200 to 400 mL, and gum of 20 to 40g. Table 2 shows the experimental design for the 20 runs that were performed in order to produce whiteboard marker ink using a three-level central.

Table 1 Variables in Coded and Actual Values for RSM Experimental Design

Variable/factor	Unit	(+2) level	(-2) level	(0) level	(+1) level	(-1) level
Charcoal	G	40	20	30	51.36	8.64
Gum	G	40	20	30	51.36	8.64
Bioethanol.	Ml	400	200	300	513.64	86.36

➢ *RSM-CCD Design of Experiment*

A three-level factor central composite design (CCD) of RSM of version 13 produce twenty experimental runs and a regression model showing the polynomial relationship between the dependent variable and independent variables as shown in Equation 1. Each experiment was performed and the viscosity of the WMI determined. The descriptive statistics and statistical tests of the experimental work were analyzed using analysis of variance (ANOVA).

$$Y = \beta_0 + \sum_{i=1}^{3} \beta_i X_i + \sum_{i=1}^{3} \beta_{ii} X_i^2 + \sum_{i=1}^{3} \sum_{j=i+1}^{3} \beta_{ij} X_i X_j \quad (1)$$

Table 3 Experimental Design Matrix for Production of WMI

Runs	Charcoal (g) A	Gum (g) B	Bioethanol (ml) C
	Coded	Coded	Coded
1	-1	-1	-1
2	0	0	0
3	0	-1	0
4	0	0	0
5	+2	-2	+2
6	-2	+2	+2

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7	0	0	0
8	0	+1	0
9	-2	-2	+2
10	0	0	+1
11	0	0	0
12	+2	-2	+2
13	0	0	0
14	-2	+2	-2
15	+2	+2	-2
16	+1	0	0
17	-2	-2	-2
18	0	0	0
19	0	0	0
20	+2	+2	+2

➢ *Characterization of Bio-Ink*

The WMI produced was characterized and compared with international standard with analytical tools such as Fourier transformed infrared (FTIR) spectroscopy. The FTIR spectra were recorded in the electromagnetic wave range of 4000 to 500cm^{-1} (Blindheim & Ruwoldt 2023).

➢ *Techno-Economic Analysis of WMI Production.*

The techno-economic feasibility of any production on a small scale in the laboratory present the technical processes and economic feasibility of the production process (Umeagukwu *et al.* 2024). This study presents the fixed capital, working capital, cost of producing WMI and revenue generated after the sale of WMI.

III. RESULTS AND DISCUSSION

➢ *Characterization of Charcoal*

- *Physiochemical Properties of Charcoal*

Table 3 depicts the result of the proximate analysis carried out using ASTM standard as reported by Abdullah *et al.*, (2011). From the table, it could be observed that charcoal has pores and surface area. The particle density, bulk density, fixed carbon and organic carbon were determined to be 1.0034gcm^{-3}, 0.921g/cm^3, 57.81 % and 0.28%, respectively as found in Table 3. The charcoal has slight acidic properties of 6.87 with no moisture content. The result is similar to Ma Grace *et al* (64.77% fixed carbon for coconut shell charcoal), and Duangkham and Thuadaji (46.9%/41.1% fixed carbon for rice straw/pineapple peals charcoal) assertion about the properties of charcoal in the year 2020 and 2023 respectively.

Table 3 Charcoal Sample and Characterization

Properties	**Values**
Fixed Carbon (%)	57.81
Particle density (g/cm^3)	1.0034
Porosity (%)	33.78
Moisture (%)	--
Ph	6.87
Conductivity (µs/cm)	10.27
Ash (%)	12.45
Bulk density (g/cm^3)	0.921
Organic carbon (%)	0.28

- *Morphological Structure of Charcoal*

The morphology of the charcoal sample is presented in Figure 1 at a magnification of 300x showing the micrographs with the presence of pores and surface area.

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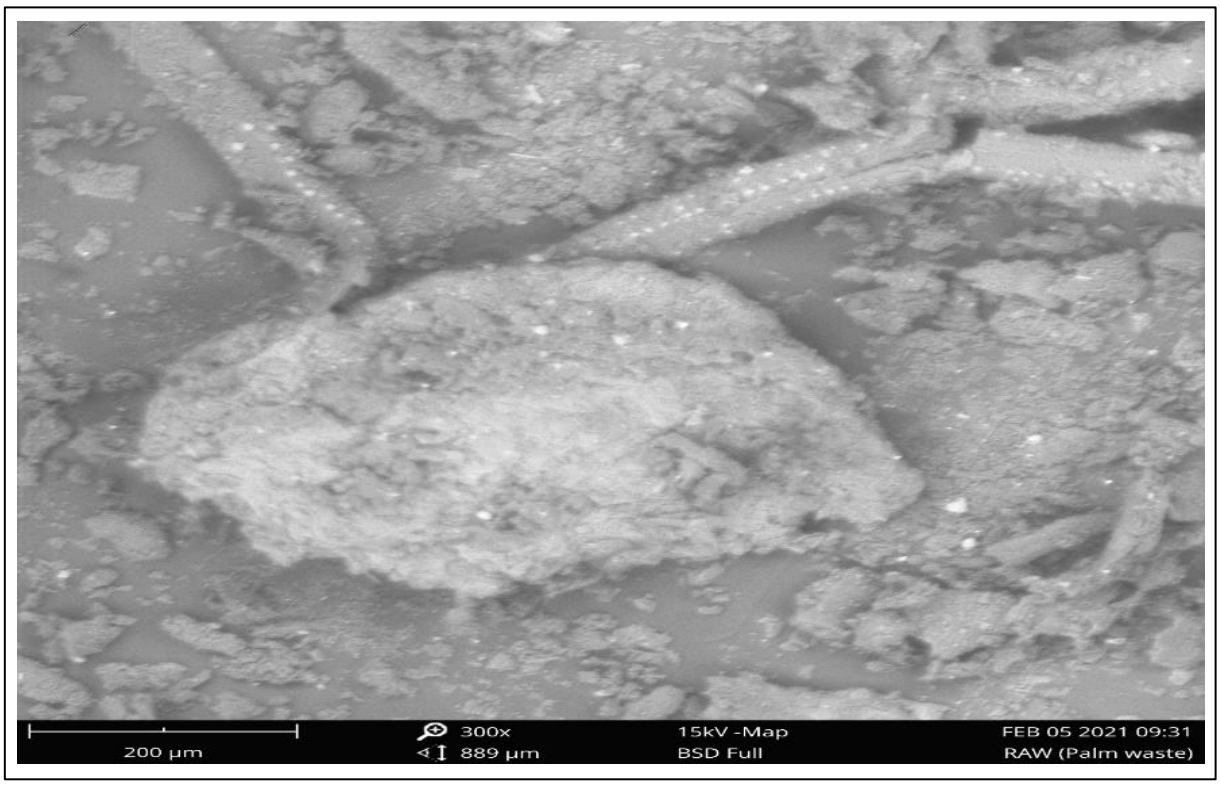


Fig 1 Micrographs of Wooden Charcoal

- *Fourier Transform Infrared (FTIR) Analysis of the Charcoal*

The FTIR spectrum in Figure 2 shows various functional group/ compound present in the pigment. The presence of carbon and OH were confirmed by FTIR spectrum in Figure 2. The peaks show the different structure of carbon/carbonyl functional groups and hydroxyl functional group and were assigned their electromagnetic wave numbers. The peak intensity at 700 – 900cm^{-1} represents the presence of carbon with aromatic ring stretching. Wave number between 1200 -1400 and 1800 – 2190.7 shows carbonxyl group. 2007-3011.7cm^{-1} wave number depicts the carbon aliphatic stretching while 3100 – 3600cm^{-1} wave number shows the hydroxyl functional group and this fall in the same range as reported by Tiguia-Arashiro *et al*. (2023).

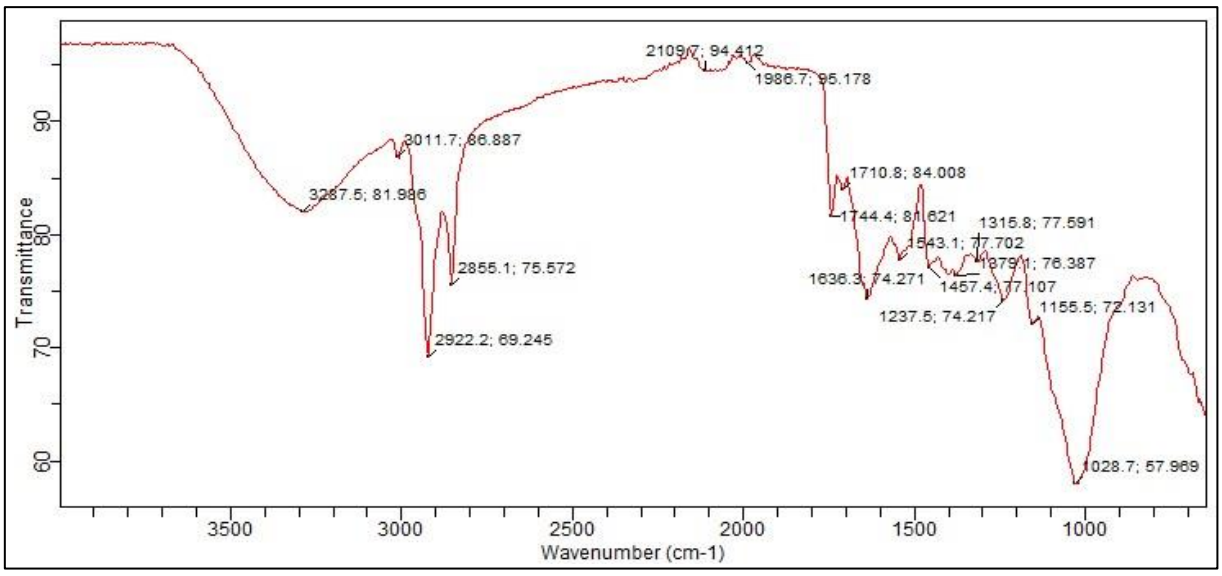


Fig 2 FTIR Spectrum of Charcoal.

- *X-Ray Diffraction Pattern of the Raw Catalyst*

Tables 4. presents the x-ray diffractometer elemental composition of the charcoal under study. It contains some alkaline and alkaline metals though with high carbon content in graphite form. Other form at which the pigment belongs to include sylvite, marialite, davyne, cristobalite and englishite group confirming the presence of alumina, alkali metals, oxides of metals and silica.

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Table 4 XRD Charcoal Qualitative Analysis Result

Phase Name	Element composition	Figure of merit
Sylvite	K, Cl	1.67
Davyne	Na, K, Ca, Al, O, Si	2.13
Cristobalite	SiO_2	2.34
Englishite	K, Ca, Al, PO_4, OH	1.67
Graphite	C	3.52
Marialite	Na, AL, Si, CL, O	1.36

➢ *Characterization of Bioethanol*

- *Physiochemical Properties of Bioethanol*

The fuel properties of bioethanol produced from plastic bottle feedstocks were analyzed and compared with ASTM D4806 as shown in Table 5 as adopted by Afia *et al*., (2025). The bioethanol properties in Table 5, confirmed its potential as a good feedstock for WMI production. Bioethanol exhibited exceptionally high-octane number value and low sulfur contents. This confirms their excellent anti-knock property. The bioethanol has low viscosity and its refractive index (1.35) is 0.02 higher than that of water (1.33). The same higher content was observed in density and water content properties as presented in the results in Table 6.

Table 5 Properties of Produced Bioethanol

Property	ASTM D4806 Specification	Bioethanol
Ethanol Content (% V/V)	≤ 92.1% (min)	74.1
Water Content (% V/V)	≤ 1.0 (max)	0.91
Density at 20°C(kg/m^3)	789.2 ± 0.3	799.1
Octane Number (RON)	≥ 99	107.2
Flash Point (°C)	12.8 – 14.0	12.5
Sulfur Content (mg/kg)	≤ 5 (max)	4.1
Pour point	< - 40	-40
Acid value mg KOH/g	≤ 0.007 (max)	0.004
Kinematic Viscosity at 40°C (mm^2/s)		1.17
Ph	> 6.5	6.9
Refractive index	1.360 – 1.362	1.35

- *Instrumentation Analysis for Bioethanol*

The FTIR spectroscopy and GC-MS were used as analytical instrument for analysis of bioethanol produced from plastic bottles.

✓ *FTIR Analysis*

The functional group in bioethanol was detected with FTIR spectroscopy. The FTIR spectrum of the bioethanol is shown in Figure 2. From the result, discernible peaks of note were recorded. The region 679.61cm^{-1} – 886.65cm^{-1} and the peak at 3160.41cm^{-1} indicate the presence of =C-H(alkenes) with bending type of vibrations and are unsaturated. The characteristics peaks found in the region 1050.15 – 1197.23cm^{-1} indicates of C-O (carboxyl group). The band region of 1387.88 cm^{-1} and 1335.67cm^{-1} can be ascribed to the bending vibration of C-H methyl groups. The region 1861-2011cm^{-1} indicates the presence of aromatic combination while region 2179.68-2281cm^{-1}, 2351.30 and 3911.89 cm^{-1} indicates the presence of O-H group stretched in hydroxyl. They are single bounded and at high energy region in the spectrum (Keke *et al.*, 2023). The peaks at 2874.75cm^{-1} and 2982.07cm^{-1} indicate symmetric and asymmetric stretching vibrations of C-H alkane groups.

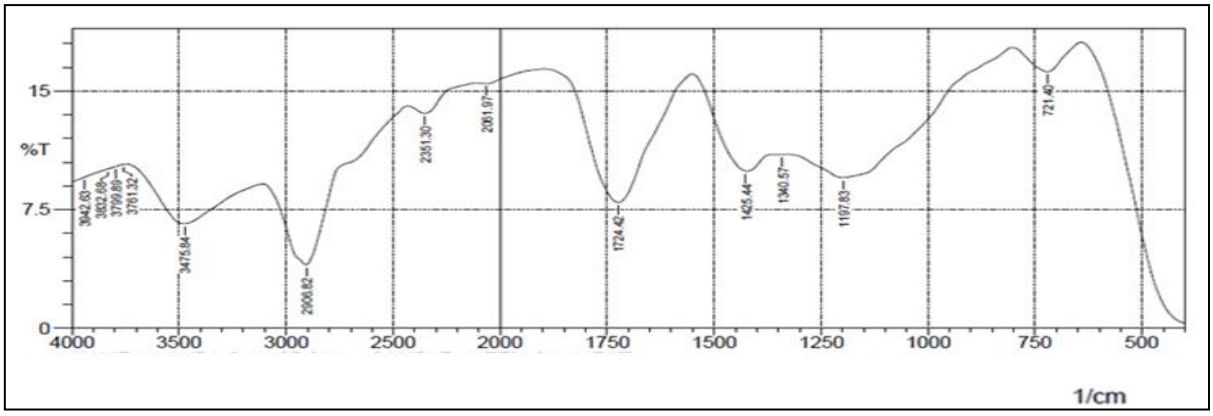


Fig 3 FTIR Spectrum of Bioethanol

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✓ *GC-MS Analysis*

The alcohol composition of bioethanol was carried out with the aid of gas chromatography mass spectrometry (GC-MS). The composition of bioethanol is shown in Table 6 and the chromatogram in Figure 4. The major analyte that forms the saturated compound discovered are; n-Hexadecanoic acid, Dodecanoic acid, Tetradecanoic, and Dodecyl acrylate. Other analytes in bioethanol are the high saturated bioethanol which gives a high proportion of ester and lower melting point olieic acid, phenol, 1-Eicosanol, 6,10-dodecatrien-1-ol and Methyl stearate.

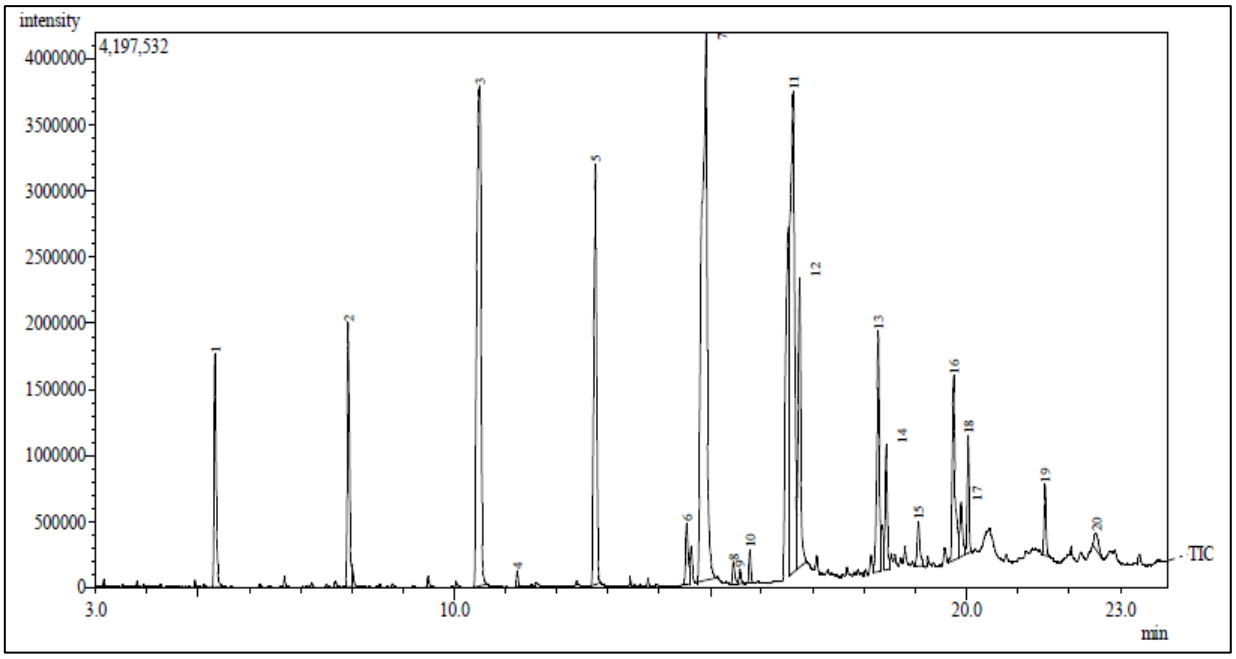


Fig 4 The Chromatogram of the Bioethanol Produced.

Table 6 Organic Composition of Bioethanol Produced.

Peak	Chemical Formular
1	n-Hexadecanoic acid
2	nonadecanol
3	Dodecanoic acid
4	Hexadecanol,
5	1,2-diethyl
6	Dodecyl acrylate
7	Methyl stearate
8	9-Octadecenol
9	Oleic acid
10	Phenol
11	Dimethylethyl
12	6,11-Dimethyl-2,
13	Tetradecanoic
14	6,10-dodecatrien-1-ol
15	1,2 di -Eicosanol

➢ *Impact of Process Variables on WMI Viscosity*

The procedure in section 2.6 was adopted and graphical results are shown in Figures 5 to 7 comparing the effect of independent variable on dependent variables keeping two independent variables constant. Other constant variables in the study on the effect of process variables are Mixing Speed at 1200rpm, mixing temperature of 30°C, 100cm^3 distilled water for 50min, and 40ml Surfactant.

- *Impact of Mass of Charcoal on WMI Viscosity*

20g to 40g of charcoal was experimented in the production of WMI and its effect on the viscosity of WMI was determined as shown in Figure 5. It was discovered that the viscosity increases as the mass of charcoal increases. The increase is due to quantity of charcoal beyond the solvent needed to dissolve the pigment.

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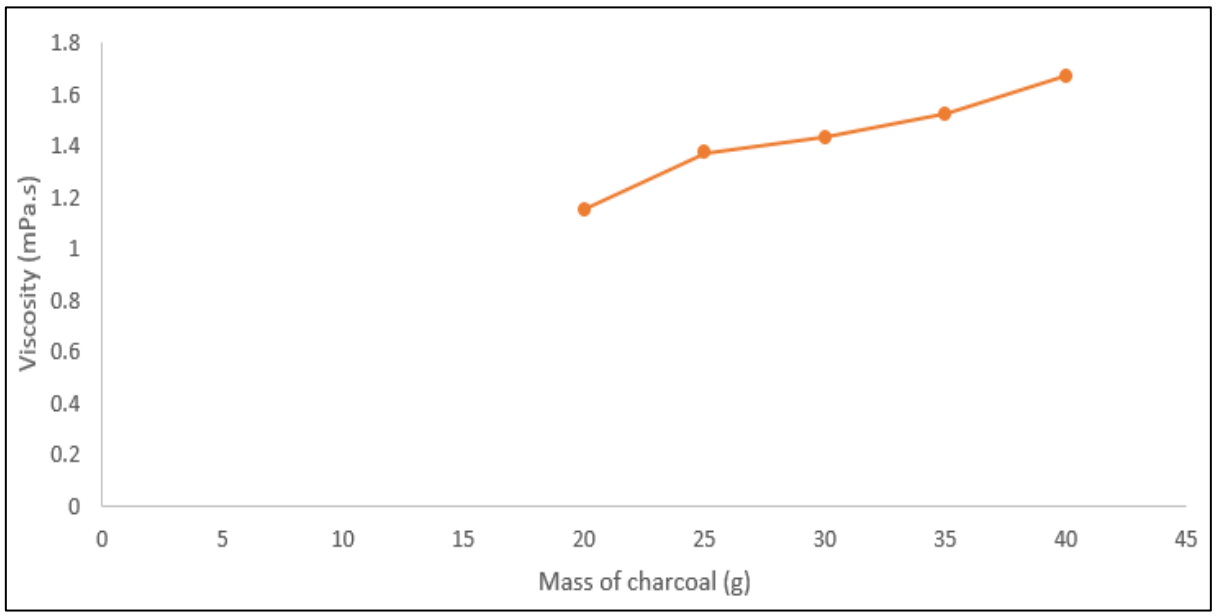


Fig 5 Mass of Charcoal Versus WMI Viscosity.

- *Impact of Mass of Gum on WMI Viscosity*

20g to 40g of gum was experimented keeping the other independent variables constant in the production of WMI, and its effect on the viscosity of WMI was determined as shown in Figure 6. It was discovered that the viscosity increases as the mass of gum increases. As the gum increase the more viscous the WMI and less legible the ink.

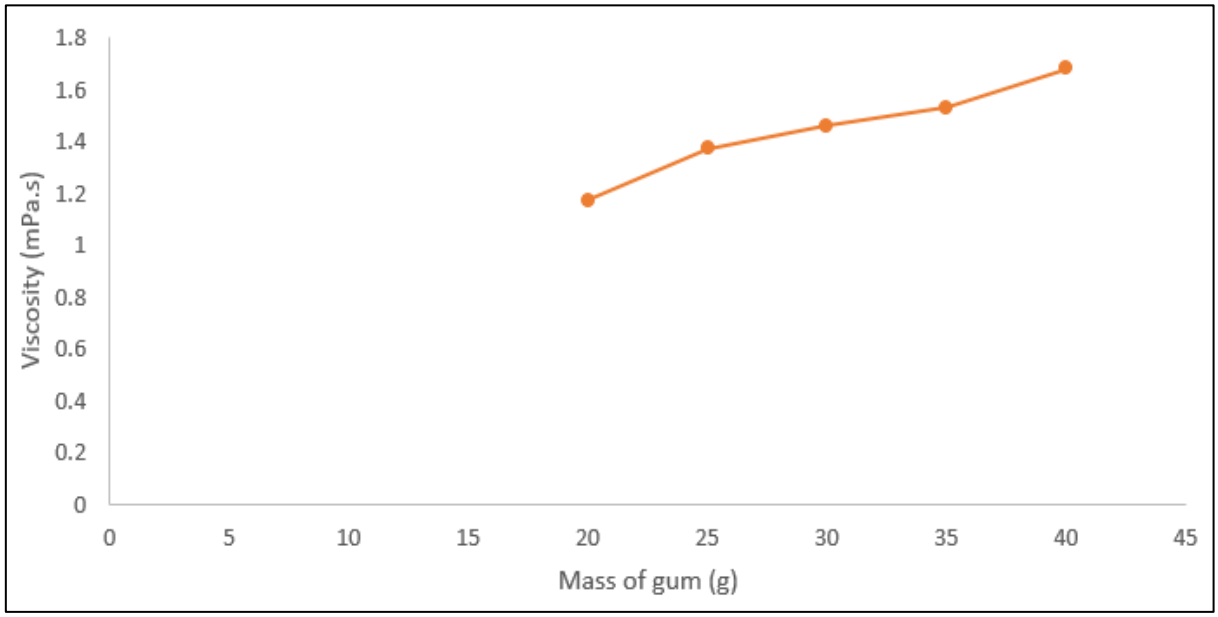


Fig 6 Mass of Gum Versus WMI Viscosity.

- *Effect of Volume of Ethanol on WMI Viscosity*

Solvent affects the viscosity of fluid. The higher the solvent, the less viscous WMI becomes and affect the opacity of the product. In this study, five magnitudes of bioethanol between the range of 200cm^3 and 400cm^3 and their effect on WMI viscosity were experimented. The experimental results show that viscosity decreases with increase in volume of bioethanol. The opacity depreciates as the volume of bioethanol increases during the experiment. This is because there was not sufficient pigment to increase the opacity of WMI. Figure 7 shows the relationship between volume of bioethanol and WMI viscosity.

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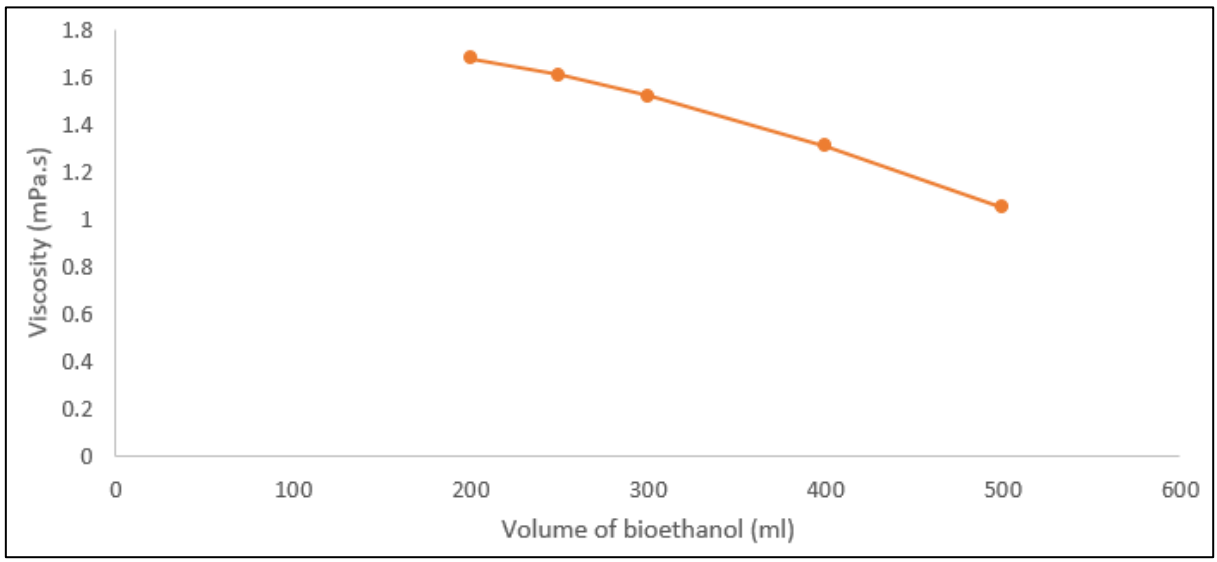


Fig 7 Volume of Bioethanol Versus WMI Viscosity

➢ *Optimization of Whiteboard Marker Ink by Response Surface Methodology (RSM)*

Table 7 shows the experimental results of WMI viscosity for three independent variables; mass of gum, mass of charcoal and volume of bioethanol. The RSM of design expert was adopted to determine the optimal conditions of these parameters for WMI formulation. A CCD-RSM polynomial model shows the regressive relationship between dependent and independent variables and the model was employed to ascertain the significance of the response components, evaluated through the sequential model sum of squares analysis. The validity of the quadratic model was confirmed by the R^2 value, which helped identify the optimal parameters for modifying the viscosity of the marker ink. Based on Table 7, the lowest viscosity recorded was 1.08 mPa·s. Conversely, the highest viscosity observed was 1.58 mPa·s, achieved from 30g of charcoal, 30g of gum and 300ml of bioethanol.

From these results, it can be concluded that the combination of the three process parameters and based on the reaction condition influenced the WMI viscosity. However, higher pigments and concentration result to higher viscosity and better color quality.

Table 7 Viscosity of WMI at Different Formulations

Runs	**Charcoal (g) A**	**Gum (g) B**	**Bioethanol (ml) C**	**Viscosity (mPa.s)**
	Coded	Coded	Coded	
1	8.64	8.64	86.36	1.25
2	30	30	300	1.51
3	30	8.64	300	1.52
4	30	30	300	1.58
5	40	20	400	1.30
6	20	40	400	1.31
7	30	30	300	1.08
8	30	51.36	300	1.50
9	20	20	400	1.08
10	30	30	513.64	1.04
11	30	30	300	1.22
12	40	20	400	1.26
13	30	30	300	1.23
14	20	40	200	1.21
15	40	40	200	1.31
16	51.36	30	300	1.51
17	20	20	200	1.15
18	30	30	300	1.23
19	30	30	300	1.28
20	40	40	400	1.29

$$\text{WMI viscosity} = +1.32 + 0.0525A + 0.0093B - 0.0789C + 0.0213AB - 0.0077AC - 0.0012BC - 0.0408A^2 - 0.0867B^2 + 0.107C^2 \quad (2)$$

Where A = Mass of charcoal, B = Mass of gum, C = Volume of ethanol

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- *Adequacy Analysis of the Models*

The 5% significance level of RSM model in the analysis of variance (ANOVA) result in Table 7 depicts that variables in linear, interactive and quadratic mode with p-value greater than 0.05 is non-significant. Two of the interactive mode AC and DE are insignificant. However, AB is significant while the linear variable and qudratic mode are also significant. The adequacy of the model is presented in Figure 8, showing a strong positive correlation between actual value of viscosity and predicted values of WMI viscosity. Normal plots of residuals in Figure 9 shows the data fitness of probanbility less than 0.05. Figure 9 shows the insight into the model's fit which affirms Rocha et al. (2023) assertion of residuals behavior.

Table 8 ANOVA for the Model of WMI Viscosity

Source	Sum of Squares	dF	Mean Square	F Value	Prob > F
Model	0.3592	9	0.0399	41.88	< 0.0001 significant
A	*0.0534*	*1*	*0.0534*	*56.00*	*< 0.0001*
B	*0.0051*	*1*	*0.0051*	*5.34*	*< 0.0434*
C	*0.1079*	*1*	*0.1079*	*113.19*	*< 0.0001*
AB	*0.0078*	*1*	*0.0078*	*8.2*	*< 0.0169*
AC	*0.0006*	*1*	*0.0006*	*0.6428*	*< 0.0001*
BC	*0.001*	*1*	*0.001*	*1.06*	*< 0.4413*
A^2	*0.0372*	*1*	*0.0372*	*39.01*	*< 0.0001*
B^2	*0.1349*	*1*	*0.1349*	*141.57*	*< 0.0001*
C^2	*0.0105*	*1*	*0.0105*	*11.02*	*< 0.0077*
Residual	0.0095	10	0.001		
Lack of Fit	*0.0084*	*5*	*0.0017*	*7.41*	
Pure Error	*0.0011*	*5*	*0.0002*		
Cor Total	0.3687	19			

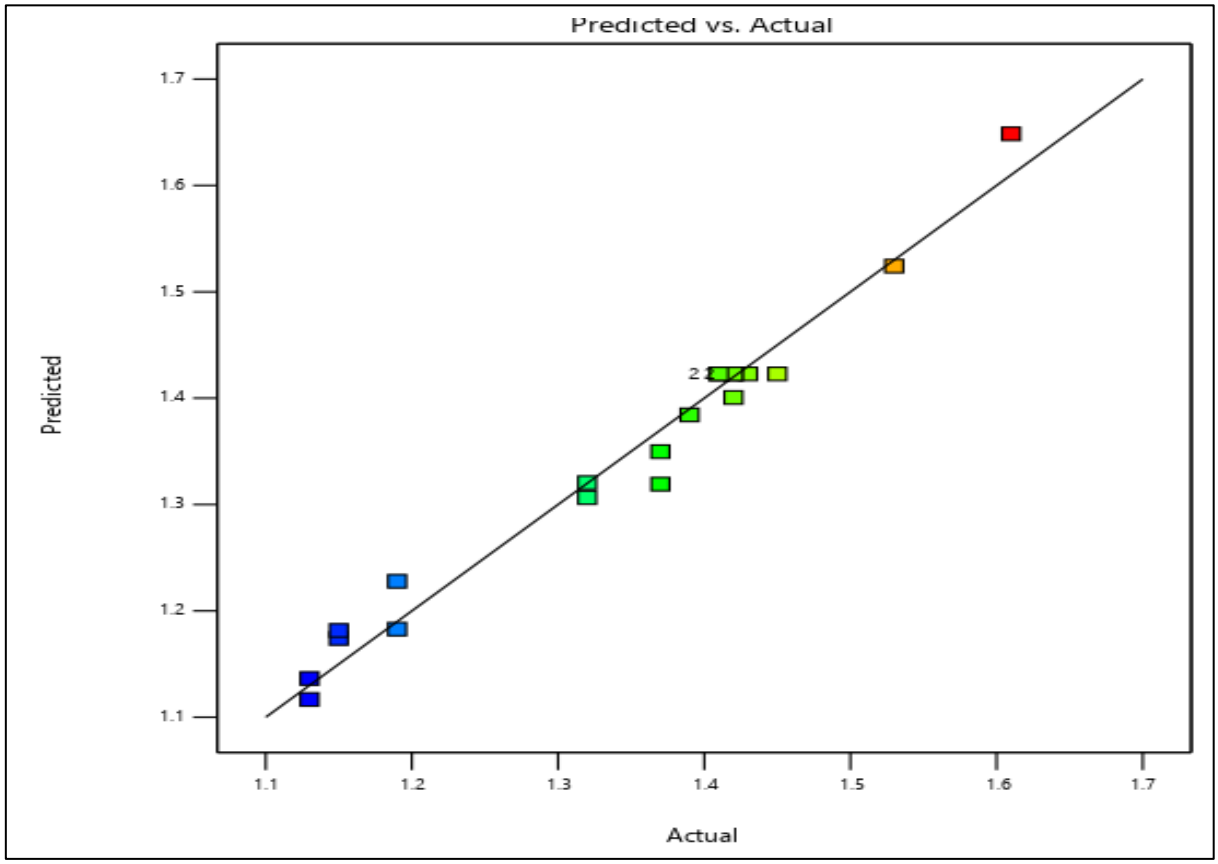


Fig 8 Plot of Predicted Values Versus Actuals Values WMI Viscosity.

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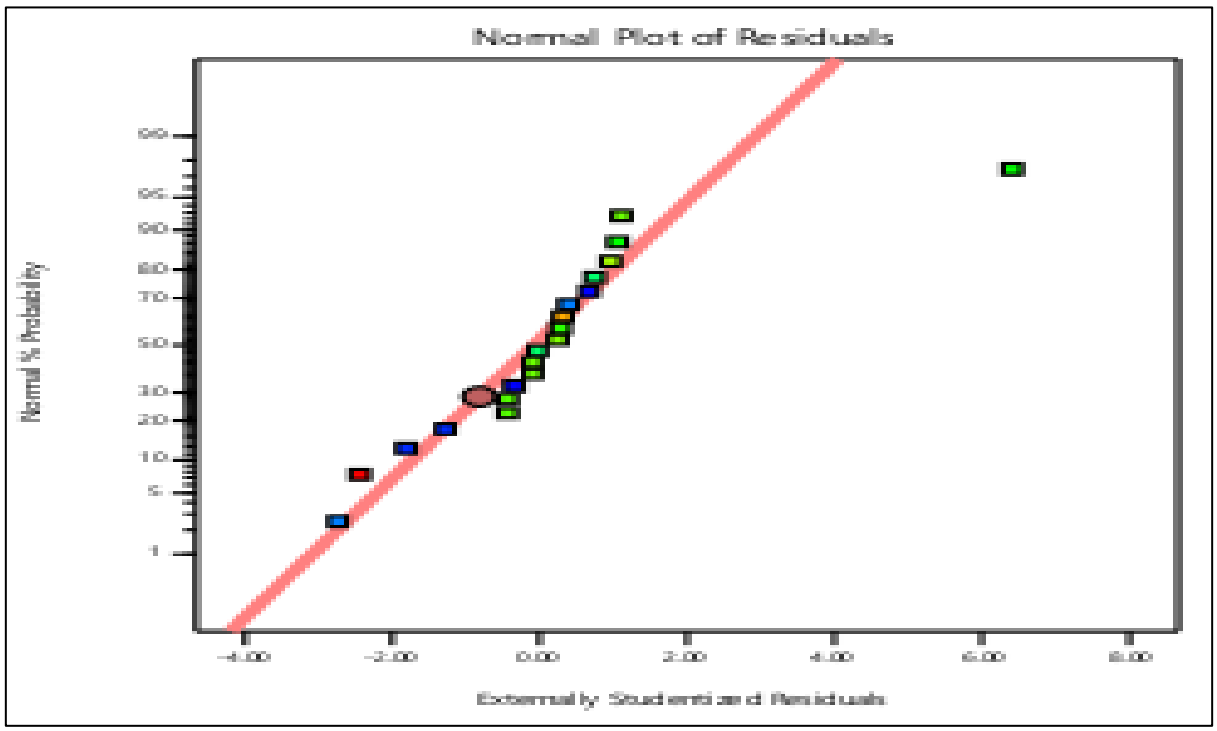


Fig 9 Normal Plots of Residuals for WMI Viscosity.

- *Surface Plots of the RSM Model of WMI*

In the study, the surface plot showing the effect of mass of charcoal and mass of gum on WMI viscosity was considered due to their level of significance as discovered in the analysis of variables. Figures 10 represent the interactive effect of charcoal and gum on WMI viscosity. The interaction is represented in a 3D surface plots to the WMI viscosity. From the three-dimensional plot in Figure 10, It could be observed that viscosity of WMI increases with increase in the mass of charcoal and mass of gum. This is as a result of strong adhesive force between the two materials.

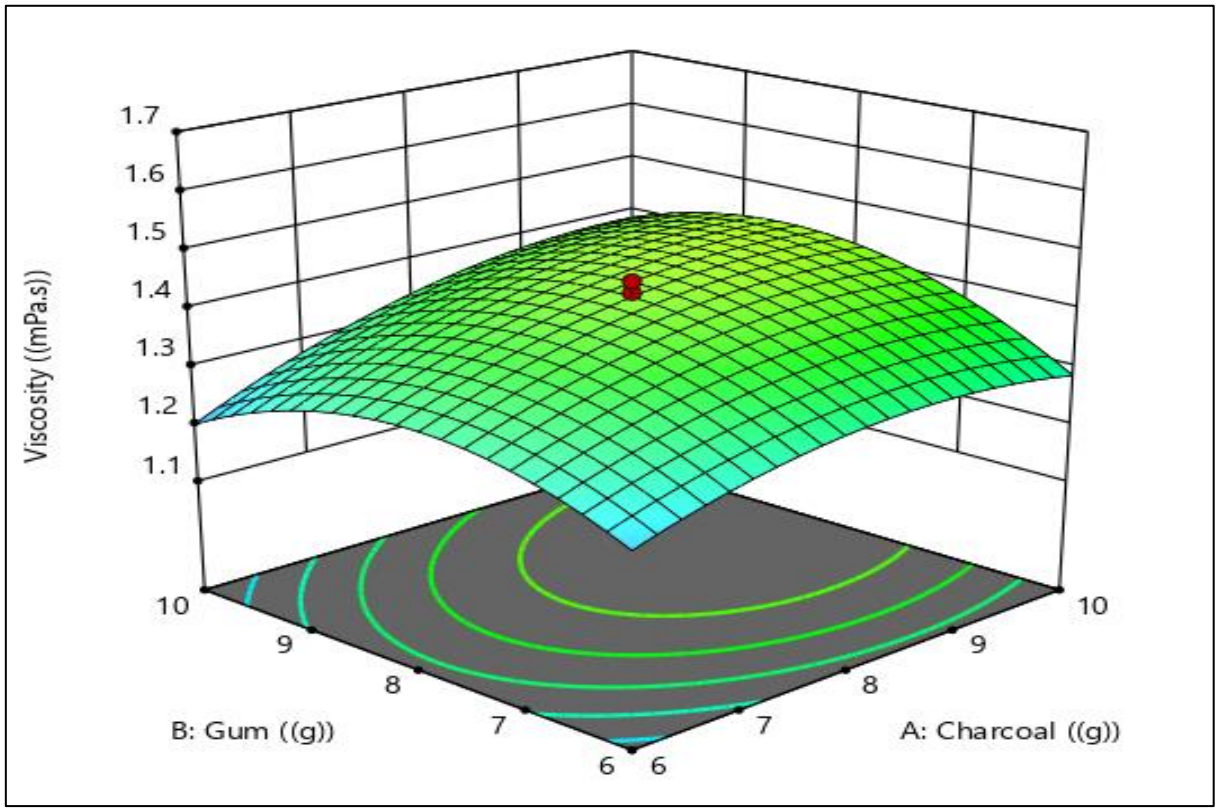


Fig 10 3D Plot Showing the Effect of Mass of Charcoal and mass of Gum on the Viscosity of WMI

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➢ *Characterization of Bio-Ink*

Table 7 presents the viscosity, erasability, adhesion and color of the WMI produced and compared with the commercial ink. The ink is easily erased with a viscosity 1.58mPa.s which is close to the viscosity of commercial ink. The difference is due to difference in density as affirm by Hamzah *et al.,* 2025 findings that quantity of pigment and gum affects the viscosity of WMI. Nwosibe *et.al.,* (2018) added that the difference is attributed to difference in process formulation. In addition, the drying time is lower compared to the conventional WMI. This may be as a result of chemical composition of the binder.

Table 9 Properties of WMI

Properties	Whiteboard Ink	Conventional Ink (SCI)
Specific gravity	0.93	0.90
Dynamic viscosity (mPa.s)	1.58	1.61
Colour	Black	Black
Drying Time (s)	3.39	2.17
Erasability	Easily erased	Easily erased

➢ *Techno-Economic Analysis*

The techno-economic analysis entails the technical process of WMI production and the economic indices of the WMI production. The technical processes include mixing and separation. The economic performance includes fixed cost, and working cost. The working cost is the running cost, which consist of cost of feedstock, utilities, tax, maintenance, labour cost, quality control and analysis. The fixed cost comprises the cost of building, installation and equipment. The economic viability was ascertained from two economic performance indicator; payback period and return on investment as shown in Table 8.

Table 8 Summary of Economic Status of WMI Produced in Small Scale.

Economic statistics	WMI
Total Fixed Cost (NG₦)	15432008
Annual Operating cost (NG₦)	22010288
Unit production cost ₦/kg	8060.92
Unit production cost ₦/litre	7180.91
Unit production revenue ₦/litre	8000
PBP (year)	1.6
ROI (%)	62.5%

IV. CONCLUSION

The study produced whiteboard marker ink (WMI) and optimized the formulation (WMI) using CCD-RSM. The optimal parameters identified were 30 g pigment, 30g of binder, and 300ml of organic solvent, resulting in WMI with desirable viscosity, drying time, and eligibility. The characterization of viscosity and drying time shows bio-based WMI as an alternative WMI. These findings suggest bio materials are alternative raw materials for WMI synthesis. The faster drying rate of the WMI, coupled with its higher viscosity, contributes to its darker color and ensures consistent application, reducing the risk of clumping and uneven distribution. SEM micrograph revealed that pigment has the surface structure and pores. In conclusion, using bio-based material as a primary feedstock in whiteboard marker ink production supports sustainable practices. This approach reduces dependence on synthetic materials while promoting the use of renewable resources, thereby contributing to environmental conservation and economic growth.

➢ *CRedit Authorship Contribution Statement*

Umeagukwu Okwudili E. - Writing original draft, Conceptualization/supervising, Methodology Ephraim R. Afia – Review and Editing, Data analysis; Inuaeyen N. Inuaeyen – Laboratory work/Methodology, supervising; Owoidoho I. Brown - Editing and Data analysis

➢ *Declaration of Competing Interest*

The authors declare that they have no known financial competing interest or personal relationship that could have appeared to influence the output of this study.

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