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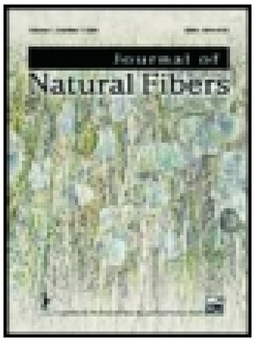

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Use of regression models to study the factors affecting the tensile and compressive properties of banana bio-composites

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ABSTRACT

Banana pseudo-stem fibers were treated with 4% sodium hydroxide, and then combined with banana peels resin to design bio-composite material. The effect of selected factors (fiber volume fraction, bio-resin, and mass of glycerin) on tensile and compressive properties of banana bio-composites were investigated. The banana bio-composite exhibited tensile strength of 4.2 MPa, Young's modulus of 12 MPa and compressive strength of 2.1 MPa using fiber volume fraction of 60% and bio-resin mass of 140 g. The mass of glycerin recorded a nonsignificant effect on the aforementioned properties of the bio-composites.

摘要

用4%氢氧化钠处理香蕉假茎纤维，然后与香蕉皮树脂结合，设计生物复合材料。研究了纤维体积分数、生物树脂和甘油质量等因素对香蕉生物复合材料拉伸和压缩性能的影响。香蕉生物复合材料表现出4.2MPa抗拉强度，对12MPa和使用60%和140克的生物树脂质量的纤维体积分数2.1MPa抗压强度，杨氏模量。甘油的质量对上述生物复合材料的性能没有显著影响。

KEYWORDS

Pseudo-stem fibers; banana peels; bio-resin; bio-composites; universal rotatable design; tensile strength

关键词

假茎纤维; 香蕉皮; 生物树脂; 生物复合材料; 万向旋转设计; 抗拉强度

Introduction

Banana pseudo-stems and peels are sometimes disposed of by burning. This need not be the case since the stems contain fibers which can be used in composite materials, as reported by several researchers (Ajith et al. 2015; Guimaraes et al. 2010; Samuel, Agbo, and Adekanye 2012; Sumaila, Amber, and Bawa 2013). Banana fiber reinforced bio-composite laminate exhibited a strength of 6.5MPa (Samuel, Agbo, and Adekanye 2012). Guimaraes et al. (2010) indicated that 35% fiber volume fraction could produce composite material of 3.56 MPa tensile strength and young's modulus of 74.35 MPa. In addition, Ajith et al. (2015) studied the tensile properties of banana reinforced phenol formaldehyde composite whose tensile strength ranged between 1.98 and 4.58 MPa, Young's modulus ranged from 2 to 9.39 GPa, and elongation ranged from 1.72% to 2.65%. The banana reinforced phenol formaldehyde composite had a better load-carrying capacity and was more flexible than plywood of same thickness, hence recommended for lighter applications. In addition, banana reinforced bio-composite laminates recorded compressive strength of 16.75 MPa while the required standard for commercial medium density fiber boards is 10 MPa (EWPAA 2008; Samuel, Agbo, and Adekanye 2012). Despite the various studies on banana bio-composites, no study was found pertaining to banana bio-composites using raw banana peels bio-resin and pseudo-stem fibers, hence the rationale for this study. This study was also inspired by the reports of a bio-resin that could be suitable for use in fiber reinforced composite material as reported by Mwesigwa et al.

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(2016). We also considered the fact that alkali treatment of natural fibers has been used to treat natural fibers with encouraging results according to Ebisike et al. (2013).

Materials and methods

Materials

Pseudo-stem banana fibers

The pseudo-stem banana fibers used in this research work were procured from Afri-Banana Uganda Limited. The linear density of the fibers was determined according to ASTM D1577-2001. The tensile properties were also determined according to ASTM D3822M-2014. The fibers were treated with 4% sodium hydroxide (purchased from Desbro Uganda Limited) according to the procedure reported by Temesgen and Sahu (2014). The properties of the treated fibers were tested according to the aforementioned procedures used for the untreated fibers.

Raw banana peels bio-resin

Raw banana peels bio-resin of viscosity and density of 242.01 MPa and 0.95g/cm^3, respectively, was used as the resin in the design of the bio-composite. The bio-resin was developed and characterized at Uganda Industrial Research Institute.

Methods

Banana bio-composites experimental design

The selected factors used to study the characterization of the banana bio-composite were fiber volume fraction (X_1), bio-resin (X_2) and glycerin (X_3). The universal rotatable experimental design using three factors at five levels was used for optimization of the design of a banana bio-composite as shown in Tables 1 and 2.

Manufacture of banana bio-composites

Banana bio-composites were manufactured using pseudo-stem fibers, banana peels bio-resin, and glycerin using the hand layup technique, and cured in an oven at 80°C for 20 minutes. The experimental design shown in Table 2 was used to select the various settings for the bio-composites manufactured, which were thereafter tested for tensile properties using a universal material tester, model type WP 310 according to ASTM D638-2014, whereas compressive strength was determined according to ASTM D695-2010.

Modeling of the influence of the experimental factors on banana bio-composite properties was done using multiple regression analysis. Standardization of the data was effected using backward elimination regression technique to remove insignificant terms during regression to maintain a hierarchical model at each step. Analysis of variance (*P*-values) and variance inflation factors were checked and verified to ensure model accuracy.

Table 1. Factor levels used for the design of bio-composites.

Factors		Levels				
		-α	Low	Medium	High	+α
	Coding	−1.682	−1	0	1	1.682
Fiber volume fraction (%)	X_1	20	30	40	50	60
Bio-resin (g)	X_2	60	76	100	124	140
Glycerin (g)	X_3	0	2	4.3	6	8

Table 2. Universal rotatable experimental design setup for the banana bio-composite.

Experiment no.	X_1	X_2	X_3
1	0	0	−1.682
2	1	−1	1
3	0	0	0
4	0	−1.682	0
5	−1	−1	1
6	1.682	1.682	1.682
7	1	1	−1
8	0	1.682	0
9	0	0	0
10	1	1	1
11	−1	1	−1
12	−1.682	−1.682	−1.682
13	0	0	0
14	−1.682	0	0
15	0	0	0
16	0	0	1.682
17	−1	1	1
18	1.682	0	0
19	1	−1	−1
20	−1	−1	1

Results and discussions

Characterization of the pseudo-stem banana fibers

Physical and mechanical properties of treated and untreated pseudo-stem banana fibers were obtained, and the results analyzed using *T*-test statistical technique are given in Table 3.

Linear density

Linear density of untreated pseudo-stem banana fibers was 24.85 tex as compared to 12.52 tex for treated fibers. This was in agreement with Ebisike et al. (2013) who noted that alkali treatment reduces fiber diameter. However, linear density values obtained in this research were higher compared to those presented by Kulkarni et al. (1983) of 6.77 tex and Mukhopadhyay, Fangueiro, and Shivankar (2009) of 7 tex, respectively. Das et al. (2010) also reported pseudo-stem banana fiber linear densities ranging from 3 to 12 tex. In addition, various banana cultivars studied in Tamilnadu (India) yielded a range of variation from 13.33 to 24.23 tex (Preethi and Balakrishna 2013), which is in the same range as those obtained in this study.

Tensile properties

Tenacity of treated pseudo-stem banana fibers was higher at 189.5 MPa when compared to the untreated fibers at 9.3 MPa. Untreated pseudo-stem fibers exhibited a lower percentage elongation at

Table 3. Paired *T*-test analysis of treated and untreated banana fibers.

Pseudo-stem banana fiber responses	Mean	Confidence interval	*P*-values
Linear density (tex) – treated fibers	12.52	(−19.33, −5.33)	0.001
Linear density (tex) – untreated fibers	24.85		
Linear density difference	−12.33		
Elongation (%) – treated fibers	0.4947	(0.1851, 0.3556)	0.0001
Elongation (%) – untreated fibers	0.2243		
Elongation difference	0.2704		
Tenacity (MPa) – treated fibers	189.5	(110.8, 249.5)	0.0001
Tenacity (MPa) – untreated fibers	9.3		
Tenacity difference	180.2		
Young's modulus (MPa) – treated fibers	3,074	(1966, 2966)	0.0001
Young's modulus (MPa) – untreated	609		
Young's modulus difference	2,465		

break of 0.22% against 0.49% of the treated fibers. Treated fibers also had a better tenacity range compared to 146.2167.2 MPa obtained by Mukhopadhyay, Fangueiro, and Shivankar (2009). This variation was supported by Alwani et al. (2015) who stated that physical and chemical composition of different agricultural fibers show high variability in properties even for the same type of fibers.

Young's modulus

Young's modulus obtained at 609 MPa represented untreated fibers while 3.074 GPa was for treated fibers. *T*-test results indicated a significant difference between modulus of treated and untreated fibers. Young's Modulus values for untreated and treated fibers were lower than those reported by Das et al. (2010) and Sumaila, Amber, and Bawa (2013).

Characterization and optimization of banana bio-composites

Tensile strength

Multiple regression analysis of tensile strength (Y_T) exhibited a model with adjusted coefficient of determination (R^2 adjusted) value of 0.91 and a P-value of 0.0001 hence significant. Table 4 was a summary of analysis of variance and variance inflation factors (VIF) statistics generated by the model.

$$Y_T = 7.32 - 0.2107X_1 + 0.091X_2 + 0.001604X_1X_1 + 0.000231X_2X_2 \qquad (1)$$

The P-values for coefficients of individual factors, curvilinear, and interaction effects were less than the alpha (α value) of 0.05 hence significant in the model. VIF values were all below 5, hence it can be concluded that there was no multi-collinearity.

Optimum settings of fiber volume fraction (60%) and bio-resin mass (140 grams) yielded maximum tensile strength of 4.2 MPa at a 95% confidence interval range of 3.5–4.9MPa. This is comparable to values of 4.5–6.5 MPa obtained by Olusegun et al. (2012) and Ajith et al. (2015). Furthermore, our result were above the required standard value for commercial medium density fiberboards of thickness 10–21 mm of 1.15 MPa (EWPAA 2008). Optimum settings for maximum tensile strength shown in Table 5 and main effects plot for tensile strength shown in Figure 1 were obtained.

From the tensile strength model and sensitivity analysis in Figure 1, it was evident that increase of fiber volume fraction (X_1) and bio-resin mass (X_2) led to an increase in banana bio-composite tensile strength. This could be due to the presence of cellulosic fibers in the bio-composites that exhibit a plasticizing effect. Addition of fibers with higher strength and stiffness to a polymer matrix greatly improves tensile properties of composites.

Table 4. Analysis of variance and variance inflation factors for tensile strength.

Source	ANOVA (P-Values)	VIF
Regression	0.000	
X_1	0.000	1.00
X_2	0.000	1.01
X_1X_1	0.000	1.05
X_2X_2	0.020	1.05
X_1X_2	0.000	1.00

Table 5. Predicted factor levels the tensile strength of bio-composite material.

Goal: Maximized tensile strength (MPa)		Solution: Optimum settings	
Predicted tensile strength (MPa)	4.21	X_1	60
95% Confidence interval	(3.50, 4.93)	X_2	140
95% Predicted interval	(3.32, 5.12)		

X_1: fiber volume fraction (%); X_2: bio-resin weight (g).

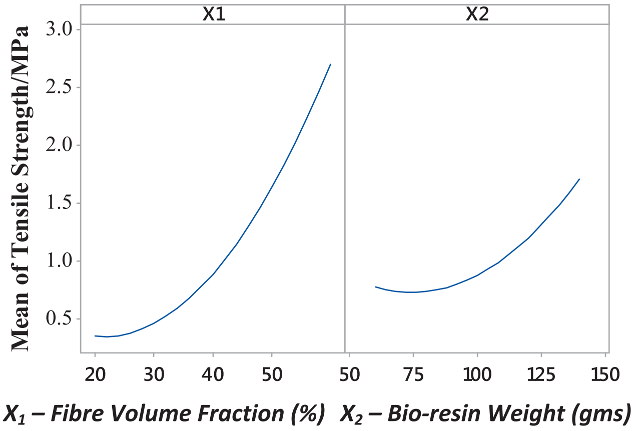

Figure1. Main effects plot for tensile strength of banana bio-composites.

X_1: Fiber volume fraction (%); X_2: Bio-resin weight (grams)

Elongation

Multiple regression analysis of percentage elongation (Y_E) exhibited a model with an R^2 value of 0.96 and a significant regression P-value of 0.0001.

$$Y_E = -1.21 + 0.057797X_1 + 0.00799X_2 + 0.1889X_3 - 0.00402X_1X_3 \quad (2)$$

Table 6 was a summary of analysis of variance and variance inflation factors generated by the elongation regression model that showed that there was no multi-collinearity and the model was significant.

The percentage elongation model predicted percentage elongation as 1.53% in Table 7 for a 95% confidence interval of 1.27–1.83%. This value was in close range to that of banana reinforced phenol formaldehyde composite between 1.72% and 2.65% (Ajith et al. 2015).

The percentage elongation model showed that increase in fiber volume fraction (X_1), bio-resin mass (X_2), and glycerin mass (X_3) contributed positively to the percentage elongation yield, whereas the interaction of fiber volume fraction and glycerin mass (X_1X_3) reduced the percentage elongation. Figure 2 was in agreement with the banana bio-composite elongation model that increase in fiber volume fraction (X_1) resulted into increase in percentage elongation (Y_E).

According to Maria et al. 2011 percentage elongation decreased with increasing fiber content for treated and untreated pseudo-stem fibers. Our research reported different results. Given the fact that

Table 6. ANOVA and VIF values for percentage elongation

Source	ANOVA (P-Values)	VIF
Regression	0.000	
X_1	0.000	1.23
X_2	0.000	1.21
X_3	0.002	1.08
X_1X_3	0.002	1.17

Table 7. Prediction and optimization for elongation of banana bio-composite.

Goal: minimized elongation (%)		Solution: optimum settings	
Predicted elongation	1.53	X_1	20
95% Confidence interval	(1.27, 1.83)	X_2	60
95% Predicted interval	(1.1, 2.1)	X_3	0

X_1: fiber volume fraction (%); X_2: bio-resin weight (g); X_3: glycerin (g).

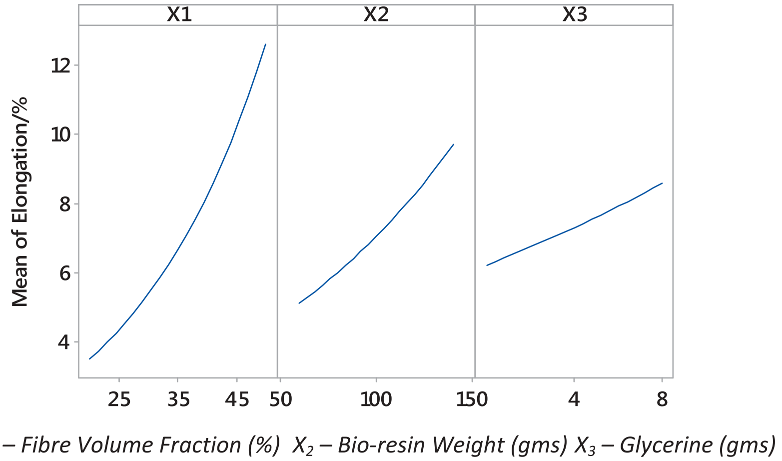

Figure 2. Settings and sensitivity for elongation of banana bio-composite material.

X_1: Fiber volume fraction (%); X_2: Bio-resin weight (grams); X_3: Glycerin (grams)

the optimum value for the mass of glycerin is zero, it could be possible that the use of glycerin could have affected the properties of the bio-composite.

Young's modulus

Multiple regression analysis of Young's modulus (Y_Y) produced models with an adjusted R^2 value of 0.921 and a significant P-value of 0.0001.

$$Y_Y(\text{Banana}) = 0.38 - 0.2091X_1 + 0.01801X_2 + 0.004706X_1X_1 \tag{3}$$

Table 8 gives a summary of ANOVA and VIF statistics generated by the model. The P-values for individual factors, curvilinear, and interaction effects revealed that all the values were less than 0.05 hence significant in the model. Variance inflation factors (VIF) proved that there was no multicollinearity among the variables, curvilinear, and interaction effects.

The regression model for banana bio-composites predicted Young's modulus as 12 MPa in a confidence interval range of 10.72–13.25MPa. Optimum settings for Young's modulus were determined as shown in Table 9. The goal was to maximize Young's modulus of banana bio-composites.

The determined optimum value for Young's modulus was less than values from previous studies. However, Young's modulus of 74.35 MPa determined at 35% fiber volume fraction by Guimaraes

Table 8. ANOVA and VIF for young's modulus of banana bio-composites

Source	ANOVA (P-Values)	VIF
Regression	0.000	
X_1	0.000	1.06
X_2	0.003	1.06
X_1X_1	0.000	1.01

X_1 – Fibre Volume Fraction (%) X_2 – Bio-resin Weight (gms)

Table 9. Prediction and optimization for banana bio-composite **Y**oung's modulus.

Goal: maximized Young's modulus (MPa)		Solution: optimal settings	
Predicted Young's modulus (MPa)	12	X_1	60
95% Confidence interval	(10.72, 13.25)	X_2	140
95% Predicted interval	(10.22, 13.75)		

X_1: fiber volume fraction (%); X_2: bio-resin weight (g).

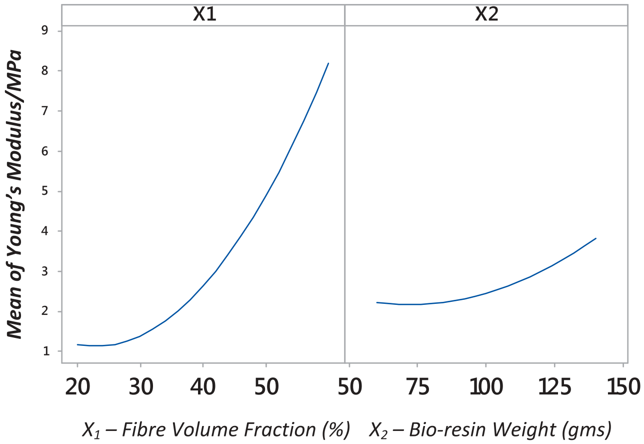

Figure 3. Main effects plot for **Y**oung's modulus of banana bio-composites.
X_1: Fiber volume fraction (%); X_2: Bio-resin weight (grams)

et al. (2010) was close to the value determined in this research. Different Young's modulus values could be explained by variations in reinforcement, type of matrix, fiber lengths, and fiber volume fractions used in previous studies.

The main effects plot for **Y**oung's modulus of banana bio-composites shown in Figure 3 revealed that increase of fiber volume fraction (X_1) resulted in increase in Young's modulus (Y_Y). Furthermore, increase in bio-resin mass (X_2) increased Young's modulus of the banana bio-composite.

Compressive strength of banana bio-composites

Multiple regression analysis of compressive strength (Y_C) exhibited a regression model with an adjusted R^2 value of 0.90 and a *P*-value of 0.0001, hence the compressive strength model was significant.

$$Y_C = 2.192 - 0.0961X_1 + 0.01764X_2 + 0.0009804X_1X_1 + 0.000549X_1X_2 \tag{4}$$

Table 10 is a summary of ANOVA and VIF statistics generated by the models. The *P*-values for individual factors, curvilinear, and interaction effects revealed that all the values were less than 0.05 hence significant in the model. VIF proved that there was no multi-collinearity among the variables, curvilinear, and interaction effects. This was because all the VIF values presented in Table 10 were below 5.

The developed regression model was used to design a prediction and optimization report for compressive strength of the developed bio-composites. The regression model for pseudo-stem banana fiber reinforced bio-composites predicted the compressive strength as 2.1 MPa in a confidence interval range of 1.79–2.39 MPa as shown in Table 11.

Table 10. ANOVA and VIF for compressive strength of banana bio-composites

Source	ANOVA(P-Values)	VIF
Regression	0.000	
X_1	0.000	1.08
X_2	0.015	1.05
X_1X_1	0.008	1.44
X_1X_2	0.003	1.41

X_1 – fibre volume fraction (%) X_2 – bio-resin Weight (gms)

Table 11. Prediction and optimization for bio-composites compressive strength.

Goal: maximized compressive strength (MPa)		Solution: optimal settings	
Predicted compressive strength	2.1	X_1	60
95% Confidence interval	(1.79, 2.39)	X_2	140

X_1: fiber volume fraction (%); X_2: bio-resin weight (g).

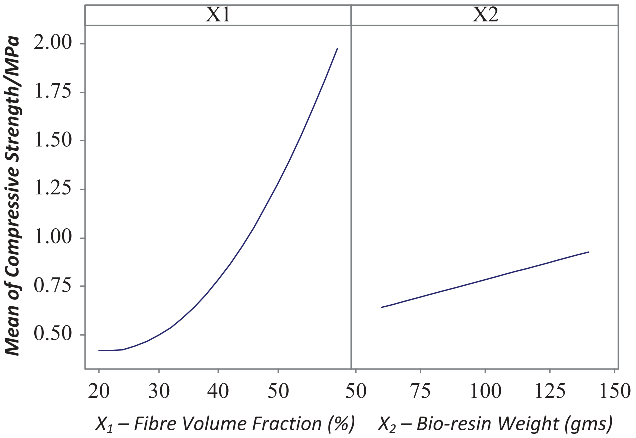

Figure 4. Main effects plot for compressive strength of banana bio-composite material.

X_1: Fiber volume fraction (%); X_2: Bio-resin weight (grams)

The main effects plot for compressive strength of banana bio-composites in Figure 4 supported the compressive strength model by revealing that an increase of fiber volume fraction (X_1^2) resulted into increase in compressive strength (Y_Y). Furthermore, increase in bio-resin mass (X_2) increased compressive strength of the banana bio-composite.

Conclusion

A study of the properties of banana pseudo-stem fibers and of their use to manufacture bio-composites using a bio-resin made from raw banana peels was undertaken and the following conclusion was made:

- The fibers used in this research work were characterized and the linear density of untreated pseudo-stem banana fibers was 24.9 tex as compared to 12.5 tex for the treated fibers. Untreated pseudo-stem fibers exhibited a lower elongation at break of 0.22% against 0.49% of the treated fibers.
- The tenacity of 189 MPa for the pseudo-stem banana fibers was far much higher compared to the tenacity of 9.3 MPa for the untreated fibers.
- Young’s modulus obtained at 609 MPa represented untreated fibers while 3074 MPa was for treated fibers.
- The paired *T*-test used in fiber properties analysis indicated a significant improvement in the linear density and mechanical properties of treated fibers when compared to the untreated fibers.
- The bio-composites manufactured exhibited tensile strength of 4.2 MPa, elongation of 1.5%, Young’s modulus of 7.2 MPa, and compressive strength of 2.1 MPa.
- Optimum tensile and compressive strength could be obtained at fiber fraction of 60% and bio-resin weight of 140 g.

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