



Response surface methodology for the optimization of the effect of fibre parameters on the physical and mechanical properties of deleb palm fibre reinforced epoxy composites

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ABSTRACT

Irrespective of the many advantages of Epoxy resins, such as a wide variety of material qualities, ease of processing, little shrinkage during cure, and good adherence to various types of fibres, its application can be further enhanced by improving its mechanical properties. Although previous studies have considered the use of different natural fibres, however, in this study, for the first time Deleb palm fibre was employed as reinforcement on Epoxy, with the purpose of increasing its physical and mechanical qualities due to some of its elemental composition. The optimum formulation of fibre parameters for the development of Epoxy-Based reinforced Deleb palm fibre composite was determined using Response Surface Methodology (RSM). The influences of fibre weight composition of 30–35 wt% and fibre length of 1–5 mm on the physio-mechanical properties: tensile modulus, tensile strength, flexural strength, impact energy and water absorption were investigated using RSM based on Central Composite Design (CCD). The RSM revealed that the fibre reinforcement composition of 38.3 wt% and fibre reinforcement length of 3 mm produced the optimum Epoxy-Deleb palm fibre composite with tensile modulus of 260.365 MPa, the tensile strength of 12.485 MPa, the flexural strength of 25.704 MPa, impact energy of 0.882 J, and water absorption of 0.369%. The results showed that the unique properties of Deleb palm fibre have effect on the physio-mechanical properties of the Epoxy-Deleb fibre composite.

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Introduction

Epoxy resins have due to vital functional features such as adhesion, flame resistance, chemical and thermal stability have become an essential material in which there has been a widespread in its use in the last century, but the last 20 years have seen tremendous advancement and development of these materials, which are still important today [1]. Epoxy resins are one of the most adaptable thermoset groups, with applications in composites, wind energy, building, electrical, and paint

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Table 1
Chemical composition of Deleb Palm Fruit [50].

Chemical	Weight Composition (%)
Cellulose	53.4
Lignin	17.0
Hemicellulose	29.6
Extractives	7.45

and coatings [2–4]. Epoxy resins are frequently combined with a hardener, which is a viscous liquid that helps the wet composite solidify. The epoxy resin becomes a stable liquid with a long shelf life when the curing agent is introduced [5]. Despite the fact that the previously outstanding resins were significantly improved by employing them for modification and as composite matrices, researchers in recent times are concerned with the development of epoxy resin composites [1].

The deleb palm (*Borassus Aethiopum*) tree is a tropical African single-stemmed evergreen palm with a sturdy trunk. The unbranched stem can reach a height of 20–30 metres and a thickness of 40–50 cm. The palm's base is usually wider than the stem, measuring up to 85 cm in thickness [6]. The tree's middle half grows larger as it matures, eventually reaching an 80 cm diameter. It has massive fan-shaped leaves with spines at the ends that are roughly 3 metres long and 4 metres wide. The deleb palm is a useful tree that can be used for food, medicine, and other things. The fibre husk of its fruit was used as a reinforcement for a polymer-based composite in this work, making use of natural fibres' multiple economic, technological, and environmental benefits [7].

A review of previous studies shows that synthetic fibres such as glass, carbon, kevlar, and aramid are used to reinforce polymer (epoxy) composites [8–11]. Synthetic fibre-reinforced epoxy composites are commonly utilised in vehicles, construction, and shape-memory applications due to their lightweight, strong strength, and good modulus. However, because the recyclability of synthetic fibres from composites after use is an issue [12], natural fibres are thought to be a better choice [13]. However, filler characteristics, filler shape, matrix properties, filler–matrix interactions, filler orientation in the matrix, and the volume fraction of the filler are all linked to composite performance [14].

Furthermore, natural fibre polymer composites are made up of a polymer matrix with high-strength natural fibres such as date palm [15], jute [16], oil palm [17–18], sisal [19], kenaf [20], and flax [21] inserted in it. The features and performance of natural fibre polymer composites can be influenced by a variety of variables. The natural fibre's hydrophilic character, as well as the fibre loading, influence the composite qualities [22]. To get good natural fibre polymer composites characteristics, considerable fibre loading is usually required. The process parameters used are another important component that has a significant influence on the composites' properties and surface features. As a result, proper process techniques and parameters should be carefully determined to get the optimal composite features [23].

Natural fibre composites can find a wide range of applications in the development of useful materials by making use of features such as low density, strong specific strengths and modulus, and reasonable prices of natural fibres over synthetic fibres [10]. Though the difficulty of its low compatibility with matrices, high natural fibre water absorption rate, and low recycling rate remains a major worry that must be addressed [11]. Different types of natural fibres have varied processing characteristics, there is no standard parameter setting for processing natural fibre composites that applies to all-natural fibres [24], necessitating the optimization of Deleb palm fruit fibre processing parameters. This is because there is a need to establish optimal parameter settings for high-performance composites when using natural fibre matrix combinations and processing methods.

Response Surface Methodology (RSM) is one of the designs of experiment (DOE) strategies for optimizing the operational parameters or conditions in a system as compared with the traditional method that cannot be optimized. RSM is particularly useful when a multitude of potential input variables influence a process or product's performance or characteristic [43]. Furthermore, when compared with other DOEs, it has the ability to evaluate the effects of multiple factors and their interactions on one or more response variables. Hence, for the first time to the best of our knowledge, this study is targeted at determining the effect of input variable of fibre parameters (fibre reinforcement weight composition and fibre reinforcement length) on the physio-mechanical properties of epoxy-based composite reinforced with Deleb palm fibre, as well as the optimization of these fibre parameters to produce the optimum Epoxy-Delab fibre composite using the Response Surface Methodology.

Materials and methods

Materials

The Deleb Palm Fibre as a natural fibre was derived from the deleb palm fruit (*Borassus Aethiopum*) after it was obtained from the fruit which was purchased in Samaru Market, Zaria, Nigeria. From the studies of Sudhakara et al. [50], the chemical composition of deleb palm fruit is given in Table 1. The high cellulose content has the potential to contribute to enhanced mechanical properties, while the hemicellulose content can be reduced through fibre treatment [44]. The Epoxy resin on the other hand was obtained from the Nigerian Institute of Leather and Science Technology Samaru, Zaria, Nigeria with the specification as in Table 2. The Epoxy resin was hardened with Hexamethylenediamine which is a popular hardener.

Table 2
Specification of epoxy resin.

Properties	Values
Appearance	Light yellow
Epoxy Equivalent Weight	187 g/eq
Viscosity at room temperature	12,600 cP

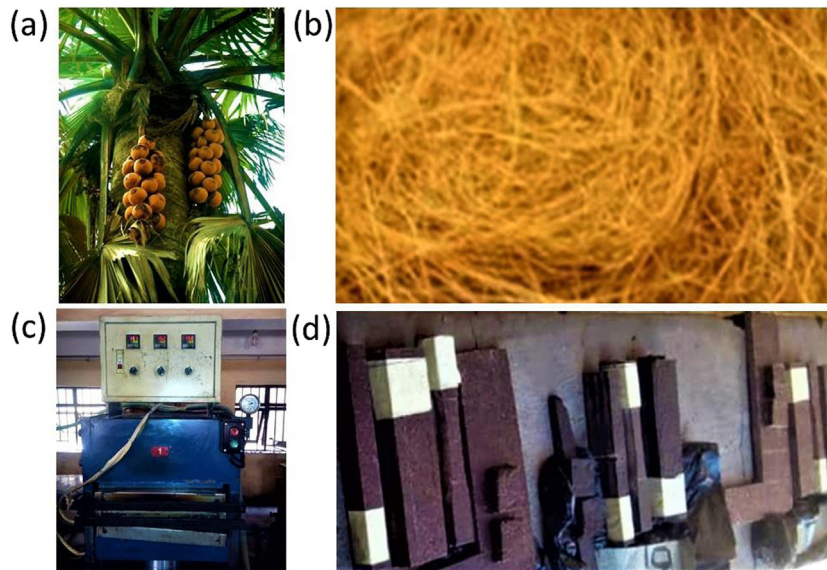


Fig. 1. (a) Deleb palm tree, (b) extracted fibre (c) Compression Moulding Machine (d) Epoxy-Deleb palm fibre composites.

Methods

Fibre treatment

The outer layer shell or the mesocarp of the deleb palm fruit was where the fibre was extracted from. The Retting process was used for extraction which allowed the fibers to be separated from the woody core. The deleb palm shells were soaked in water to allow for the decomposition of the pulp on the shell, after which the fibres were extracted by pulling them out and the fibres were washed to remove the embedded dirt between the fibres and air-dried for 48 h. During the process of extraction, the fibres were properly blended to reduce the effects of variation.

Although there are different chemical treatments of fibres with the purpose of improving their properties by increasing the cellulose content, and water resistance properties, new methods such as Silane coupling agents were developed, [48–49], however, alkali treatment, which helps to increase the fibre surface roughness, and cause better mechanical properties [47] was employed for this study. In order to prepare the composites with fabric treated with alkali (NaOH) solution, the fibre was dipped in the NaOH solution with a concentration of 6% for 24 h at room temperature with a constant liquor ratio. Further, the acetic solution was used to wash the fibres and then washed with water which is further dried in sunlight for 24 h. A similar approach was employed by previous studies [25–27].

Composite formulation

Following the processing of the fibres, they were placed in an 80 mm x 30 mm x 5 mm release spray-coated mould. According to the hand lay-up method, a mixture of resin and hardener was poured over the fibre in stages while the following layers of fibre were laid over the preceding layer to achieve the appropriate thickness. The samples were then cured for 5 min at temperatures between 150 °C under a mould pressure of 2.5 MPa. A similar approach was employed by previous studies [28–29]. Fig. 1 shows the deleb palm tree, extracted fibre, and the composites formed for this study.

Optimization of the effect of Deleb fibre parameters using response surface methodology experimental design

The formulation of the fibre reinforcement weight (30–40 wt% composition) and fibre reinforcement length (1–3 mm) of the Deleb fibre give optimum physio-mechanical properties were determined using the RSM technique. RSM was applied to investigate the effects of independent variables: fibre reinforcement weight (X_1), and fibre reinforcement length (X_2) on the responses: tensile modulus (Y_1), tensile strength (Y_2), flexural strength (Y_3), impact energy (Y_4) and water absorption (Y_5) of the Epoxy-Deleb palm fibre composite.

Table 3

Actual levels of coded factor levels of independent variables used in the RSM.

Symbol	Independent Variable	Actual Levels at Coded Factor Levels		
		−1	0	1
X ₁	Fibre reinforcement weight (%wt)	30	35	40
X ₂	Fibre reinforcement length (mm)	1	3	5

Table 4

Central Composite Formulation Design of different Deleb fibre Parameters.

Run	Epoxy Resin Weight (%wt)	Reinforcement Weight (%wt)	Reinforcement Length (mm)
1	65	35	1
2	70	30	2
3	70	30	1
4	65	35	2
5	60	40	3
6	60	40	1
7	70	30	3
8	60	40	2
9	65	35	5

RSM with central composite design (CCD) of two independent variables and their combinations was used in this experiment to determine the formulation for the optimum Deleb fibre parameters in terms of tensile modulus, tensile strength, flexural strength, impact energy and water absorption. All independent variables including fibre reinforcement weight and fibre reinforcement length were run at three levels in terms of CCD (Table 3) for each of the individual coded values (−1, 0, and 1). The CCD is performed to investigate the effect of each independent variable and the interaction between independent variables on the response. A first-order polynomial equation was applied to indicate the responses that were a function of the independent variables (Eq. (1)).

$$Y_i = a_0 + a_1X_1 + a_2X_2 + a_{12}X_1X_2 \quad (1)$$

where Y_i is response function ($i = 1, 2, 3, 4$ and 5), a_0 is a constant, coefficient in Eq. (1) are linear (a_1 , and a_2) and interaction (a_{12}) coefficients, respectively. The coded values (x_i) of the parameters can be obtained by using Eq. (2) [30].

$$x_i = \frac{X_i - X_0}{\Delta X} \quad (2)$$

where X_i is the actual value for the independent variable, X_0 is the actual value for the independent variable at the centre point, and ΔX is the step of change values for the independent variable. RSM with three coded levels (−1, 0, and 1) was employed to examine the effects of fibre reinforcement weight (X_1 : 30–40 wt%) and fibre reinforcement length (X_2 : 1–3 mm) on the tensile modulus (Y_1), tensile strength (Y_2), flexural strength (Y_3), impact energy (Y_4) and water absorption (Y_5) of the Epoxy-Deleb palm fibre composite. Actual levels and coded factor levels of two independent variables for optimizing the formulation of Epoxy-Deleb palm fibre composite using RSM are shown in Table 3.

The RSM with CCD of 3 coded levels, 2 independent variables, and 9 experimental runs including three centre points (Table 4) was used to optimize the formulation of Epoxy-Deleb palm fibre composite including fibre reinforcement weight (X_1), and fibre reinforcement length (X_2) using Design-Expert software (Version 13, Stat-Ease).

Determination of the physio-mechanical properties

Mechanical properties

Tensile tests were performed in accordance with ASTM D-638 using specimens of 250 × 25 mm in the form of dumbbell-shaped samples, which were exposed to a tensile force at a crosshead speed of 2 mm/min. Using the Motorized Automatic Recording Tensometer, a flexural test was performed according to ASTM D7028–07–2015 standard with a rectangularly shaped specimen having a cross-section of 80.0 mm in length, 30.0 mm in breadth, and 5.0 mm in thickness. The Izod impact test was performed in accordance with the ISO 8256 (2004) DENT standard. The impact study was performed with the following dimensions: 64 mm x 12.7 mm x 5 mm, with a 1.5 m/s impact velocity and a 60° falling angle.

Physical property

Water absorption is an issue in fibre-reinforced polymer composites because it can lead to matrix cracking, dimensional instability, and poor mechanical properties [42]. The ASTM D 570–98 standard was used to determine the composites' water absorption behaviour. The initial mass of the samples was noted down using a precision weighing balance machine and regarded as the starting mass of the sample prior to exposing them to the water absorption test. The samples were then immersed in water and their masses recorded. This was regarded as the composite's final mass. The water absorption test

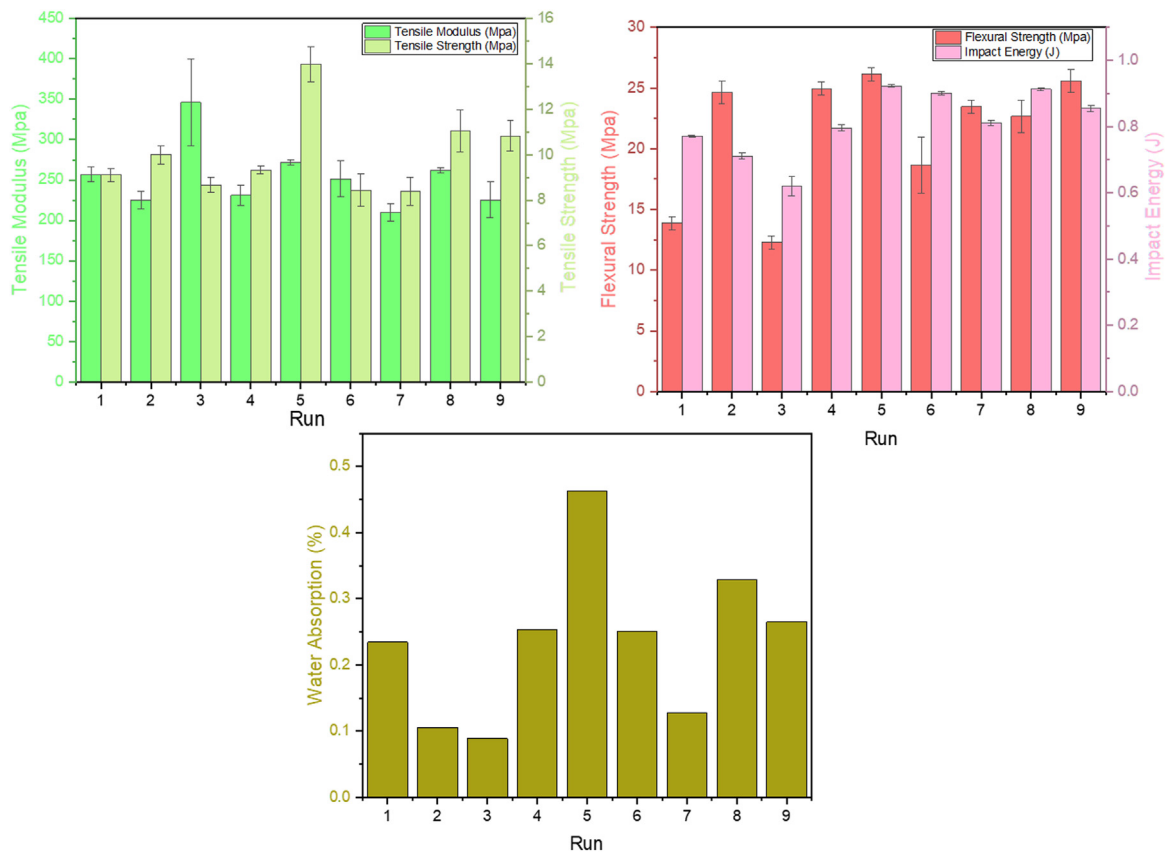


Fig. 2. Effects of fibre reinforcement weight and fibre reinforcement length on the tensile modulus, tensile strength, flexural strength, impact energy and water absorption of the Epoxy-Deleb palm fibre composites.

lasted for seven days (168 h). Prior to weighing the composites, the surplus water on the surface was blotted with the filter paper, and the water absorption percentage is calculated using Eq. (3).

$$\text{Moisture Content} = \frac{M_2 - M_1}{M_1} * 100 \quad (3)$$

where, M_1 is the weight of the sample before immersion, and M_2 is the weight of the sample after immersion.

Statistical analysis

Using IBM SPSS Statistics Software, the analysis of variance (ANOVA) was utilised to examine the statistically significant differences between the means of independent variables (Version 26.0, IBM SPSS Inc.). Using Design Expert software, a step-wise process was utilised to construct two-dimensional surface plots for investigating the connection between a response and two independent factors (Version 13, Stat-Ease). If the P-value is less than 0.05, the model term is significant.

Results and discussion

Physio-Mechanical properties of the Epoxy-Deleb palm fibre composite

Fig. 2 presents the effects of fibre reinforcement weight and fibre reinforcement length on the tensile modulus and tensile strength of the Epoxy-Deleb palm fibre composites. In general, the tensile modulus of the composite range is between 208 and 347 MPa, while the tensile strength of the composite range is between 9 and 14 MPa. The tensile modulus and strength help in evaluating how stiff the composite is and its expected plastic deformation under elastic loading [31]. Similarly, Fig. 2 presents the effects of fibre reinforcement weight and fibre reinforcement length on the flexural strength and impact energy of the Epoxy-Deleb palm fibre composites. In general, the flexural strength of the composite range is between 12 and 27 MPa, while the impact energy of the composite range is between 0.6 and 1 J. The flexural strength gives information on the application suitability and longevity as well as end user's safety of the developed composites [32]. The impact energy on the other hand informs on the energy required to fracture the developed composites [33]. Furthermore,

Table 5

Comparison of some of the mechanical properties of Natural fibre reinforcement on epoxy composites.

Reinforcement	Tensile Strength (MPa)	Flexural Strength (MPa)	Impact Energy (J)
Coir-epoxy	23.68	46.63	0.264
Sisal-epoxy	37.40	52.8	0.57
Groundnut shell	18.09	28	0.24
Areca	27.50	25	0.93
Coir-pitch	9	23	0.18
Deleb-epoxy (present study)	14	27	1

Table 6ANOVA of the regression coefficient of the fitted linear equations for tensile modulus (Y_1), tensile strength (Y_2), flexural strength (Y_3), impact energy (Y_4) and water absorption (Y_5) of the Epoxy-Deleb palm fibre composite.

Variables		Main Effect		Interaction Effect	Model	R^2	Adjusted R^2
		X_1	X_2	$X_1 \times X_2$			
Tensile modulus (Y_1)	Mean square	40.97	3247.4	6121.84	3136.74	0.7242	0.5588
	F-value	0.0572	4.53	8.54	4.38		
	P-value	0.8205	0.0865	0.0329	0.00729		
Tensile strength (Y_2)	Mean square	5.95	7.46	8.51	7.31	0.8487	0.758
	F-value	7.62	9.55	10.88	9.35		
	P-value	0.0398	0.0271	0.0215	0.0171		
Flexural strength (Y_3)	Mean square	5.03	155.5	3.48	54.67	0.7568	0.6109
	F-value	0.4774	14.5	0.3305	5.19		
	P-value	0.5204	0.0121	0.5902	0.054		
Impact energy (Y_4)	Mean square	0.0576	0.0138	0.0072	0.0262	0.9665	0.9464
	F-value	105.75	25.27	13.13	48.05		
	P-value	0.0001	0.004	0.0152	0.0004		
Water absorption (Y_5)	Mean square	0.083	0.0109	0.0076	0.0338	0.9052	0.8483
	F-value	39.05	5.11	3.59	15.92		
	P-value	0.0015	0.07333	0.1167	0.0054		

Fig. 2 presents the effects of fibre reinforcement weight and fibre reinforcement length on the water absorption property of the developed Epoxy-Deleb palm fibre composites. The percentage water absorption of the composite range between 0.08% and 0.5%. Natural fibres are prone to water absorption due to their chemical composition rich in cellulose, hydrophilic in nature. Water absorption of natural fiber is more likely to increase with the increase in cellulose content of the fiber due to the increase in the number of free hydroxyl groups existing in the fiber. Hence, it can be said that water absorption is an undesirable property of polymer fibre [34].

Table 5 gives a comparison of the mechanical properties such as tensile strength, flexural strength, and impact energy of Epoxy-Deleb palm fibre composites with other natural fibre-epoxy composites as obtained from Jeyapragash et al. [45]. The variation in the mechanical properties as a result of natural fibre reinforcement can be attributed to factors such as enrichment of cellulose content as well as better bonding between natural fibre and epoxy matrix. The better impact energy of this present study can be attributed to the high microfibrillar property of Deleb Palm Fruit fibre [44]. According to Prasad et al. [46], reinforcing fibres with high microfibrillar angles tends to result in high impact strength.

Optimization of the fibre parameters using response surface methodology

For the physio-mechanical properties of a polymer-fibre composite, fibre reinforcement weight composition may cause a rapid change in the physio-mechanical properties of the resulting composite. Increasing the fibre reinforcement weight in most cases enhances most of the physio-mechanical properties apart from water absorption capability. Besides fibre reinforcement weight composition, fibre reinforcement length is also an important factor affecting the physio-mechanical properties of polymer-fibre composites [35]. Some studies have observed that increasing the length of the fibre reinforcement tends to improve the physio-mechanical properties, however, beyond a particular length, distinctive of different fibres, the physiochemical properties tend to reduce [35–36]. Therefore, the effects of fibre reinforcement weight composition and length were investigated in this study to find the optimum combination for an Epoxy-Deleb palm fibre composite.

Table 6 shows the coefficient of multiple determinations (R^2) and the adjusted coefficient of multiple determinations (adjusted R^2) of tensile modulus, tensile strength, flexural strength, impact energy and water absorption, indicating whether a regression model is adequate. ANOVA was used to determine the significance of the coefficient of the quadratic polynomial equations. A large F-value and small P-value demonstrates a significant effect of each term [37].

The results showed that the variables with largest to smallest effects ($P \leq 0.05$) on the Tensile modulus were the linear effect of the interaction between fibre reinforcement weight composition and length, while the largest to smallest effects ($P \leq 0.05$) on the Tensile strength were the single effect of fibre reinforcement weight, fibre reinforcement length, and the linear effect of the interaction between fibre reinforcement weight composition and length. Also, the largest to smallest

Table 7

First-order polynomial models for the tensile modulus, tensile strength, flexural strength, impact energy and water absorption of the Epoxy-Deleb palm fibre composite.

Response	First-order Polynomial Model
Tensile modulus	Coded: $Y = 253.32 + 2.27X_1 - 20.25X_2 + 39.12X_1X_2$ Actual: <i>Tensile Modulus</i> = $825.59 - 15.19X_1 - 294.1X_2 + 7.82X_1X_2$
Tensile Strength	Coded: $Y = 9.98 + 0.87X_1 + 0.97X_2 + 1.462X_1X_2$ Actual: <i>Tensile Modulus</i> = $22.29 - 0.41X_1 - 9.24X_2 + 0.29X_1X_2$
Flexural Strength	Coded: $Y = 21.36 + 0.79X_1 + 4.43X_2 - 0.93X_1X_2$ Actual: <i>Tensile Modulus</i> = $-6.15 + 0.53X_1 + 10.96X_2 - 0.19X_1X_2$
Impact Energy	Coded: $Y = 0.81 + 0.085X_1 + 0.042X_2 - 0.042X_1X_2$ Actual: <i>Tensile Modulus</i> = $-0.46 + 0.034X_1 + 0.034X_2 - 0.0085X_1X_2$
Water Absorption	Coded: $Y = 0.24 + 0.1024X_1 + 0.0370X_2 + 0.044X_1X_2$ Actual: <i>Tensile Modulus</i> = $0.056 + 0.00301X_1 - 0.27X_2 + 0.0087X_1X_2$

effects ($P \leq 0.05$) on the Flexural strength was the single effect of fibre reinforcement length, while the largest to smallest effects ($P \leq 0.05$) on the Impact energy were the single effect of fibre reinforcement weight, fibre reinforcement length, and the linear effect of the interaction between fibre reinforcement weight composition and length. Similarly, the largest to smallest effects ($P \leq 0.05$) on the Water absorption were the single effect of fibre reinforcement weight, fibre reinforcement length, and the linear effect of the interaction between fibre reinforcement weight composition and length.

Generally, the high R^2 values (especially for tensile strength, impact energy, and water absorption) indicated that the linear model was highly efficient for fitting the data under the condition of the experiment and adjusted R^2 values implied a good agreement between the predicted and the experimental values of the model as shown in Table 6. However, for tensile modulus, and flexural strength, the relatively low adjusted R^2 values indicated some disparities between the experimental and modelled result. However, the P-value of the model indicated a good significance of the model. Table 7 shows the first-order polynomial models and response surface model regression coefficients for tensile modulus, tensile strength, flexural strength, impact energy, and water absorption. The findings revealed that decreasing the fibre reinforcement composition and length resulted in higher tensile modulus and tensile strength while increasing the fibre reinforcement composition and length increased flexural strength and impact energy. However, increasing the fibre reinforcement composition and reducing the fibre reinforcement length increased water absorption.

It can be concluded that the RSM models could be used to study the linear, and interaction effects of fibre reinforcement composition and length on the tensile modulus, tensile strength, flexural strength, impact energy and water absorption. Therefore, the application of the RSM with CCD was suitable for optimizing the Epoxy-Deleb palm fibre composite with desirable responses. The experimental data collected from the responses of the independent variables were analysed. The results showed that the linear polynomial equation could be used to illustrate the response surface plots and forecast the tensile modulus, tensile strength, flexural strength, impact energy and water absorption. Fig 3 show the response surface and contour plots of the linear polynomial models that present the effect of independent variables on the tensile modulus, tensile strength, flexural strength, impact energy and water absorption of the Epoxy-Deleb palm fibre composite.

The surface plot of the two-dimensional response for the tensile modulus of the Epoxy-Deleb palm fibre composite is presented in Fig. 3(a). The effects of fibre parameters on the tensile modulus indicated that the tensile modulus of the composite was minimum at 220 MPa. Decreasing the fibre reinforcement weight composition and length tended to increase the tensile modulus. This was against previous results obtained for other fibres such as karka, flax and jute probably because of their crystalline nature as a result of the strong intermolecular forces between its molecules, thereby resulting in higher tensile modulus [38]. On the other hand, the effects of fibre parameters on the tensile strength (Fig. 3(b)) indicated that the tensile strength of the composite was minimum at 9 MPa. Increasing the fibre reinforcement weight composition and length tended to increase the tensile modulus. This result is in line with other results obtained for other fibres such as karka, flax and jute [39].

The surface plot of the two-dimensional response for the flexural strength of the Epoxy-Deleb palm fibre composite is presented in Fig. 3(c). The effects of fibre parameters on the flexural strength indicated that the flexural strength of the composite was minimum at 16 MPa. The fibre reinforcement weight composition tends to have no effect, however, increasing the fibre reinforcement length tended to increase the flexural strength. This was in line with previous results obtained for other fibres that observed that with an increase in fibre length up to some levels, there is an increase in the flexural strength of the resulting composite [40]. On the other hand, the effects of fibre parameters on the impact energy (Fig. 3(d)) indicated

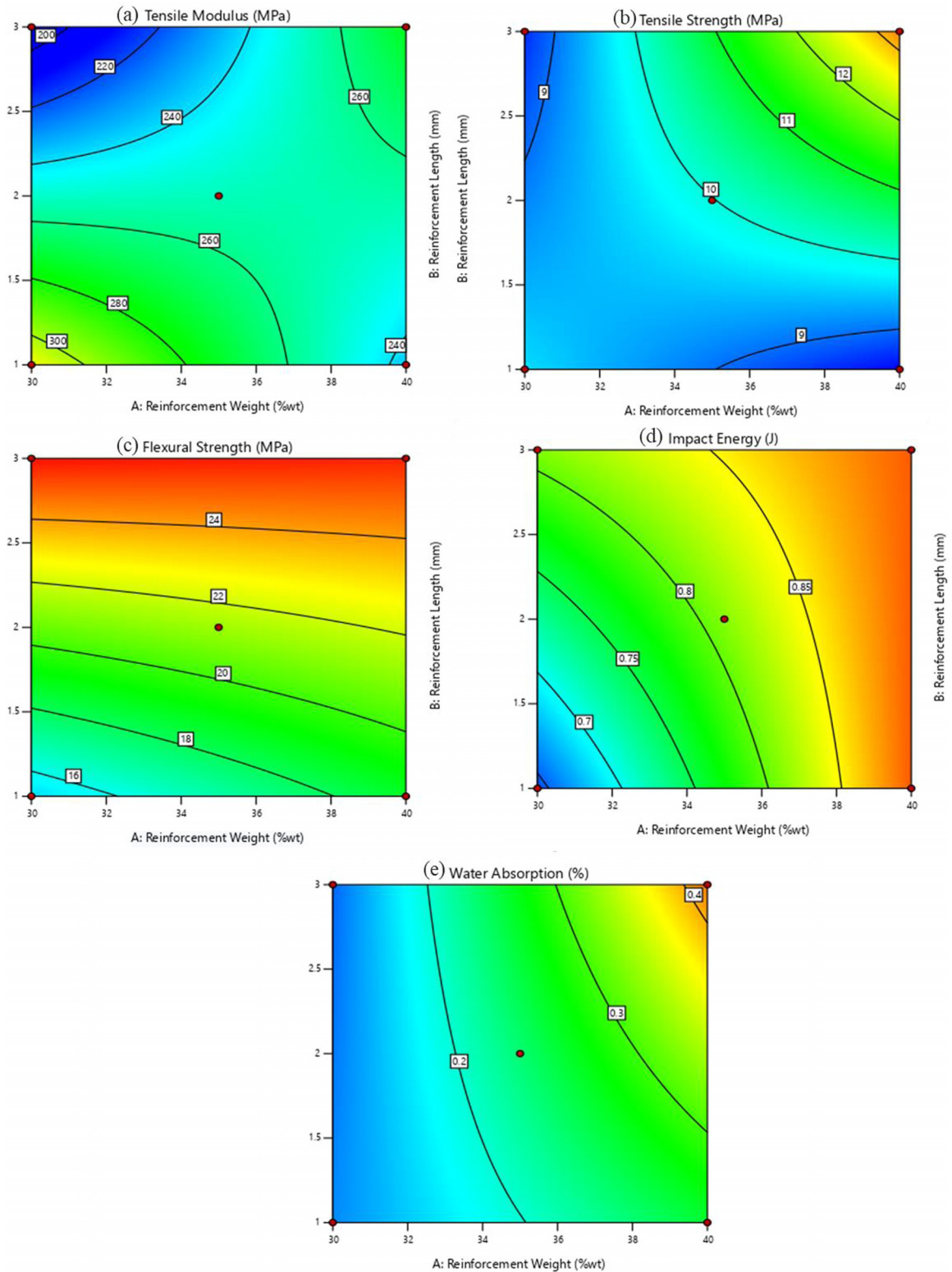


Fig. 3. Response surface and contour plots of the interactions between fibre reinforcement composition and length on (a) tensile modulus; (b) tensile strength; (c) flexural strength; (d) impact energy; (e) water absorption of the Epoxy-Deleb palm fibre composite.

that the impact energy of the composite was minimum at 0.7 J. Increasing the fibre reinforcement weight composition and length tended to increase the impact energy. This was in line with other results obtained for other fibres [41,34].

The surface plot of the two-dimensional response for the water absorption of the Epoxy-Deleb palm fibre composite is presented in Fig. 3(e). The effects of fibre parameters on the water absorption indicated that the water absorption of the composite was minimum at 0.2%. Reducing the fibre reinforcement weight composition and length tended to reduce the water absorption. This was in line with previous results obtained for other fibres that observed that with an increase in fibre length and weight composition, water absorption of natural fiber is more likely to increase due to the increase in cellulose content of the fiber as a result of the increase in the number of free hydroxyl groups existing in the fiber [43].

Conclusion

The optimum fibre parameters for preparing the Epoxy-Deleb fibre composite were determined using the RSM based on CCD. Specifically, the CCD was employed to fit the first-degree polynomial model to produce the Epoxy-Deleb fibre composite. The results suggested that fibre reinforcement composition and fibre reinforcement length affected majorly the tensile strength, flexural strength, impact energy and water absorption of the formulated Epoxy-Deleb fibre composite. Based on the numerical optimization models, the fibre reinforcement composition of 38.3 wt% and fibre reinforcement length of 3 mm was suitable to give the optimum Epoxy-Deleb fibre composite with high tensile modulus, tensile strength, flexural strength, impact energy, and low water absorption.

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Code availability

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Ethics approval

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Consent to participate

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Consent for publication

Not applicable.

Authors' contributions

Ibrahim Iliyasu: Conceptualization, Data curation, Formal analysis, Investigation, Methodology. **Bello James Bitrus:** Conceptualization, Data curation, Investigation, Methodology. **Oyedeji Ayodeji Nathaniel:** Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Writing – original draft. **Salami Kazeem Adeniyi:** Writing – original draft. **Oyedeji Elijah Oyewusi:** Writing – original draft.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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References

- [1] M. Kisiel, B. Mossety-Leszczak, Development in liquid crystalline epoxy resins and composites—a review, *Eur. Polym. J.* 124 (2020) 109507.
- [2] O. Dagdag, E.E. Ebenso, C. Verma, M. El Gouri, Chemical modification of epoxy prepolymers as anticorrosive materials: a review, in: *Environ. Sustain. Corrosion Inhibitors*, 2022, pp. 273–288.
- [3] Karak, N. (2021). Overview of Epoxies and Their Thermosets. In *Sustainable Epoxy Thermosets and Nanocomposites* (pp. 1–36). American Chemical Society.
- [4] Gibson, G. (2017). Epoxy resins, *Brydson's Plastics Materials*.
- [5] E.O. Oztug, M.H. Oztug, Effects of epoxy, hardener, and diluent types on the hardened state properties of epoxy mortars, *Constr. Build. Mater.* 187 (2018) 360–370.
- [6] K.V. Salako, F. Moreira, R.C. Gbedomon, F. Tovissodé, A.E. Assogbadjo, R.L.G. Kakaï, Traditional knowledge and cultural importance of *Borassus aethiopicum* Mart. in Benin: interacting effects of socio-demographic attributes and multi-scale abundance, *J. Ethnobiol. Ethnomet.* 14 (1) (2018) 1–16.
- [7] O. Zongo, F. Tapsoba, F. Leray, C. Bideaux, S. Guillouet, Y. Traoré, A. Savadogo, Nutritional, biochemical and microbiological composition of *Borassus aethiopicum* Mart. sap in Burkina Faso, *J. Food Sci. Technol.* 57 (2) (2020) 495–504.
- [8] ... & Y. He, Q. Chen, H. Liu, L. Zhang, D. Wu, C. Lu, Z. Guo, Friction and wear of MoO₃/graphene oxide modified glass fiber reinforced epoxy nanocomposites, *Macromol. Mater. Eng.* 304 (8) (2019) 1900166.
- [9] S.R. Karnati, P. Agbo, L. Zhang, Applications of silica nanoparticles in glass/carbon fiber-reinforced epoxy nanocomposite, *Compos. Commun.* 17 (2020) 32–41.
- [10] V. Chinnasamy, S.P. Subramani, S.K. Palaniappan, B. Mysamy, K. Aruchamy, Characterization on thermal properties of glass fiber and kevlar fiber with modified epoxy hybrid composites, *J. Mater. Res. Technol.* 9 (3) (2020) 3158–3167.
- [11] X. Jing, J. Wei, Y. Liu, B. Song, Y. Liu, Deployment analysis of aramid fiber reinforced shape-memory epoxy resin composites, *Eng. Sci.* 11 (2) (2020) 44–53.
- [12] R.M. Bajracharya, A.C. Manalo, W. Karunasena, K.T. Lau, An overview of mechanical properties and durability of glass-fibre reinforced recycled mixed plastic waste composites, *Mater. Des.* (1980–2015) 62 (2014) 98–112.
- [13] F.I. Mahir, K.N. Keya, B. Sarker, K.M. Nahian, R.A. Khan, A brief review on natural fiber used as a replacement of synthetic fiber in polymer composites, *Mater. Eng. Res.* 1 (2) (2019) 86–97.
- [14] N. Agrawal, O.P. Thakur, A.K. Singh, Role of shape, size and concentration of filler particles on filler matrix interface: a mathematical analysis, in: *Materials Today: Proceedings*, 44, 2021, pp. 890–894.
- [15] W. Ghorri, N. Saba, M. Jawaid, M. Asim, A review on date palm (*Phoenix dactylifera*) fibers and its polymer composites, *IOP conference series: materials science and engineering*, 368, 2018, June IOP Publishing.
- [16] H. Chandekar, V. Chaudhari, S. Waigankar, A review of jute fiber reinforced polymer composites, *Mater. Today: Proc.* 26 (2020) 2079–2082.
- [17] A.N. Oyediji, U.A. Umar, K.L. Shettima, Investigation of the Allometry of Oil Palm Trees in Nigeria for Mechanization of the Farming Process, *ATBU J. Sci. Technol. Educ.* 9 (2) (2021) 123–130.
- [18] T. Alfatah, E.M. Mistar, M. Syabriyana, M.D. Supardan, Advances in oil palm shell fibre reinforced thermoplastic and thermoset polymer composites, *Alexandria Eng. J.* 61 (6) (2022) 4945–4962.
- [19] K. Senthilkumar, N. Saba, N. Rajini, M. Chandrasekar, M. Jawaid, S. Siengchin, O.Y. Alotman, Mechanical properties evaluation of sisal fibre reinforced polymer composites: a review, *Constr. Build. Mater.* 174 (2018) 713–729.
- [20] ... & C.H. Lee, A. Khalina, N.M. Nurazzi, A. Norli, M.M. Harussani, S.A. Rafiqah, N. Ramli, The challenges and future perspective of woven kenaf reinforcement in thermoset polymer composites in malaysia: a review, *Polymers (Basel)* 13 (9) (2021) 1390.
- [21] M. Ramesh, Flax (*Linum usitatissimum* L.) fibre reinforced polymer composite materials: a review on preparation, properties and prospects, *Prog. Mater. Sci.* 102 (2019) 109–166.
- [22] ... & N.M. Nurazzi, M.R.M. Asyraf, A. Khalina, N. Abdullah, H.A. Aisyah, S.A. Rafiqah, S.M. Sapuan, A review on natural fiber reinforced polymer composite for bullet proof and ballistic applications, *Polymers (Basel)* 13 (4) (2021) 646.
- [23] D.K. Rajak, D.D. Pagar, P.L. Menezes, E. Linul, Fibre-reinforced polymer composites: manufacturing, properties, and applications, *Polymers (Basel)* 11 (10) (2019) 1667.
- [24] S.O. Onyekwere, M.H. Oladeinde, R.O. Edokpia, Multi-response optimization of bamboo fiber reinforced unsaturated polyester composites using hybrid taguchi – grey relational analysis method, *J. Ind. Prod. Eng.* (2020) 2–11.
- [25] V. Mahesh, V. Mahesh, D. Harursampath, Influence of alkali treatment on physio-mechanical properties of jute–epoxy composite, *Adv. Mater. Process. Technol.* (2021) 1–12.
- [26] R. E gala, S. Gangi Setti, Influence of surface modifications of Castor oil fibre on mechanical properties of fibre reinforced Epoxy composites, *Adv. Mater. Process. Technol.* (2021) 1–39.
- [27] M.H. Islam, M.R. Islam, M. Dulal, S. Afroj, N. Karim, The effect of surface treatments and graphene-based modifications on mechanical properties of natural jute fibre reinforced composites: a review, *Iscience* (2021) 103597.
- [28] A.H.F. Elahi, M.M. Hossain, S. Afrin, M.A. Khan, Study on the mechanical properties of glass fiber reinforced polyester composites, in: *International Conference on Mechanical Industrial and Energy Engineering*, vol. ICMIEE-PI, 2014, pp. 1–5.
- [29] N. Yousefi, A.D. Evans, L.T. Harper, H.A. Maples, T. James, A. Bismarck, Solid epoxy resin systems for automated composite manufacturing, *Composites, Part A* 142 (2021) 106205.
- [30] Montgomery, D.C. (2017). *Montgomery: Design and Analysis of Experiments*. John Wiley & Sons.
- [31] S. Kostic, J. Milojkovic, G. Simunovic, D. Vukelic, B. Tadic, Uncertainty in the determination of elastic modulus by tensile testing, *Eng. Sci. Technol. Int. J.* 25 (2022) 100998.
- [32] B. Zheng, T. Deng, M. Li, Z. Huang, H. Zhou, D. Li, Flexural behavior and fracture mechanisms of short carbon fiber reinforced polyether-ether-ketone composites at various ambient temperatures, *Polymers (Basel)* 11 (1) (2018) 18.
- [33] M. Zubair, Y. Pai, Review on impact response of polymer composites, *J. Mech. Eng. Res. Dev.* 42 (4) (2019) 238–242.
- [34] A.A. Bachchan, P.P. Das, V. Chaudhary, Effect of moisture absorption on the properties of natural fiber reinforced polymer composites: a review, in: *Materials Today: Proceedings*, 2021.
- [35] H. Jariwala, P. Jain, A review on mechanical behavior of natural fiber reinforced polymer composites and its applications, *J. Reinf. Plast. Compos.* 38 (10) (2019) 441–453.
- [36] M. Alhijazi, Q. Zeeshan, B. Safaei, M. Asmael, Z. Qin, Recent developments in palm fibers composites: a review, *J. Polym. Environ.* 28 (12) (2020) 3029–3054.
- [37] A.M. Joglekar, A.T. May, E. Graf, I. Saguy, Product excellence through experimental design, *Food Product Dev.: From Concept Marketplace* 211 (1987).
- [38] G. Rajesh, A. Revuri, M.S. Arekapudi, G.R. DBM, Evaluating tensile properties of phragmites karka fibre reinforced polyester composites, *Mater. Today: Proc.* 18 (2019) 8–14.
- [39] C. Baley, M. Lan, A. Bourmaud, A. Le Duigou, Compressive and tensile behaviour of unidirectional composites reinforced by natural fibres: influence of fibres (flax and jute), matrix and fibre volume fraction, *Mater. Today Commun.* 16 (2018) 300–306.
- [40] H. Oliver-Ortega, Q. Tarrés, P. Mutjé, M. Delgado-Aguilar, J.A. Méndez, F.X. Espinach, Impact strength and water uptake behavior of bleached kraft softwood-reinforced PLA composites as alternative to PP-based materials, *Polymers (Basel)* 12 (9) (2020) 2144.
- [41] B.F. Valente, A.J. Silvestre, C.P. Neto, C. Vilela, C.S. Freire, Effect of the micronization of pulp fibers on the properties of green composites, *Molecules* 26 (18) (2021) 5594.

- [42] J.A. Halip, Effect of treatment on water absorption behaviour of natural fibre-reinforced polymer composites, *Sci. Direct* (2019) 141–156, doi:[10.1016/B978-0-08-102292-4.00008-4](https://doi.org/10.1016/B978-0-08-102292-4.00008-4).
- [43] I. Tharazi, A.B. Sulong, F. Mohd Salleh, Application of response surface methodology for parameters optimization in hot pressing kenaf reinforced biocomposites, *J. Mech. Eng. (JMEchE)* 17 (3) (2020) 131–144.
- [44] M.A. Aremu, R. Salau, A.A. Suleman, Compositional evaluation of young shoot of deleb palm (*Borassus aethiopum*, mart) and white yam (*Dioscorea rotundata*) flours, *Int. J. Chem. Sci.* 5 (3) (2012) 168–174.
- [45] R. Jeyapragash, V. Srinivasan, S.J.M.T.P. Sathiyamurthy, Mechanical properties of natural fiber/particulate reinforced epoxy composites—A review of the literature, *Mater. Today: Proc.* 22 (2020) 1223–1227.
- [46] N.A. Prasad, V. Kumar, S. Agarwal, S. Sinha, Hybridization Effect of Coir Fibre on Physico-Mechanical Properties of Polyethylene-Banana/Coir Fibre Hybrid Composites, *DE GRUYTER* (2018), doi:[10.1515/secm-2015-0446](https://doi.org/10.1515/secm-2015-0446).
- [47] A. Zegaoui, M. Derradji, R.K. Ma, W.A. Cai, A. Medjahed, W.B. Liu, G.X. Wang, Influence of fiber volume fractions on the performances of alkali modified hemp fibers reinforced cyanate ester/benzoxazine blend composites, *Mater. Chem. Phys.* 213 (2018) 146–156.
- [48] A. Zegaoui, M. Derradji, R. Ma, W.A. Cai, A. Medjahed, W.B. Liu, J. Wang, Silane-modified carbon fibers reinforced cyanate ester/benzoxazine resin composites: morphological, mechanical and thermal degradation properties, *Vacuum* 150 (2018) 12–23.
- [49] M. Derradji, N. Ramdani, T. Zhang, J. Wang, L.D. Gong, X.D. Xu, W.B. Liu, Thermal and mechanical properties enhancements obtained by reinforcing a bisphenol-a based phthalonitrile resin with silane surface-modified alumina nanoparticles, *Polym. Compos.* 38 (8) (2017) 1549–1558.
- [50] P. Sudhakara, K. Obi Reddy, C.V. Prasad, D. Jagadeesh, H.S. Kim, B.S. Kim, J.I. Song, Studies on *Borassus* fruit fiber and its composites with Polypropylene, *Compos. Res.* 26 (1) (2013) 48–53.