

# Analytical and Finite Element Analysis of Natural Fiber Reinforced Composites for Application in Food Packaging Industry

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**Abstract** As a contribution to the race of moving towards green materials for manufacturing products in every field, this research has been conducted by considering a completely biodegradable matrix and five different natural fibers (NFs). The elastic properties of five different NF-based composites are studied by considering each of these fibers separately with polylactic acid (PLA) as the base material. The elastic properties of these composites are predicted by using the rule of mixture and Halpin–Tsai method. This study reveals that the elastic properties of the composites made from banana, pineapple leaf, and jute are comparatively higher than those of bamboo and sisal. Banana fiber composite shows the highest longitudinal Young’s modulus among all the five composites. Young’s modulus and shear modulus of all the composites increases with an increase in the volume fraction of fiber. The major Poisson’s ratio declines with an increment in fiber volume fraction except for sisal fiber composite. Therefore, considering banana/PLA composite to be the best one among all the five composites in terms of mechanical strength, a finite element analysis (FEA) has been carried out for a six-liter water gallon made of banana/PLA composite as well as polyethylene terephthalate (PET) using ANSYS workbench software. The deformation and equivalent stress induced have also been found for a comparative study between two water gallons.

The FEA infers that the banana/PLA composite could be a promising material to replace PET in the food packaging industry.

**Keywords** Natural fiber composites · Biodegradable · Elastic properties · Finite element analysis · Stress · Food packaging

## Introduction

Natural fibers (NFs) are biodegradable and hence, the utilization of these fibers in composite materials as substitutes for synthetic fibers is a contribution towards sustainable development. Along with biodegradability, properties such as lightweight, low cost, and their capability to replace synthetic fibers in automotive or aerospace industries are the fascinating features of natural fiber-reinforced composites (NFRCs) [1]. Natural fibers, when combined with a biodegradable matrix, lead to a sustainable biodegradable composite material that can find extensive applications in our daily life. With rising demands in the area of environmental sustainability, an entirely biodegradable material that has comparable properties with contemporary materials is something that today’s world is striving towards.

Earlier, Syduzzaman et al. [2] presented a review on the fabrication of NFRCs with plant fiber reinforcement and their use in different industries including sports, medicine, automobile, aerospace, etc. Zandvliet et al. [3–5] fabricated and performed different tests of Jute/poly(lactic acid) (PLA) and flax/PLA composites and reported that jute/PLA composites can replace wood based panels in interior applications [3, 4]. They have also reported that the treated jute/PLA composite exhibits better water resistance properties, and both the treated composites show effective improvement

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upon aging for use in furniture [5]. Recently, Khieng et al. [6] reviewed the variation of mechanical properties of NFRCs under different strain rates. They reported that with an increment in strain rate, the strength of the composite increases, but it makes the material brittle due to short stress relaxation time and the composite subsequently experiences a brittle failure with a further increase in strain rate. North-eastern India, especially Assam is abundant in forests and agriculture which consists of fiber-producing plants like bamboo, jute, sisal, banana, pineapple, etc. Assam produces high strength natural fibers which are relatively inexpensive. These fibers can thus act as a replacement for synthetic fibers in terms of strength. Assam produces the highest quantity of raw jute among all the northeastern states. It holds the third position among all the Indian states in jute fiber production [7]. Barpeta, Darrang, Nagaon, and Goalpara are the major districts of Assam where jute is being largely cultivated [8]. Gogna et al. [9] reviewed jute fiber reinforced composites (JFRCs) and mentioned that jute is a low cost fiber that possesses significantly high strength. The mechanical, electrical, water absorption, or wear properties of the composite depend largely on the fiber loading, fiber length, surface treatment of the fiber, and fabrication technique. Chandekar et al. [10] reviewed the interfacial adhesive strength between jute and polymer matrix and the mechanical properties of JFRCs. JFRCs show exceptional improvement in mechanical properties upon hybridization with glass fiber and these composites can be termed as structural because they find application in the construction industry along with geotextile and furniture industry. Similarly, there are various types of bamboo available in Assam. Among all the Indian states, Assam produces and exports the highest quantity of bamboo to different parts of the country, even outside the country. Cachar, North Cachar Hills, Nagaon, Karbi Anglong, and Lakhimpur are the main bamboo growing districts in Assam [11]. Liu et al. [12] discussed bamboo fiber reinforced polymer composites (BFRPCs) and mentioned that a relatively fair mechanical property of bamboo fibers makes it eligible for different industrial applications including textile, paper, and construction sectors. Chin et al. [13] fabricated BFRPCs and compared the mechanical and thermal properties of treated (alkali) and non-treated fibers. They observed that treated fibers exhibit much higher thermo-mechanical properties due to the effacing of impurities and higher surface roughness of fibers, which leads to better matrix-fiber adhesion. They also reported that BFRPCs exhibit optimum tensile and flexural properties at 40% fiber loading. Sema et al. [14] reported that more than 40% of the total production of pineapple in India comes from the northeastern region. Pineapple leaf fiber (PALF) composites become much stronger and the water uptake capacity of the composites reduces when they are hybridized with another synthetic fiber [15]. Borah et al. [16] investigated the structural response of thin

laminated plates made of NFRCs. They concluded that there was a significant impact of fiber volume fraction ( $V_f$ ) and aspect ratio of the plate on frequency. Assam is also home to the largest banana market in Asia, which is located in Darrangiri in the district of Goalpara [17]. Therefore, it has a huge resource of banana fiber. Earlier, Adeniyi et al. [18] studied the elastic properties of polymer composites with banana fiber reinforcement by applying finite element method (FEM), where they documented that the stiffness of the composites rose with increasing  $V_f$ . Additionally, sisal is also a cellulosic fiber with promising mechanical properties. Barreto et al. [19] fabricated epoxy-based bio-composites with sisal fiber reinforcement and they reported that the crystallinity of the fiber decreases upon chemical treatment due to the removal of amorphous components like lignin, wax, and hemicellulose. However, the composite showed better thermal stability with chemical treatment of the fiber. Sisal fiber composites exhibit good flexural strength in seawater environments and therefore, it can be used for marine applications as well [20].

Potluri et al. [21] discussed a few analytical models to pre-visualize the elastic nature of NFRCs and compared those properties with experimental results. They found that the rule of mixture method yielded good results for major Poisson's ratio and longitudinal Young's modulus, but the Halpin-Tsai method could not match with the experimental results. Islam et al. [22] analyzed some prediction models to find the elastic behavior of NFRCs and concluded that semi-empirical methods like modified Halpin-Tsai and Bowyer-Bader model could satisfactorily predict Young's modulus of the composites. However, Joardar et al. [23] revealed that all the elastic properties of a composite cannot be predicted by using one unified model. Only specific models can be used for predicting different elastic properties for a varying  $V_f$  in the composite.

Along with application in structural, automobile, and other fields, NFRCs are being tried to use in food processing as well. Some of them have shown outstanding results to replace plastics in the food processing industry. Hazrati et al. [24] reported a review on bio-based food packaging with NFs and they mentioned that due to good water vapor permeability, NFs can be sustainable substitutes in the food packaging industry. Berthet et al. [25] studied the effect of the size of wheat straw fiber in its composite for application in food packaging, which infers that wheat straw fiber composites can also be used in the food processing industry. Zang et al. [26] reviewed that to limit food borne diseases and to maintain food quality, polymer composites are one of the promising materials for use in food packaging.

Till now, numerous research works on NFRCs have been reported. However, researchers have hardly emphasized the quality of the fibers which are grown in northeastern India and very limited research has been found on the comparative

study of the properties of the composites made from these fibers. The present study aims at comparing the elastic properties of composites reinforced with five dissimilar NFs which are abundantly found in the northeast Indian state of Assam. Moreover, the use of NFs in food packaging has not gained much popularity till now because adequate research is not done yet in this field. Coconut fiber is one of the few NFs that has been commercially used in food packaging so far [27]. There are a lot of other fibers which can prove to be suitable for use in food packaging. The second objective of this study is to look into the applicability of a green composite of PLA with NF as reinforcement in food packaging. Water is the most essential consumable for human survival and to store water, usually, bottles, gallons, or tanks are used. These bottles, gallons, or tanks are generally made of high-density polyethylene (HDPE) or polyethylene terephthalate (PET). These are not environment-friendly materials. To replace the conventionally used materials with NFRCs, the mechanical properties of NFRCs such as deformation occurring or stress induced in the body of the object on the

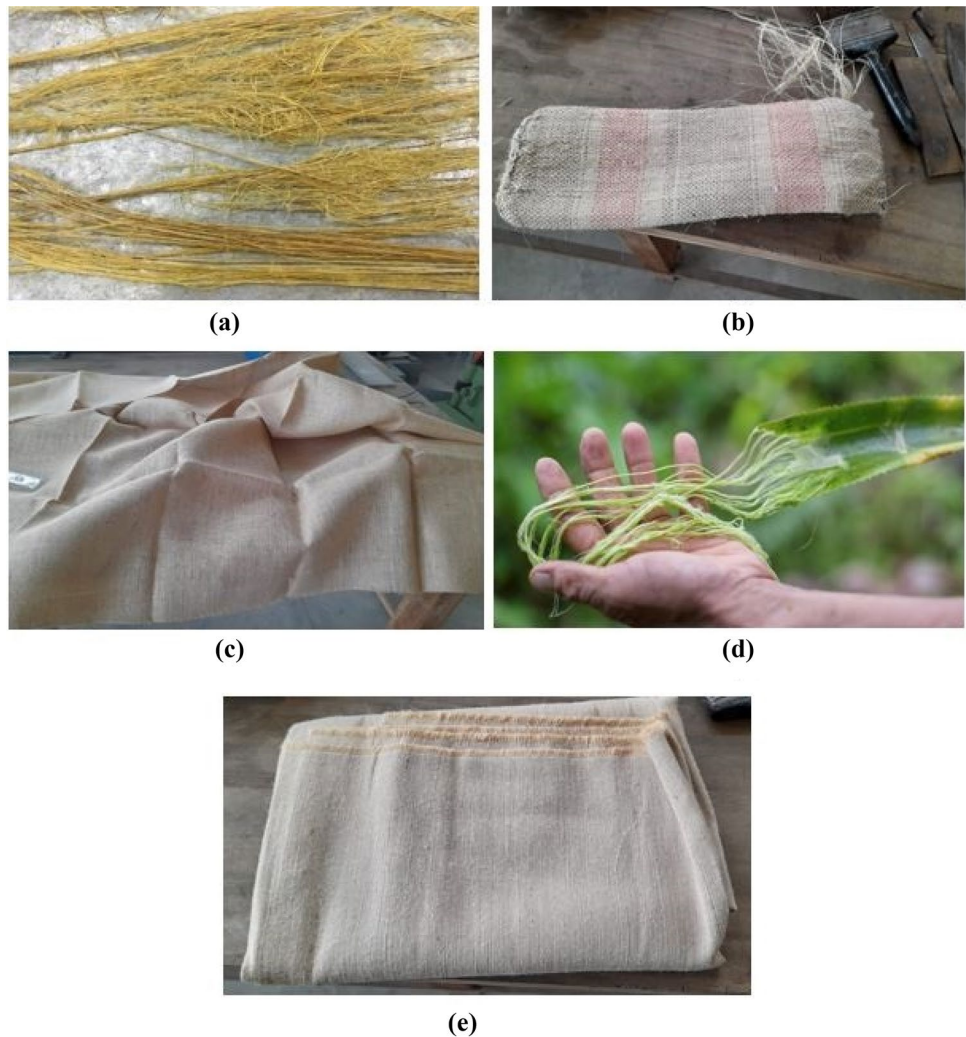
application of load need to be inspected. Therefore, finite element analysis (FEA) has been performed on a water gallon using ANSYS commercial software. The water intake capacity of the NFRCs is another important aspect to study for checking the applicability of these composites in food packaging. This aspect can be looked into experimentally in future work.

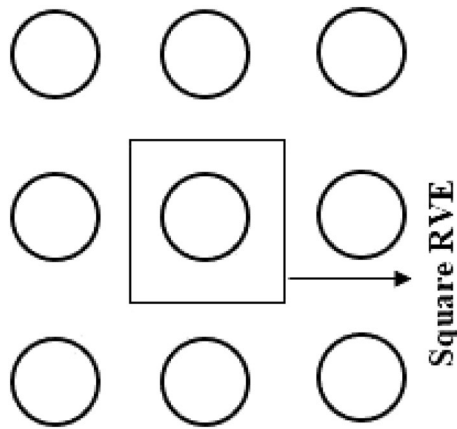
## Materials and Methods

### Materials

In this study, PLA has been considered as the matrix and five different types of NFs viz. banana, bamboo, jute, sisal, and PALF have been considered as reinforcement materials. All these five NFs are shown in Fig. 1. PLA is an aliphatic polyester compound which is completely biodegradable. Banana is a stem fiber containing 63%–64% cellulose. Bamboo fiber is also a stem fiber with high content of cellulose. These

**Fig. 1** a Bamboo fiber [28], b banana fiber, c jute fiber, d pineapple leaf fiber [29], and e sisal fiber





**Fig. 2** Representative volume element of circular fiber in a packing geometry of square array

**Table 1** Properties of PLA and the five natural fibers

Materials	Young’s modulus (GPa)	Poisson’s ratio
PLA	4.107 [30]	0.332 [30]
Bamboo	9.80 [2]	0.22 [31]
Banana	30.0 [32]	0.28 [32]
Jute	26.5 [10]	0.32 [32]
Pineapple leaf	29.3 [32]	0.3 [32]
Sisal	13.0 [33]	0.42 [33]

are widely used in textile industries. Jute is a kind of bast fiber containing cellulose and lignin as its main constituent. Pineapple fiber is extracted from the leaf of the pineapple plant which has comparable properties with jute, cotton, etc. Sisal is also a leaf fiber which is known for its strength and durability. It is generally used in making carpets.

**Theoretical Analysis**

The fibers are considered to be of circular cross-section dispersed in a packing geometry of square arrays shown in Fig. 2. It has been found from the literature review that the properties of a particular NF are different in different literature. The quality and properties of a particular NF vary due to the different climatic conditions of the region in which they grow or are being cultivated. For this study, the elastic properties (EPs) of the five different NFs and PLA have been listed in Table 1 as reported in various pieces of literature [2, 10, 30–33].

Elastic properties of the composites viz. longitudinal Young’s modulus ( $E_{11}$ ), transverse Young’s modulus ( $E_{22}$ ), in-plane shear modulus ( $G_{12}$ ), and major Poisson’s ratio ( $\nu_{12}$ ) have been determined using two different methods. The rule of

mixture method (ROM) is used to determine  $E_{11}, \nu_{12}$ , while  $E_{22}$  and  $G_{12}$  are determined using the Halpin–Tsai (H-T) method.

*Rule of Mixture*

The ROM is an empirical method to determine the elastic behavior of composites. Mechanical properties of composites depend on the volume fraction of the matrix and reinforcement. So, there is a cause-effect relationship between the volume fraction of the constituent materials and the properties of the composites. The elastic properties of the composite may improve or worsen with the increase in the volume fraction of a certain constituent. The  $E_{11}$  and  $\nu_{12}$  of the composites for varying  $V_f$  have been calculated using the ROM method [34].

$$E_{11} = E_f V_f + E_m V_m, \tag{1}$$

$$\nu_{12} = \nu_f V_f + \nu_m V_m \tag{2}$$

and

$$\text{Where, } V_m + V_f = 1 \tag{3}$$

where,  $E_m$  and  $E_f$  denote Young’s modulus of matrix and fiber respectively;  $\nu_m$  and  $\nu_f$  represents the Poisson’s ratio of matrix and fiber respectively. The volume fraction of matrix is denoted by  $V_m$ .

*Halpin–Tsai Method*

This is a semi-empirical method that is widely adopted to evaluate the EPs of composites. This method takes the individual properties of the matrix, reinforcement, and the reinforcing factor of the fiber into consideration to predict the property of the composite. In this method, there is also a cause-effect relationship between the volume fraction of the constituent materials and the properties of the composite. Halpin and Tsai developed this new model when they realized that the analytical and experimental results of transverse modulus and in-plane shear modulus using the ROM method did not agree well with each other. In the present study, the  $E_{22}$  and  $G_{12}$  are determined by using the (H-T) method [34].

$$\frac{E_{22}}{E_m} = \frac{1 + \xi_{22} \eta_{22} V_f}{1 - \eta_{22} V_f} \tag{4}$$

$$\frac{G_{12}}{G_m} = \frac{1 + \xi_{12} \eta_{12} V_f}{1 - \eta_{12} V_f} \tag{5}$$

$$\text{where, } \eta_{22} = \frac{\frac{E_f}{E_m} - 1}{\frac{E_f}{E_m} + \xi_{22}} \tag{6}$$



$$\eta_{12} = \frac{\frac{G_f}{G_m} - 1}{\frac{G_f}{G_m} + \xi_{12}} \quad (7)$$

where,  $\xi_{12}$  and  $\xi_{22}$  are reinforcing factors and they depend on the geometry and packing arrangement of the fiber. For fibers with circular cross-section in square array,  $\xi_{22} = 2$  and  $\xi_{12} = 1$ .  $G_m$  and  $G_f$  denotes the shear modulus of the matrix and reinforcement respectively.

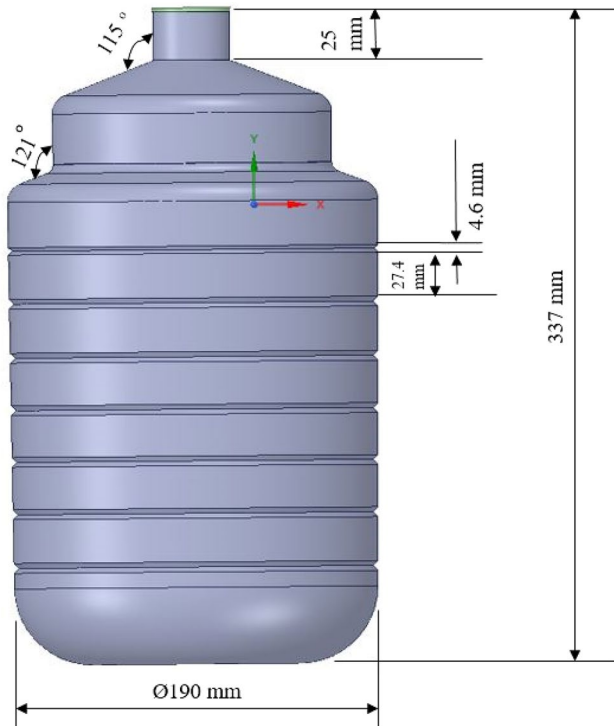


Fig. 3 Dimensions of the water gallon

### Finite Element Analysis

A water gallon of six liters is designed in SolidWorks with dimensions as shown in Fig. 3.

The design is imported to ANSYS workbench and it is modeled by keeping the lower portion of the gallon fixed. A top load equivalent to 4 layers of vertical stacks of the same gallon package i.e. 245.25 N [35] is applied on the gallon. Hydrostatic pressure is applied on the inner wall of the gallon for a water height of 337 mm. The loading conditions are shown in Fig. 5.

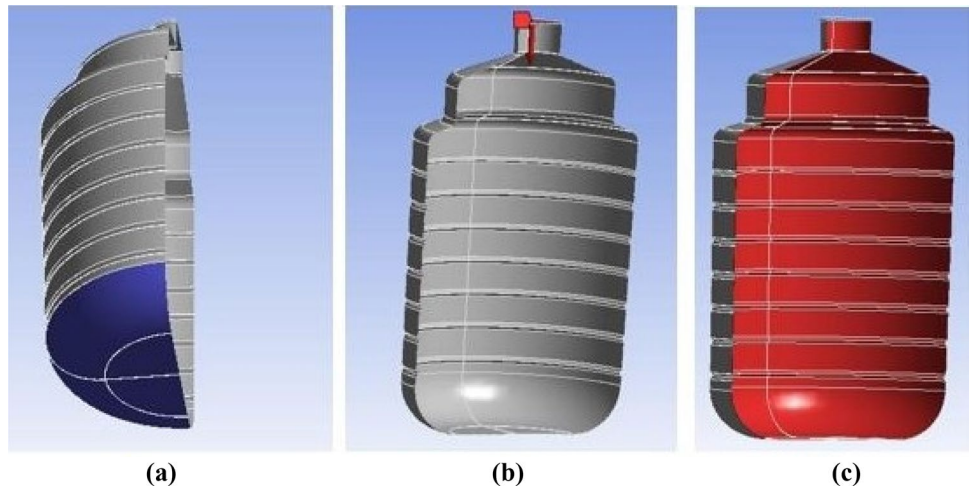
### Mesh Convergence Analysis

Mesh was generated in the whole body of the model by using tetrahedron method. As a result, tetrahedral elements were generated in the body. The deformation in the body was checked by reducing the element size from 5 mm to 1.3 mm. It could be seen that the deformation value converges as the element size decreases beyond 1.5 mm as shown in Fig. 4a. Therefore, the FEA is done with an element size of 1.5 mm. The FE mesh with zoomed view of the water gallon is shown in Fig. 4b.

### Results and Discussion

Calculations of all the four EPs of the five NFRCs for different fiber volume fractions have been conducted numerically using MATLAB. Ideally, there are some maximum limits of  $V_f$  based on the geometrical packing, beyond which the elastic properties of the composites show substantial deviation. For circular fiber with square array packing, this maximum limit is 78.54% [34]. But in this study, the range of fiber volume fraction has been considered upto 40% based on the findings by Chin et al.

Fig. 4 Loads applied on the water gallon a fixed support b top load c hydrostatic pressure



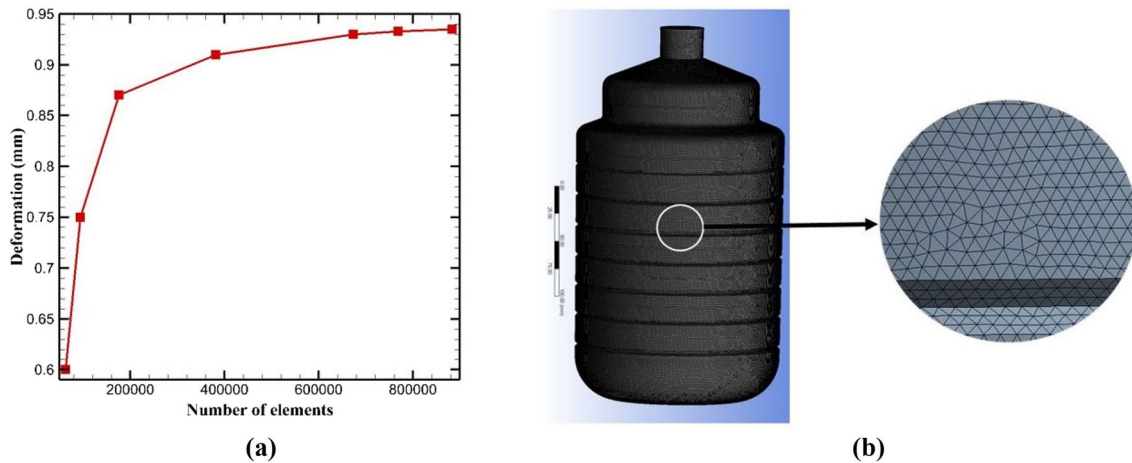


Fig. 5 a Finite element mesh convergence analysis b finite element mesh of the water gallon with zoomed view

[13], where they mentioned that the bamboo fiber composites show higher tensile and flexural strength at 40% fiber loading.

### Elastic Properties

#### Longitudinal Young's Modulus

The  $E_{11}$  for all NFRCs has been calculated using Eq. (1). The variation of  $E_{11}$  of the NFRCs for all the five fibers with  $V_f$  is shown in Fig. 6.

It can be observed in Fig. 6 that the  $E_{11}$  of the composites exhibits linear increment for all the NFRCs with the increase in  $V_f$ . The composite reinforced with banana fiber shows the highest  $E_{11}$  since banana fiber has the maximum Young's modulus among all the five fibers. It can also be seen from Fig. 6 that the value of  $E_{11}$  of banana/PLA composite at 40% fiber loading is equal to 14.46 GPa. Therefore, it can be concluded that the  $E_{11}$  of banana/PLA composite increases by 252% from 10 to 40% fiber loading. On the other hand, the composite with bamboo fiber reinforcement shows the lowest  $E_{11}$  since bamboo has the minimum Young's modulus among all the five fibers. It can also be observed from Fig. 6 that there is a negligible difference between the  $E_{11}$  value of banana/PLA and PALF/PLA composite because Young's modulus of banana and PALF are almost equal. Figure 6 also shows that the  $E_{11}$  of jute/PLA is comparable with the  $E_{11}$  of banana/PLA and PALF/PLA composites. In the fiber reinforced composite material, the fiber is the main load carrying member and the functions of the matrix material are to hold the fiber and transfer the stress from the matrix to the fiber. Therefore, with the rise in fiber loading, the composite becomes more capable of bearing the load, and hence, the  $E_{11}$  increases.

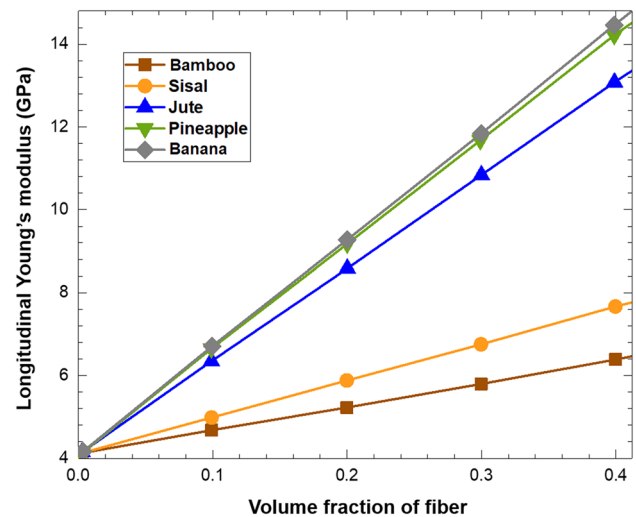


Fig. 6 Longitudinal Young's modulus of NFRCs with increasing volume fraction of fibers

#### Transverse Young's Modulus

The  $E_{22}$  of the composites has been calculated using Eq. (4). The variation of  $E_{22}$  for all the fiber reinforced composites with different  $V_f$  is shown in Fig. 7.

Unlike  $E_{11}$ , a non-linear pattern has been observed in this case. But the value of  $E_{22}$  is less than the value of  $E_{11}$  since the fibers are aligned in the longitudinal direction. The reason for the increase in  $E_{22}$  is due to the presence of the parameters ( $\eta_{22}$  and  $\xi_{22}$ ) in Eq. (4). The composites with banana and PALF reinforcement show a maximum value of  $E_{22}$ . The  $E_{22}$  of banana/PLA composite increases by 110% with an increase in fiber loading from 10 to 40%. It can also be observed from Fig. 7 that there is a negligible difference between the  $E_{22}$  values of banana/PLA and PALF/

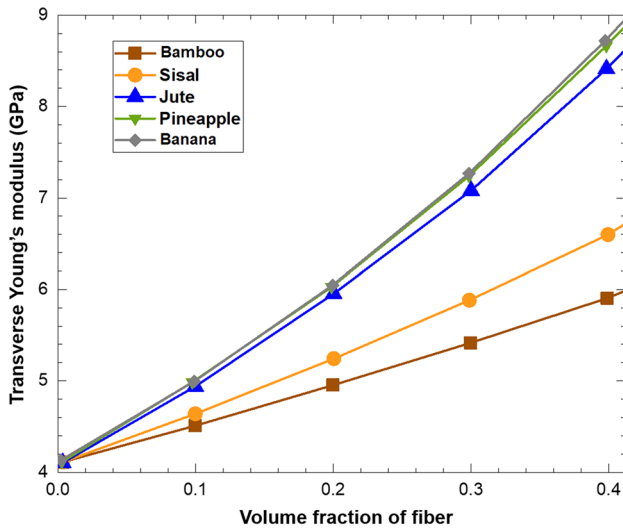


Fig. 7 Transverse Young's modulus of NFRCs with increasing volume fraction of fiber

PLA composite because banana and PALF possess almost the same Young's modulus. The  $E_{22}$  of jute/PLA composite is also comparable with the  $E_{22}$  of banana/PLA and PALF/PLA composites. A minimum increase of 43% in  $E_{22}$  has been observed in the case of bamboo/PLA composite till 40% of fiber loading.

Major Poisson's Ratio

Equation (2) has been used to calculate the  $\nu_{12}$  of the NFRCs. The variation of  $\nu_{12}$  with  $V_f$  is shown in Fig. 8. The composite with sisal fiber as reinforcement possesses the maximum  $\nu_{12}$  because sisal fiber has the maximum value of Poisson's ratio among all five fibers. Only the  $\nu_{12}$  of sisal/PLA composite is found to be increasing by 9% with a rise in  $V_f$  from 10 to 40%. This can be attributed to the fact that the Poisson's ratio of sisal fiber is more than that of PLA. Other than sisal, the  $\nu_{12}$  value of the composites reinforced with banana, bamboo, jute, and PALF decrease linearly with an increase in  $V_f$  because these fibers possess a lower value of Poisson's ratio than the matrix material. It is also observed from Fig. 8 that the minimum  $\nu_{12}$  is found for bamboo/PLA composite and it decreases by 14% till 40% of fiber loading.

IN-PLANE Shear Modulus

To evaluate the value of the  $G_{12}$  of all the five NFRCs, Eq. (5) has been used. The variation of  $G_{12}$  with the increase in  $V_f$  is shown in Fig. 9. Variation of shear modulus follows a similar pattern as the variation of  $E_{22}$  with the increment in fiber loading. The  $G_{12}$  of all the composites increases due to the use of parameters ( $\eta_{12}$  and  $\xi_{12}$ ) in Eq. (5). The banana, PALF, and jute fiber reinforced

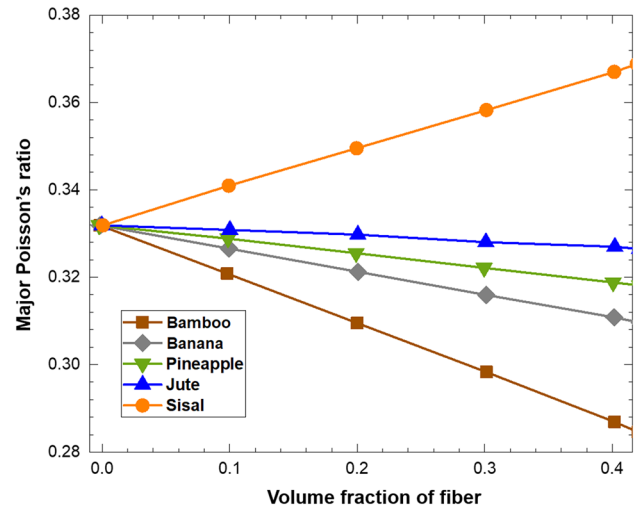


Fig. 8 Major Poisson's ratio of NFRCs with increasing volume fraction of fiber

composites show the maximum value of  $G_{12}$  and other composites have lesser values because Young's modulus of bamboo and sisal are less than the rest of the fibers.

For banana/PLA composite, 93% increase in  $G_{12}$  can be seen till 40% increase in fiber loading. It can also be observed from Fig. 9 that there is a negligible difference in the  $G_{12}$  value among banana/PLA, PALF/PLA, and jute/PLA composites because Young's modulus of banana, PALF, and jute are almost equal, whereas a minimum increase of 46% can be observed in the case of bamboo/PLA composite with 40% of fiber loading.

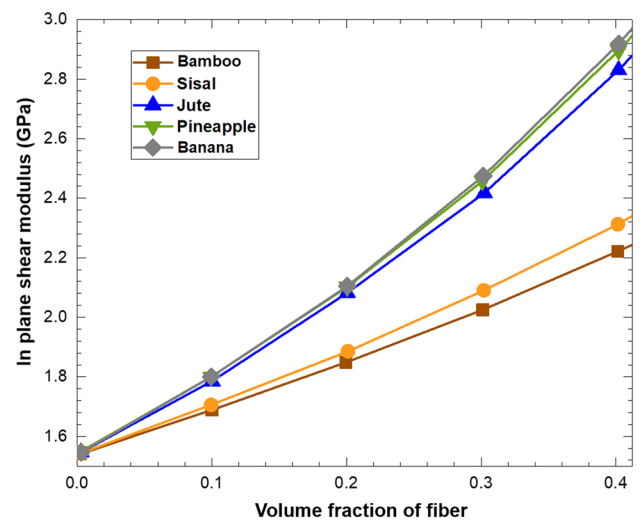


Fig. 9 In-plane shear modulus of NFRCs with increasing volume fraction of fiber

### Validation of the Present Analytical Results with Experimental Results

Many experimental works on the evaluation of mechanical properties of composites made from PLA and NFs have been performed so far. In Table 2, the analytical results obtained in this study are compared with some experimental results for PLA composites documented by other researchers [36–40].

It can be seen in Table 2 that the experimental results are lesser than the analytically predicted results. Lots of factors affect the experimental results and the major one among them is the manufacturing defect. The presence of void or imperfect orientation of fiber sometimes brings down the value of the mechanical properties from the actual ones. Another important reason behind the deviation of experimental value from the predicted value is that the analytical models assume perfect fiber orientation, spacing, fiber geometry, and perfect adhesion at the fiber-matrix boundary. This is not quite always possible practically. However, it can also be seen that the predicted value of Young's modulus of sisal/PLA composite is nearly equal to the experimentally obtained value.

### Finite Element Analysis of Water Gallon

The analytical study reveals that out of all the five different NFs, banana fiber composite exhibits the best elastic properties. Therefore, the FEA has been performed on a water gallon made of banana/PLA composite. The water gallon is considered to be fully filled with water. The deformation occurred and the stress induced in the gallon has been investigated in this analysis.

#### Validation of Finite Element Model

The FEA for deformation of the water gallon performed in the present study is validated with the analysis of Thongkaew and Naemsai [35], where they performed FEA of deformation of a 6-L bottle made of polyethylene terephthalate (PET) and obtained a deformation of nearly 4 mm. For the same design with the same loading conditions, the

present analysis showed a deformation of 4.519 mm in the water gallon. From this result, it can be concluded that the present FE result is in good agreement with the result obtained by Thongkaew and Naemsai [35].

#### Deformation of Water Gallon

Figure 10a illustrates the deformation of the water gallon made of banana/PLA composite. In this study, total deformation in the water gallon has been inspected. The total deformation is defined as the square root of the summation of square of the deformation along X, Y and Z directions. For the given loading conditions, the water gallon showed a total deformation of 0.93 mm. But in the case of PET water gallon the total deformation is found to be 4.519 mm. The less deformation in the composite gallon compared to the PET gallon can be attributed to the fact that the composite has a higher Young's modulus than PET.

#### Equivalent von Mises Stress

Figure 10b shows the stress contour in the water gallon for the applied loads. The stress is more at the upper portion of the gallon. The magnitude of maximum von Mises stress in the tank is found to be 40.736 MPa which is less than the yield strength of the individual components i.e. polylactic acid (60 MPa) [41] and banana fiber (52.57 MPa) [42]. This infers that the banana/PLA composite used in the water tank will not yield in the given loading conditions.

This comparative study of the mechanical properties of a water gallon made of banana/PLA composite and PET with the help of FEA has been performed to investigate the ability of the composite to replace PET. The FEA reveals that the deformation that occurred in the gallon is much lower than that of the PET gallon. Since the deformation of 4 mm is safe for the PET gallon [35], it is obvious that the deformation in this composite gallon also lies in the safe zone. Moreover, the composite gallon can withstand higher stress than the PET gallon.

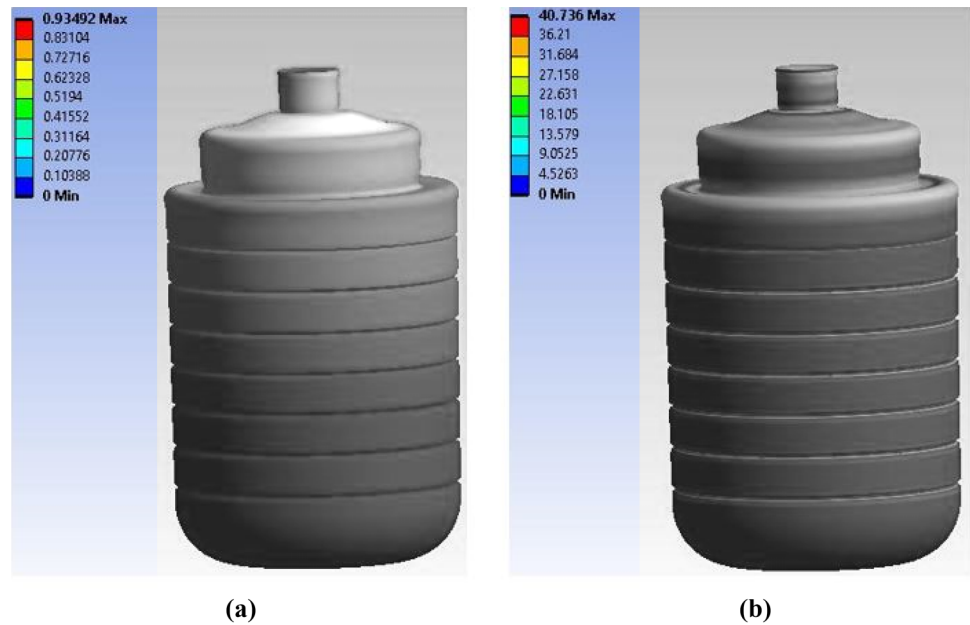
A lot of researches are being carried out around the globe on NFRCs. These researches reveal that the property of the composites are different even when they are reinforced with same fiber from different parts of the world, because the quality of plant fibers depend on the climatic condition of the region where they grow. The fibers grown in north-east Indian region have hardly been paid attention to so far. The present study is an attempt to look into that aspect. Moreover, it has inspected the applicability of one of the promising fibers found in north-east Indian region which has not been commercially popular till now for application in food packaging.

**Table 2** Comparison of analytical result with experimental result

Fiber	Fiber volume fraction (%)	Young's modulus (GPa)	
		Present analysis	Experimental
Bamboo	30	5.81	2.36–2.63 [36]
Banana	30	11.87	4.6–4.8 [37]
Jute	10	6.3	1.9 [38]
Pineapple	10	6.6	3.2 [39]
Sisal	10	4.9	3.6–3.8 [40]



**Fig. 10** a Deformation b equivalent von Mises stress in the water gallon



## Conclusions

The study of elastic properties of composites reinforced with five dissimilar NFs altogether, which are found in the northeastern part of the Indian sub-continent provides an extended panoramic view of the elastic properties of the NF based composites. This study tries to investigate the capacity of NFs of northeastern India, in terms of their resistance against load, for application in food packaging. The conclusions drawn from this study are listed below:

- Young's modulus and shear modulus of all the composites improves with an increase in the volume fraction of fiber.
- Banana fiber composite shows the highest longitudinal Young's modulus among all the five NFRCs.
- Banana and PALF composites show an increase of 110% in transverse Young's modulus with an increase in fiber loading from 10 to 40%.
- The major Poisson's ratio of sisal/PLA composite improves with higher volume fraction but for the rest of the composites, it deteriorates with increasing volume fraction.
- Water gallon made of banana/PLA composite undergoes less deformation than that made of PET. The stress induced in the banana/PLA gallon is also more than that of the PET gallon.
- Considering load bearing capacity, banana/PLA composite can be a promising and potential material to replace PET in the food processing industry.

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**Declaration**

**Competing Interests** The authors have no relevant financial or non-financial interests to disclose.

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