Analytic Hierarchy Process (AHP)-Based Materials Selection System for Natural Fiber as Reinforcement in Biopolymer Composites for Food Packaging

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The biodegradability of a material has been an important measure in packaging design. Green biocomposites, which are made of natural fiber and biopolymer matrix, are promising alternative materials in single-use packaging to replace conventional materials. Selection of the most suitable natural fiber for reinforcement in green biocomposites is an initial attempt towards reducing resources depletion and packaging waste dumping. A selection system of analytic hierarchy process (AHP)-based method is proposed. Food packaging materials' requirements and production factors are the basis of selecting 13 vital characteristics of natural fibers as the selection criteria. Nine natural fibers were assessed based on data gathered from recent literature. From the results, *ijuk* obtained the highest priority score (14%). Whilst, sisal had the lowest rank with a score of 8.8%. Sensitivity analysis was then performed to further validate the results, and *ijuk* remained at the top rank in four out of the six scenarios tested. It was concluded that *ijuk* is the most suitable natural fiber for reinforcement in green biocomposites for food packaging design. Nonetheless, for future development, more comprehensive selection criteria, such as fiber specific properties, fiber processing, and fibre treatment, are suggested to be included in the framework for more comprehensive results.

Keywords: AHP; AHP rating mode; Natural fiber selection; Green biocomposites; Food packaging; Design process

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INTRODUCTION

Natural fiber is fibrous plant material produced as a result of photosynthesis and generally classified into two categories that are based on the plants producing natural fibers: primary and secondary. Primary plants are those planted for their fiber content, whereas secondary plants are grown for other utilization, and the fibers come as a by-product. Jute, hemp, kenaf, sisal, and flax are examples of primary plants, while pineapple, sugar palm, oil palm, and coir are examples of secondary plants. The growing awareness of environmental issues influence the demand of goods produced from natural products, including natural fibers. Natural fiber can replace synthetics fiber for reinforcement in biopolymer composites. The resulting "green biocomposites," are more environmentally friendly, as they are renewable, biodegradable, compostable, and reduce the reliance on fossil fuel (Soroudi and Jakubowicz 2013; Othman 2014; Ramamoorthy *et al.* 2015; Al-

Oqla and Omari 2017). Natural fibers in composites materials provide stiffness and sufficient strength, and they contribute to the unique properties of the final materials (Sapuan *et al.* 2011; Johansson *et al.* 2012; Al-Oqla *et al.* 2015; Sanyang *et al.* 2016). They also generally have lower density, high specific properties, good thermal properties, and high resistance to fracture (Puglia *et al.* 2005; Cheung *et al.* 2009; Majeed *et al.* 2013; Salit 2014). These properties make natural fibers suitable candidates for high quality reinforcement in composites materials (Mitra 2014; Al-Oqla *et al.* 2017).

The choice of a more environmentally friendly material starts with the right selection of composites' constituents to create innovative biocomposites materials. Proper material selection boosts the desired properties of both physical and meta-physical of the intended consumer products design.

Concurrent engineering (CE) environment helps in developing the design requirements of the composites product design by the designers or material engineers, as they receive input from various stakeholders to ensure the design objective is fulfilled (Sapuan and Mansor 2014). This encompasses the selection of natural fiber and polymer matrix to form innovative composites materials. Selecting the right constituent materials in designing composites materials is not an easy task and it is a critical aspect in CE approach. Appropriate material selection has become a crucial process to achieve successful sustainable designs at the same time meeting customer satisfaction features. In the packaging sector, the utilization of natural fiber for reinforcement in biocomposites materials is often restricted by several constrains and factors. Selection of the most suitable type of natural fiber for an application is a complex matter for which thorough decisions are necessary.

In the past, many studies have been carried out focusing on the material selection process under the topics of composites product development and product design. Mastura *et al.* (2018) recently conducted an innovative study on selection of thermoplastic polymers that could be used in natural fiber-reinforced polymer composites for an automotive anti-roll bar. The selection process was to find the most suitable thermoplastic polymer by performing the Quality Function Deployment for Environment (QFDE) technique. On the other hand, the packaging design requirements demand a very complex process due to the active nature of food products. Sanyang and Sapuan (2015) studied the bio-based polymer materials selection for a specific packaging application (packed fruits, dry food, and dairy products). They proposed a selection process was through the development of an expert system using the Exsys Corvid software, and it applied an "If-Then" rule-based system. The system screened materials that first satisfied all determined criteria, such as gas and water vapor barrier and mechanical properties. The system then produced a list in sequence according to their scores of proximities to the design specifications. Another study on material selection process by Almeida *et al.* (2017) aimed their efforts towards a refillable water bottle design. This process utilized environmental accounting based on energy. This energy accounting approach provided information on the environmental cost of each selection decision of the material. However, the evaluated materials were limited to glass, polyethylene terephthalate (PET), and aluminum, which are the resources most available in Brazil.

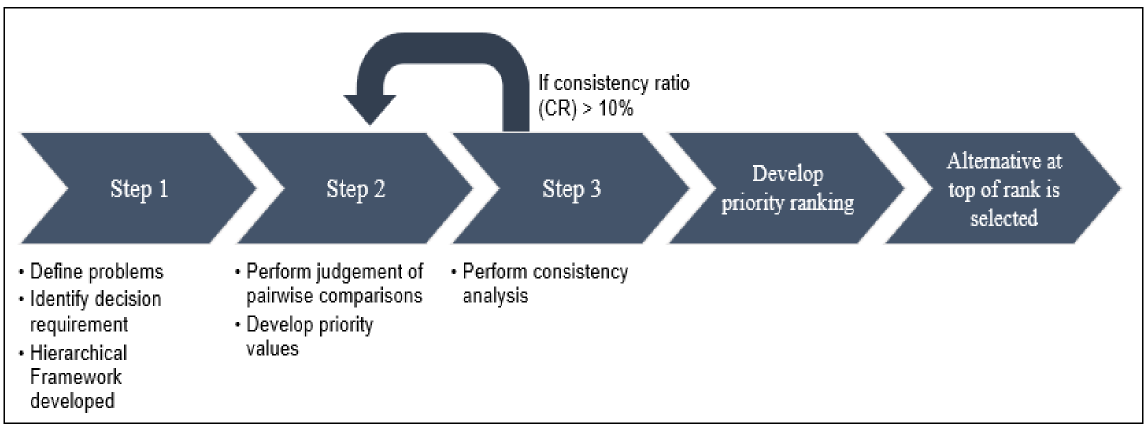
Analytic hierarchy process (AHP) is the most common technique of multi-criteria decision-making (MCDM) approach utilized in many material selections studies. AHP was first introduced by Saaty in 1977, and it has been continuously developed since then (Saaty and Vargas 2012). Hambali *et al.* (2010) demonstrated its application in a materials selection study to find the most suitable composite materials from six alternatives for the application of an automotive bumper beam design. They assessed eight main selection factors and 12 sub-factors. Based on priority vector values of each composite material, AHP revealed the most appropriate material. To further validate the results, six different scenarios were tested in the sensitivity analysis. Similarly, Sapuan *et al.* (2011) applied AHP to select the most suitable natural fiber reinforced composites (NFRC) for a dashboard panel design. They evaluated 29 NFRC alternatives according to their characteristics and features including density, Young's modulus, and tensile strength. A more recent study by Al-Oqla *et al.* (2016) also applied AHP to evaluate and select the most appropriate composites to be used for the design of interior parts of a vehicle. Fifteen potential alternatives of non-woven natural reinforcement fiber/polypropylene-based composites were deliberated in this study, and the selection criteria were tensile strength, tensile modulus, flexural strength, flexural modulus, impact strength, and the maximum water absorption of the composites.

Apart from selection of composites materials, there are also studies on the selection of its constituents' natural fiber as a reinforcing agent for a particular application. Mansor *et al.* (2013), for instance, used the AHP method in the selection of the most suitable natural fiber to be used in combination with glass fiber reinforced polymer composites. The resulting hybrid biocomposite materials were for the design of another automotive component, *i.e.* the center lever parking brake. They assessed 13 candidates of natural fiber materials, and the investigation was based on three main performance categories according to its product design specifications (PDS). Kenaf bast fiber exhibited the highest score, and hence it was judged to be the most suitable for the formulation of the hybrid polymer composites for the component construction. The study also performed sensitivity analyses to verify the results and discovered that the same fiber scored highest in two out of three simulated situations. Another work done by Mastura *et al.* (2018) to select the most suitable natural fiber for a hybrid biocomposites material for an automotive anti-roll bar design, applied AHP combined with the Quality Function Deployment for Environment (QFDE) method. The AHP was used to determine weighting values, which were based on product requirements, *i.e.* quality, cost, and environmental concerns in the early phase of the study. There were 15 alternatives with respect to the Voice of Environment (VOE) to be prioritized, and the resulted weights were incorporated in the QFDE method to select the best natural fiber. As an added value, Life cycle assessment (LCA) was also performed in that study to further verify the results. The results showed that sugar palm fiber best satisfied the design requirements by obtaining 21.51% of the total score, followed by kenaf at 20.18%.

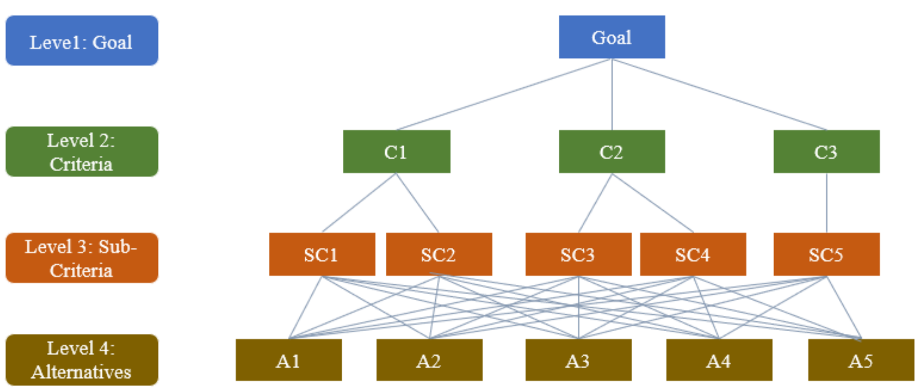
Generally, it can be concluded that previous studies on composites materials selection and their constituents are focusing on automotive or other high-performance structural applications. From literature, it is relatively uncommon to find similar studies for consumer products application, such as food packaging. Sanyang and Sapuan (2015) and Almeida *et al.* (2017) are among the limited recent studies on materials selection specifically for food packaging application, and to the best of authors knowledge, there are none yet on the selection of natural fiber as a reinforcing element in biocomposites specifically for food packaging design application. Selection of the right natural fibers to be unified with biodegradable polymers will permit biodegradability and compostability of the packaging materials (Duhovic *et al.* 2008; Salit 2014; Sani *et al.* 2016). Therefore, a straightforward and systematic selection method would be beneficial to aid designers and material engineers in the selection process for food packaging application. A framework model based on a systemic and well-known AHP method is proposed in this study for the selection of the best natural fiber as reinforcement in green biocomposites for food packaging application. The study also utilized the Expert Choice Version 11.5 AHP-based software.

METHOD

The AHP method has three main steps that need to be performed to achieve appropriate decisions (Al-Oqla *et al.* 2016). The first step is forming a hierarchical structure based on the complex decision problem. The hierarchical structure is broken down into multi sub-problems, including goal, criteria, and sub-criteria, as well as decision alternatives. The main goal (objective) must be at the top level. The main criteria, sub-criteria, and decision alternatives of the problem are arranged in a hierarchical structure. In the second step, pairwise comparisons for alternatives, criteria, and their subs are conducted to determine the relative importance of each criterion within each level of the structure.



(a)



(b)

Fig. 1. (a) The AHP procedure; (b) The AHP hierarchy structure (Sapuan *et al.* 2011; Al-Oqla *et al.* 2016)

Finally, the last step is to perform the consistency check for all judgments developed to ensure that the values are acceptable. Then, the alternatives' overall priority values are ranked with consideration to the selection criteria in the model. The candidates with the highest priority values would be at the top of the rank and deliberated as the most preferred or as the best options with respect to the goal or the study objective (Al-Oqla *et al.* 2016). Figure 1a is the AHP flow chart for the selection process of natural fiber as a reinforcement in green biocomposites for food packaging. Figure 1b is the AHP hierarchy structure employed in this study.

Identification of the Selection Requirements

In this study, the model for the MCDM framework was developed based on food packaging materials requirements (Siracusa *et al.* 2008; Bugnicourt *et al.* 2013; Cagnon *et al.* 2013; Rhim *et al.* 2013; Robertson 2014). The key attributes for the selection of materials for food packaging application are both the proper barriers and the mechanical properties, where these qualities help preserve food quality and safety during storage and handling, as well as prevent premature deterioration of materials (Sanyang and Sapuan 2015). Food packaging requirements are based on the type of food that is packed, as varying materials are needed to fulfill different requirements (Bugnicourt *et al.* 2013). However, it is also worthy to note that Garofalo *et al.* (2018) has stated in their report that biocomposites materials applications have difficulties penetrating the market. Two of the three main obstacles revealed are cost related: (1) material cost, and (2) manufacturing cost (and time). The third one is sustainability, *i.e.*, obtaining raw materials and recyclability. These aspects discussed are among the key foundation in developing the selection criteria to select the most appropriate natural fiber as a reinforcement in biocomposites.

As previously mentioned, the main requirements for food packaging materials are mechanical properties and barrier properties. According to Russo and Camanho (2015), since the AHP analysis of decision making involves a selection of the possible alternatives, it would be acceptable that the selection criteria are defined based on the alternatives. Thus, 13 attributes of natural fiber have been identified, and these criteria were clustered according to both the general requirements of the materials for food packaging application and the aspect of design and manufacturing. "Strength" and "moisture resistance" were determined as the main criteria to fulfill the materials requirement where attributed mechanical properties and barrier properties of natural fiber would be assessed. "Weight" and "Cost" (price) were the other two main criteria established. Cost was selected as a main criterion because, generally, almost all departments influence a company's costs, and product development and production are the most essential (Ehrlenspiel *et al.* 2007). Therefore, the "cost" of natural fiber was decided as one of the main criteria, as it could influence the total manufacturing cost. Weight is a crucial factor in food packaging products for convenience on the filling and packaging line and in distribution (Emblem and Emblem 2012). Consumers are also looking for packages that offer convenience attributes, such as container portability, in which lightweight materials are preferred (Marsh and Bugusu 2007). Moreover, concepts for lightweight design also result in low-cost machines (Ehrlenspiel *et al.* 2007). The structure of the main selection criteria and the 13 natural fibers' attributes that will be appraised in selecting the most suitable natural fiber in green biocomposites for food packaging application is illustrated in Fig. 2.

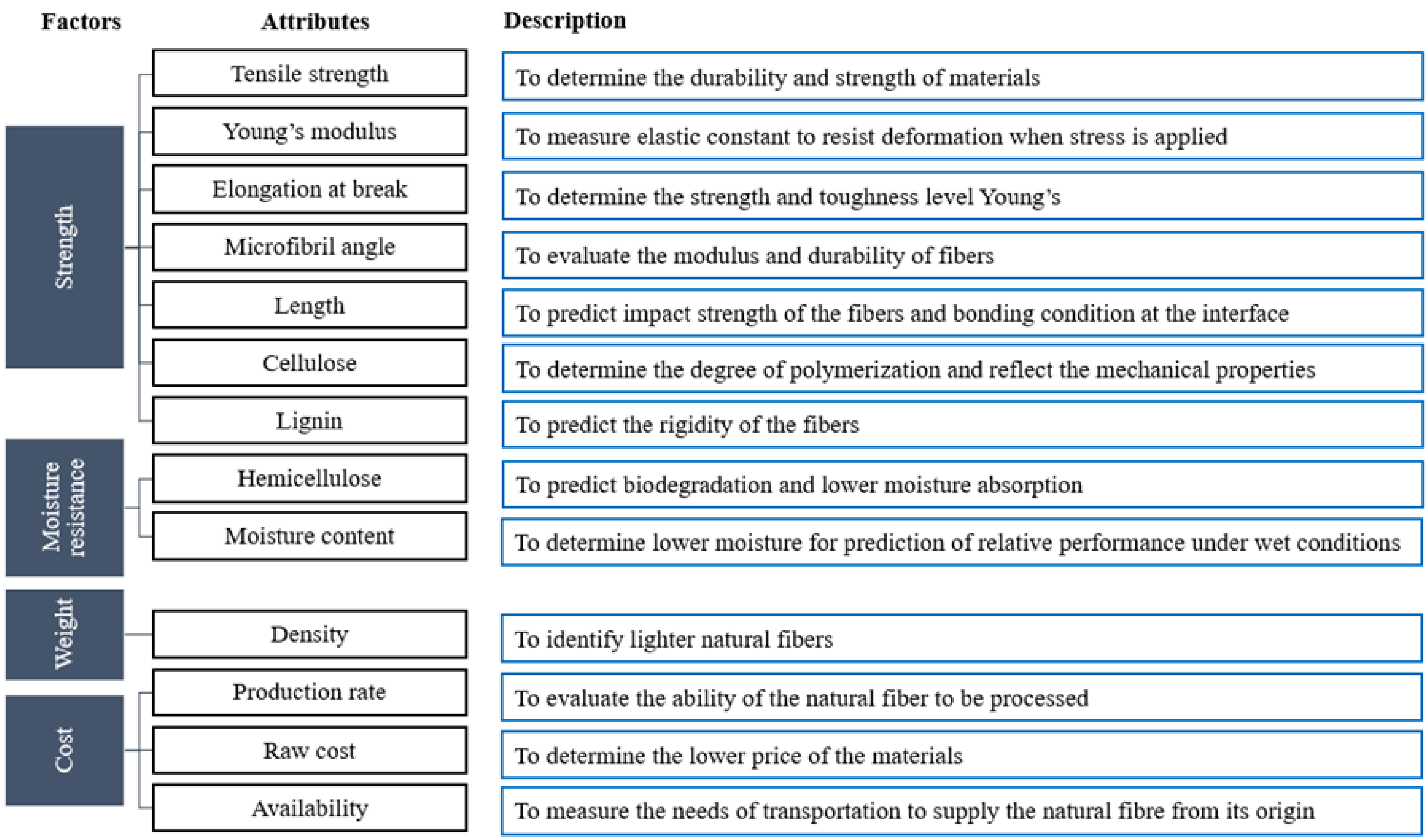


Fig. 2. Selection factors and attributes developed to find the most suitable natural fiber in biocomposites for food packaging application (Al-Oqla and Salit 2017; Mastura *et al.* 2017)

Development of database of Natural Fiber Alternatives

Nine natural fibers were selected because of their comparable and complete data obtained from the literature. These natural fiber candidates are shown in Fig. 3 according to their classifications. Physical and mechanical properties of the selected natural fiber could have been obtained by carrying out experimental work for data validation. However, this is beyond the scope of the study and resources and time were limited. Thus, data were collected from recent and prominent literature. Comparable and complete data of the nine natural fiber alternatives were gathered from recent literature published from 2016 to 2018. The selected natural fiber data are arranged in Table 3.

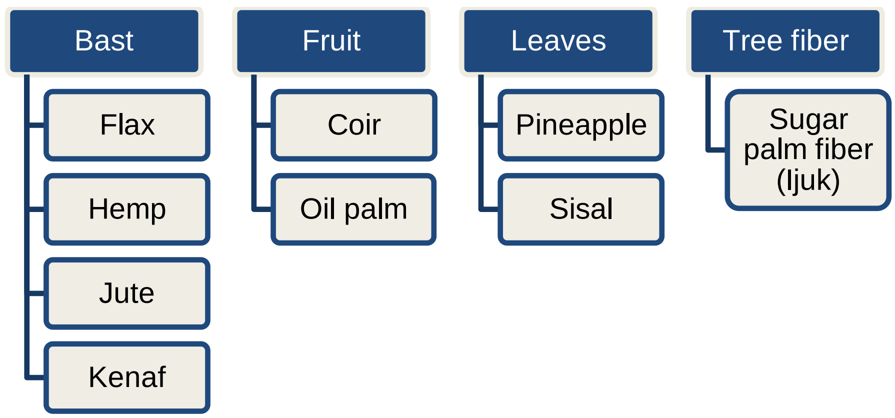


Fig. 3. Nine candidates of natural fibers according to their class

Criteria System and Evaluation of Criteria Weightings

The AHP is a method of building an evaluation model with the following main characteristics: (1) the evaluation model is structured in a hierarchical way, (2) the same assessment technique is used at each node of the hierarchy, and (3) the assessment of the *"children"* nodes of a common *"parent"* node is based on pairwise comparisons (Bouyssou *et al.* 2015). In this study, there were four levels of evaluations, where the top of the hierarchy, represented by the goal of study, was the parent node of the main criteria level. The second level contained the four main criteria nodes, where each criterion was the parent node for a set of sub-criteria children nodes. The sub-criteria level comprised the 13 attributes that were applied to assess the different natural fibers alternatives. The alternatives level, at the lowest position, represented nine natural fiber alternatives. Each parent node implied a decision matrix of order nxn, where n was the number of children nodes.

Weights Evaluation of the Main Criteria

The hierarchy model structure represented the criteria and sub-criteria of the selection of the most suitable natural fiber. It was developed based on varying factors and its attributes. The second level of the hierarchy is the main criteria level. This level denoted the four selection factors, *i.e.*, 1) strength, 2) moisture resistance, 3) weight, and 4) cost. The judgement made on the relative importance of every pair compared with the four main criteria were done and arbitrarily assigned the same weight to each criterion. The assigned value for each pair wise comparison is 1.0, which indicate they are equally important. The pair-wise matrix for main criteria with respect to goal and the weights produced for each main criterion is shown in Fig. 3. Strength, moisture resistance, weight and cost main criteria contribute the equal priority vector. The priority vectors and the consistency ratio were examined after performing pair-wise comparison judgement as the value of consistency ratio (CR=0.00) is less than 0.1, therefore the judgement is acceptable.

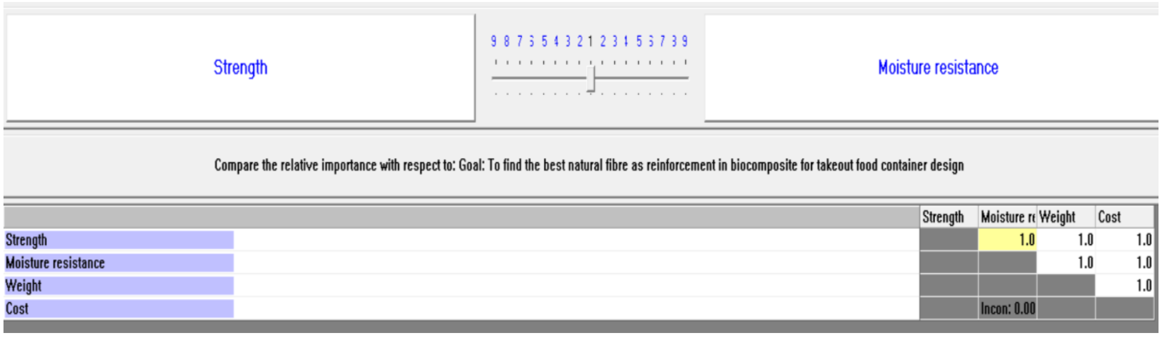


Fig. 4. Pair-wise comparison of the main criteria with respect to the Goal

Sub-Criteria Weightings

The 13 selected attributes of natural fiber were selected to understand their priorities. Experts' evaluations were gathered using an electronic survey questionnaire that was sent personally to the identified experts in the field of natural fiber composites. The identified experts must at least have a degree in a related area of study with at least 3 years of experience in a biocomposites related industry. From 16 experts who participated in the survey, 14 of them are PhD holders and published at least one peer-reviewed paper, and 15 of them have more than five years of experience in research related to biocomposites study.

Though AHP can be used by a single decision-maker, it can also combine the judgments obtained from a group of several people, as done in this work. To get a single judgement from many experts, Roubens (1997) claims that it is necessary to pass through a two-stage sequence: Aggregation Phase and Exploitation Phase. First the set of individual's preference values are transformed into a unique set of collective preference by means of an aggregation operator; then the decision rule is applied over the collective preference set in the exploitation phase which allows the decision unit to obtain a sorting among the alternatives (Mora Díaz *et al.* 2009). Using rating mode instead of relative measurement (classic mode) implies that experts do not make pairwise comparison directly, but instead it is the analyst who mathematically derives it from predefined ratings categories from which the experts selected their evaluations of each attributes related with natural fiber appraisal. In general, pairwise comparison is demanding on experts because each decision about n alternatives requires n $(n - 1) / 2$ paired comparisons, whereas in rating mode by contrast there are necessary only n value judgements to rate n alternatives. So, instead of asking the experts to complete the pairwise comparisons matrix, they simply rated the importance of each criterion using the scale, as shown in Table 1.

It is understood that AHP's foundation is reciprocal judgments. In reciprocal judgments, for any pair of compared items, if one of them (object i) is α times preferred to the other (object j), and when compared in the opposite order, the value of the comparison is 1 / α. The mathematical expression in Eq. 1 represents this.

$$\alpha_{ij} = 1 / \alpha_{ji} \tag{1}$$

Table 1. Coding Value to Interpret Answer Choice

ANSWER CHOICE	VALUE
Extremely low priority	1
Very low priority	2
Low priority	3
Somewhat low priority	4
Neutral	5
Somewhat high priority	6
High priority	7
Very high priority	8
Extremely high priotity	9

From Eq. 1, $\alpha_{ii} = 1$. As such, all the entries on the principal diagonal of any AHP matrix are equal to one. The values that any pair-wise comparison can take is defined by the Saaty classical odd reciprocal scale (1/9, 1/7, 1/5, 1/3, 1, 3, 5, 7, 9), but even numbers and their reciprocals can be used as compromise solutions. A matrix was built by means of researcher judgment about the relative AHP reciprocal preference between each survey scale score, as shown in Table 2. This pairwise judgement matrix of the scale of importance was done by utilizing Expert Choice software. Normalizing the synthesized results produced by the software is the idealized priorities values for each scale score presented in Fig. 2 and Table 4.

Table 2. Comparison Matrix for the Absolute Scale

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
1	**1**	1/2	1/3	1/4	1/5	1/6	1/7	1/8	1/9
2	2	**1**	1/2	1/3	1/4	1/5	1/6	1/7	1/8
3	3	2	**1**	1/2	1/3	1/4	1/5	1/6	1/7
4	4	3	2	**1**	1/2	1/3	1/4	1/5	1/6
5	5	4	3	2	**1**	1/2	1/3	1/4	1/5
6	6	5	4	3	2	**1**	1/2	1/3	1/4
7	7	6	5	4	3	2	**1**	1/2	1/3
8	8	7	6	5	4	3	2	**1**	1/2
9	9	8	7	6	5	4	3	2	**1**

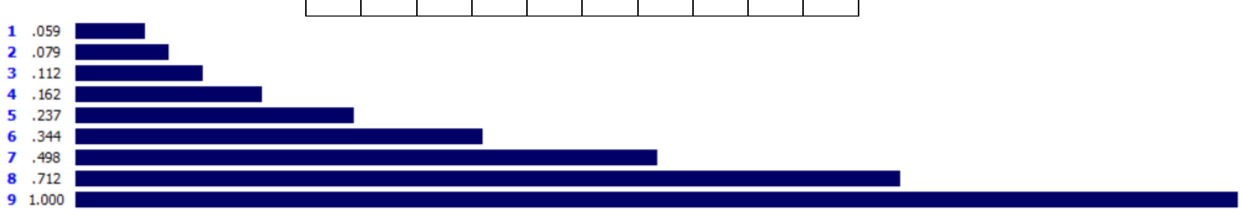


Fig. 5. Synthesis results of comparison matrix of scale score produced by Expert Choice software

Table 3. Dataset of Natural Fiber Alternatives in Green Biocomposites Intended for Food Packaging Application (Pickering *et al.* 2016; Huzaifah *et al.* 2017; Mastura *et al.* 2017; Nayak *et al.* 2017; Ramesh *et al.* 2017; Singh *et al.* 2017)

Fiber	Density (g/cm^3)	Moisture content (%)	Tensile Strength (MPa)	Elongation at break (%)	Young's modulus (GPa)	Cellulose (%)	Hemicellulose (%)	Lignin (%)	Fiber's length (mm)	Microfibril angle	Raw Cost	Production Rate (10^3 tonne)	Availability
Coir	1.2 to 1.6	0.2 to 8	108 to 230	14 to 40	3 to 7	19.9 to 43.8	0.15 to 20	0.15 to 53.3	20 to 150	9	5	100	5
Flax	1.3 to 1.5	8 to 12	340-1600	1.1 to 3.3	25 to 81	62 to 72	16.7 to 20.6	2 to 5	5 to 900	5	8	830	2
Hemp	1.1 to 1.6	6.2 to 12	550-900	0.8 to 3	70	55 to 80.2	12 to 22.4	2.6 to 13	5 to 55	3	7	214	3
Ijuk (Sugar Palm)	1.22 to 1.45	5.5 to 8.67	122-304.2	8.9 to 29.9	2.11 to 5.9	43.75 to 52.3	9.94 to 13.3	31.5 to 41.97	1190	1	1	40	9
Jute	1.3 to 1.5	10 to 13.7	385-800	1.4 to 2.1	9 to 31	45 to 71.5	12 to 21	0.2 to 13.26	1.5 to 120	4	6	2300	4
Kenaf	0.6 to 1.5	12	223-1191	1.5 to 4.3	11 to 60	31 to 72	17.6 to 24	8 to 21	500	2	4	970	6
Oil Palm	0.7 to 1.6	65	50-400	3.2 to 25	0.6 to 25	42.7 to 65	14.94 to 33.5	13.2 to 29	100 to 130	8	2	40	8
Pineapple	0.8 to 1.6	11.8	150-1627	2.4 to 14.5	1.44 to 82	57.5 to 81	9.45 to 80.7	4.4 to 12.7	30	6	3	74	7
Sisal	1.3 to 1.6	10 to 22	227-700	1.9 to 15	8.5 to 40	60 to 78	10 to 14.2	8 to 14	900	7	9	378	1

Table 4. Idealized Priority Values of Each Survey Scale Score

Scale Score	Idealized Priority
1	0.0590
2	0.0790
3	0.1120
4	0.1620
5	0.2370
6	0.3440
7	0.4980
8	0.7120
9	1.0000

All scores from each expert for each sub-criterion were converted into their idealized priority values. Later, geometric mean (GM) was used to aggregate the 16 experts' judgments about each one of the 13 sub-criteria by using the mathematical formula in Eq. 2.

$$f(A_i, A_j) = \left[\prod_{k=1}^{n} P_k(A_i, A_j)\right]^{\frac{1}{n}} \quad (2)$$

The weights of each sub-criteria were the results of normalized GM values. However, these weights are the global weights. So, the final weights values were obtained when these calculated weight values for each sub-criterion were multiplied by the weights of the main criteria associated with them. The tabulated values of the survey scores, their idealized priority and weights are available in the Appendix I.

Utilization of AHP Expert Choice 11.5 Software

The following steps explain how Expert Choice 11.5 software based was utilized in this study:

Step 1: Goal statement or objective of study

The goal of study is inserted to develop the hierarchy. The goal entered is 'To select the most appropriate natural fiber for reinforcement in green biocomposites for food packaging design'

Step 2: Hierarchy model development for natural fiber selection

The hierarchy structure developed in the software were based on model in Fig. 1b.

Step 3: Pair-wise comparison matrix construction

Once the hierarchy model was created, Expert Choice 11.5 software automatically constructed the pair-wise comparison judgment matrices.

Step 4: Judgment of pair-wise comparison execution

Pair-wise comparisons were commenced by comparing the relative importance of the two selected nodes with respect to their parent node by using numerical pair-wise comparisons. For the level of main criteria, this has been explained in 'Weights Evaluation of the Main Criteria' section. Whereas for sub-criteria level, weights of each sub-criteria were already attained using AHP rating mode described above. The weightings for the main criteria and sub-criteria are arranged in Table. All weights values were inserted directly into the "Value" column at the "Assessment" section provided by the Expert Choice 11.5 software. Weights recorded for all sub-criteria under "Strength" criteria are shown in

Fig..

Table 5. Main Criteria and Sub-Criteria Final Weight Values

Criteria	Weight	Sub-criteria	Weight
Performance	0.25	Tensile strength	0.1873
		Elongation at break	0.1494
		Young's modulus	0.1705
		Cellulose	0.1371
		Lignin	0.1019
		Fibre length	0.1421
		Microfibril angle	0.1116
Water absorption and barrier properties	0.25	Moisture content	0.6225
		Hemicellulose	0.3775
Weight	0.25	Density	1.0000
Cost	0.25	Raw cost	0.4012
		Availability	0.3321
		Production rate	0.2667

Pair-wise judgement at the alternatives level (list of alternatives in Table 1) were compared one by one in pairs with respect to all sub-criteria. The judgment values for each assessed pair were based on the comparison ratio technique demonstrated by Sapuan *et al.* (2011). For example, from Table 3, the value for tensile strength of coir is 169 MPa, and flax is 970 MPa. So, the ratio of coir and flax is 970:169 = 5.740. The ratio calculation is reversed since the assigned value cannot be smaller than 1. Therefore, the assigned value for coir when comparing the relative importance to flax with respect to the tensile strength is 5.740, red color figures appeared in the software because flax has higher value of tensile strength compared with coir. Another example for moisture content involves the values for coir 4.1% and sisal 16%. So, the ratio of coir and sisal is 16:4.1 = 3.902 (reversed calculation so that assigned value > 1). Hence, the assigned value for coir when compared to the relative importance to sisal with respect to the tensile strength is 3.9024, but this time it was presented in black color because coir has lower moisture content, so coir has higher priority. Pair-wise judgement matrix results for all sub-criteria are in Appendix II.

Steps 5 and 6: Synthesizing and consistency of the pair-wise comparison

The results of the priority vectors and consistency test for the alternatives with respect to every sub-criterion were calculated by the software. The priority vectors and the consistency ratio must be analysed after performing judgment on pairwise comparison. For consistency ratio (CR) values less than 10% (0.1), the judgment was accepted, but if the value was more than

0.1, the judgment was reviewed and corrected to obtain a more consistent matrix.

Step 7: Develop overall priority ranking

Completed judgment of the hierarchy model synthesized results with respect to the Goal after all prior steps were completed.

Step 8: Selection of the most suitable natural fiber

The final priority vectors results produced an overall ranking of all nine natural fiber alternatives. The one at the top of the rank with the highest values attained was deduced to be the most appropriate.

RESULTS AND DISCUSSION

Expert Choice 11.5 Results

The AHP model structure developed in Expert Choice 11.5 software is shown in Fig. 5 with all the recorded weightings.

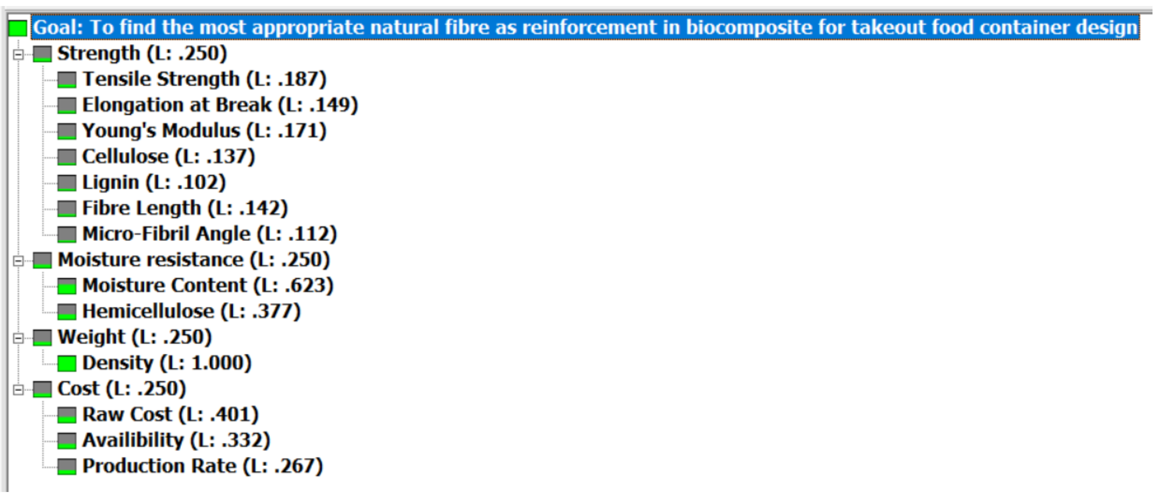


Fig. 6. The hierarchy structure with recorded weights for main criteria and sub-criteria developed in Expert Choice 11.5

Synthesized results with respect to the goal produced a list with nine alternatives of natural fiber ranked according to their priority vector scores calculated by the software. The results from the software with respect to goal is shown in Fig. 6. These results were very pleasing with a perfect overall CR of 0.00 (0%). *Ijuk* (sugar palm fiber) had the highest priority vector score of 0.14 (14.0%), which was at the top of the rank. The second highest score was coir with a score of 0.125 (12.5%), followed by kenaf, pineapple, hemp, jute, and oil palm scores of 0.116 (11.6%), 0.114 (11.4%), 0.110 (11%), 0.107 (10.7%), and 0.102 (10.2%), respectively. Flax and sisal were at the bottom of the rank with a priority score of no more than 10%, *i.e.*, 0.099 (9.9%) and 0.088 (8.8%), correspondingly. *Ijuk* was found to be the most suitable natural fiber in a Mastura *et al.* (2017) study, although their selected natural fiber was hybridized with a glass fiber-reinforced polymer composite for an automotive anti-roll bar design. Further, the AHP method was only employed in their study to evaluate Voice of Consumer (VOC) and VOE in QFDE method. It was concluded that a lighter fiber of *ijuk*, lower energy consumption, and lower CO_2 footprint satisfy the desired materials' mechanical properties in automotive application.

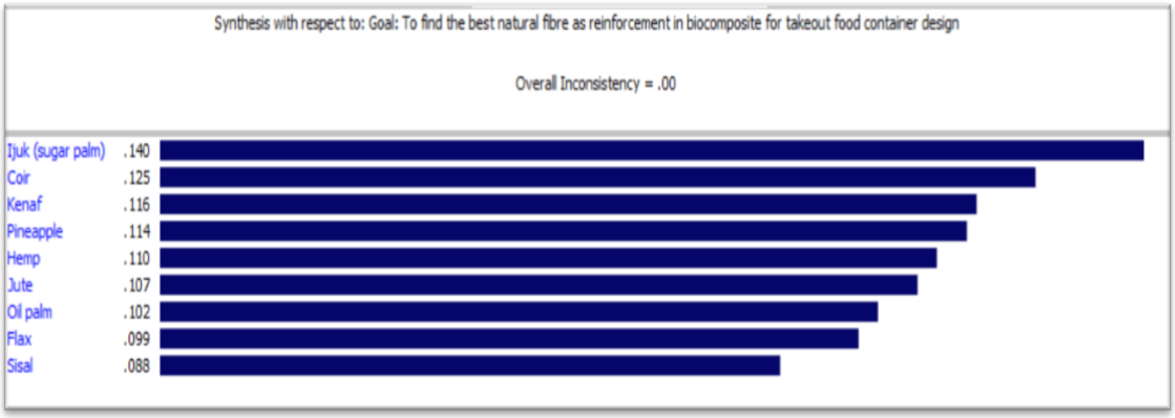


Fig. 7. AHP Expert Choice 11.5 final synthesized results with respect to Goal

Mansor *et al.* (2013) found kenaf bast fiber as the most suitable fiber to be used together with glass fiber for hybrid reinforced polymer composites for the design of a passenger vehicle center lever parking brake component. Their AHP model structure was based on the formulated product design specifications (PDS) of a center lever parking brake. Three main criteria determined were performance, weight, and cost. The sub-criteria of "performance" criteria were tensile strength, Young's modulus, density, and elongation at break. All these sub-criteria were only from a mechanical properties' viewpoint because the design specification for center lever parking brakes demand strong materials for their performance. However, it is important to note that a wider selection criteria in the selection process would allow for a more comprehensive assessment of natural fiber alternatives and, thus, better informative decisions could be made (Al-Oqla *et al.* 2015).

It is important to acknowledge that each natural fiber has different properties corresponding to their chemical composition and morphology (Johansson *et al.* 2012; Huzaifah *et al.* 2017). Therefore, as supplementary to the overall results, the scores with respect to each main criteria node were also recorded and translated into a performance graph of each alternative (Fig. 7). Coir clearly obtained a high score in the "Moisture Resistance" node compared to the other nodes. This score was also the highest of all other scores across all criteria, whereas oil palm was the complete opposite. Flax obtained about the same scores for all nodes. Notably, *ijuk*'s priority score was the highest for the "Cost" node, but it obtained relatively high scores for all three other main criteria nodes. Hemp and pineapple both had about the same scores and gained the highest scores for the "Strength" node.

Then, the three highest weights value of "Strength" sub-criteria nodes, namely "Tensile Strength," "Young's Modulus," and "Elongation at Break," were synthesized, and the alternatives' performance are shown in Fig.. Sisal's scores were similar for all the three sub-criteria, whereas coir's score for "Elongation at Break" was the highest across the three nodes. *Ijuk*'s score for "Elongation at Break" was high, but its score for "Young's Modulus" was among the lowest. In contrast, hemp performed well for "Young's Modulus," but it scored relatively low for "Elongation at Break." Flax's scores for both

"Young's Modulus" and "Tensile Strength" were quite high and almost equal. Flax's score was very low for "Elongation at Break."

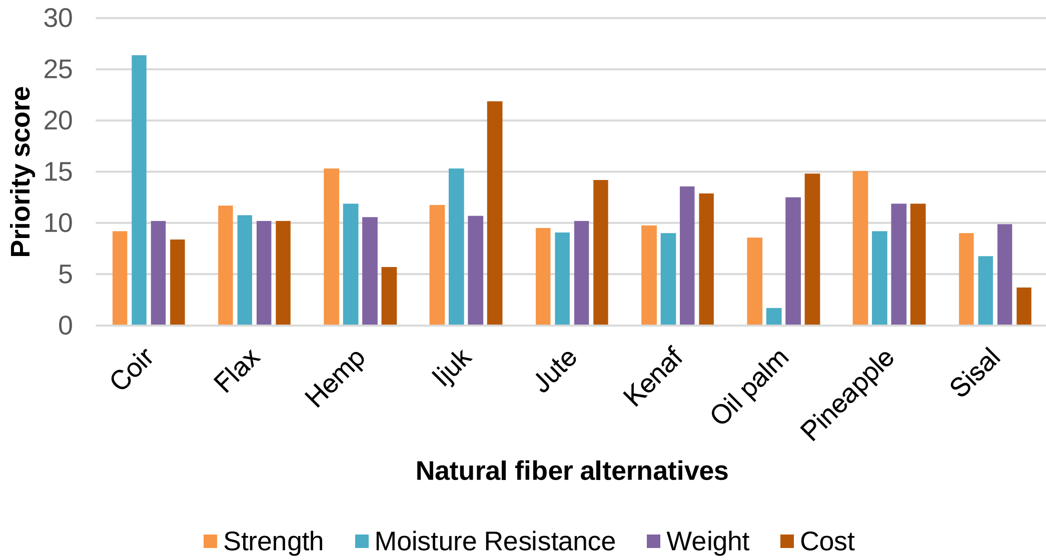


Fig. 8. Natural fiber scores with the corresponding main criteria (%)

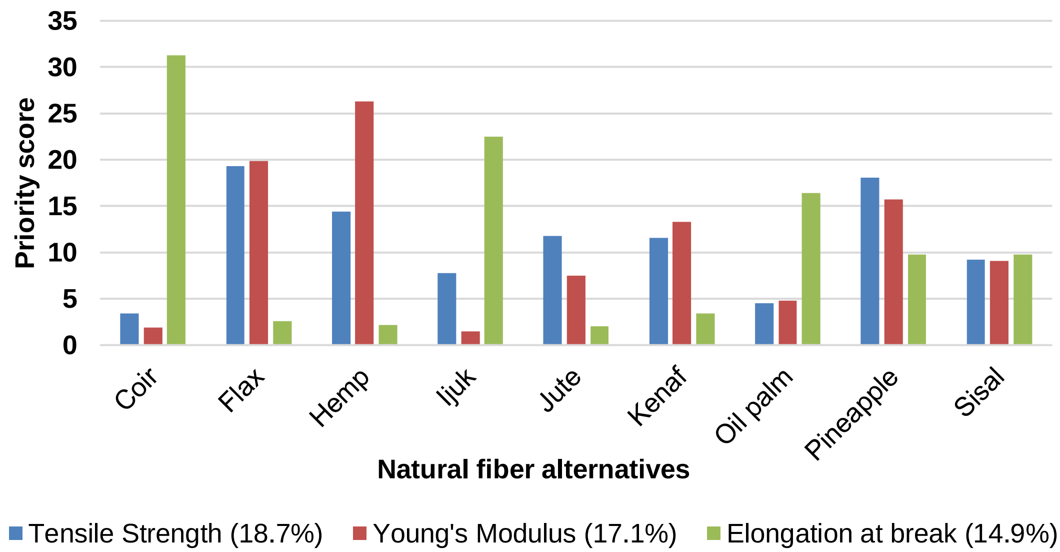


Fig. 9. Performance of alternatives for the three highest weights sub-criteria under "Strength" node

Observation on performance of each alternative with respect to each sub-criteria of "Moisture Resistance," *i.e.*, "Moisture Content" and "Hemicellulose," was also performed, and the results are depicted in Fig. 9. From the chart, coir's score for "Moisture Content" was the highest of all, and oil palms was the lowest. Sisal had a high score for "Hemicellulose," but had a lower score for "Moisture Content." Interestingly, *ijuk*'s performance was satisfactory for both sub-criteria and the scores were almost alike to each other. According to Ishak *et al.* (2013), *ijuk* is known for its high durability and its resistance to sea water. These two characteristics are the main advantages of *ijuk*, as other natural fibers are usually hydrophilic in nature. This characteristic is important to ensure that packaging is not easily deteriorated by the contained food.

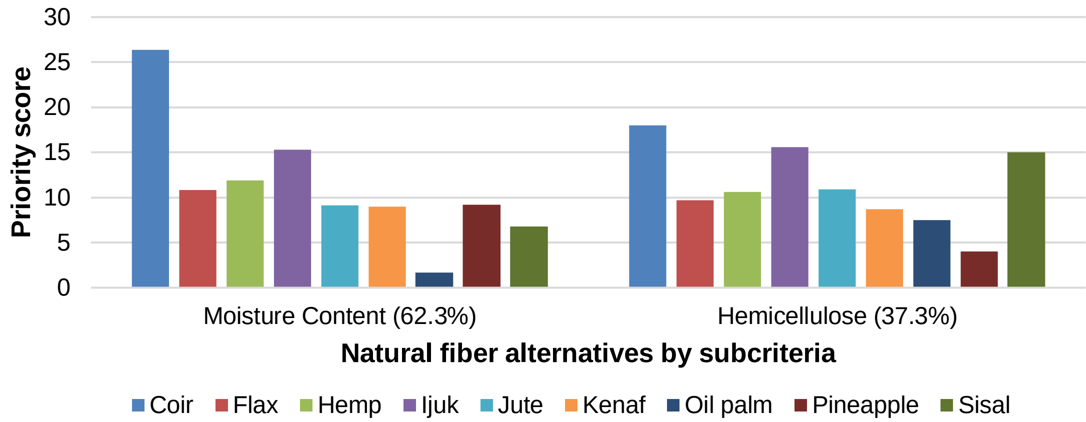


Fig. 10. Natural fiber priority score on sub-criteria nodes under the "Moisture Resistance" node

Similar analysis was done for sub-criteria of "Cost." The results were recorded and interpreted into a graph to understand each alternative's performance with the corresponding sub-criteria (Fig. 10). Jute had the highest score for "Production Rate," but had a low score for both "Raw Cost" and "Availability." *Ijuk* scored the highest for "Raw Cost," had a satisfactory score for "Availability," and scored lowest for "Production Rate." Oil palm and pineapple had similar trends: a high "Raw Cost" and "Availability," but a low score for "Production Rate." Coir, hemp, and sisal scored low for all three of the sub-criteria.

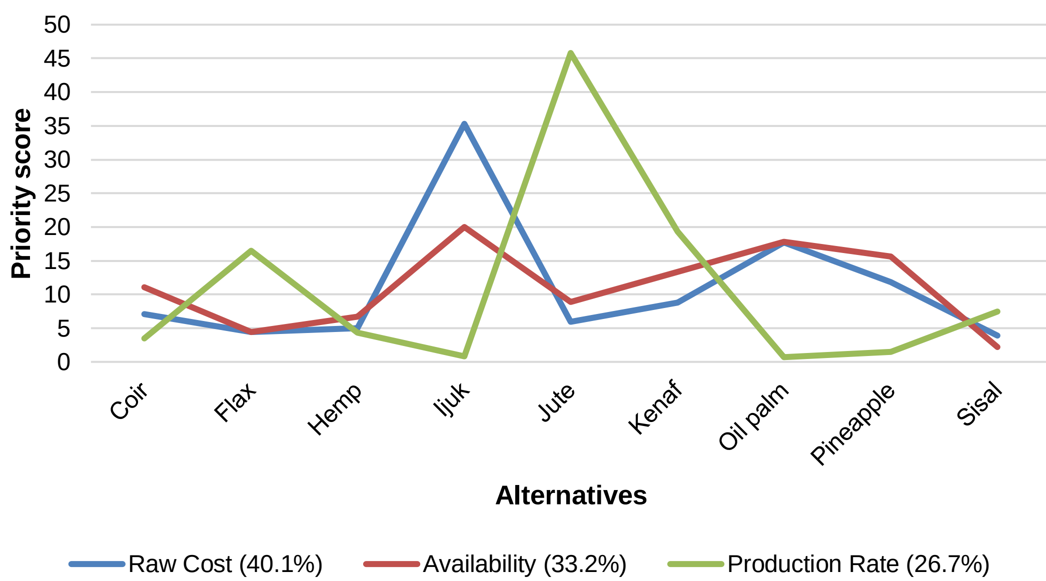
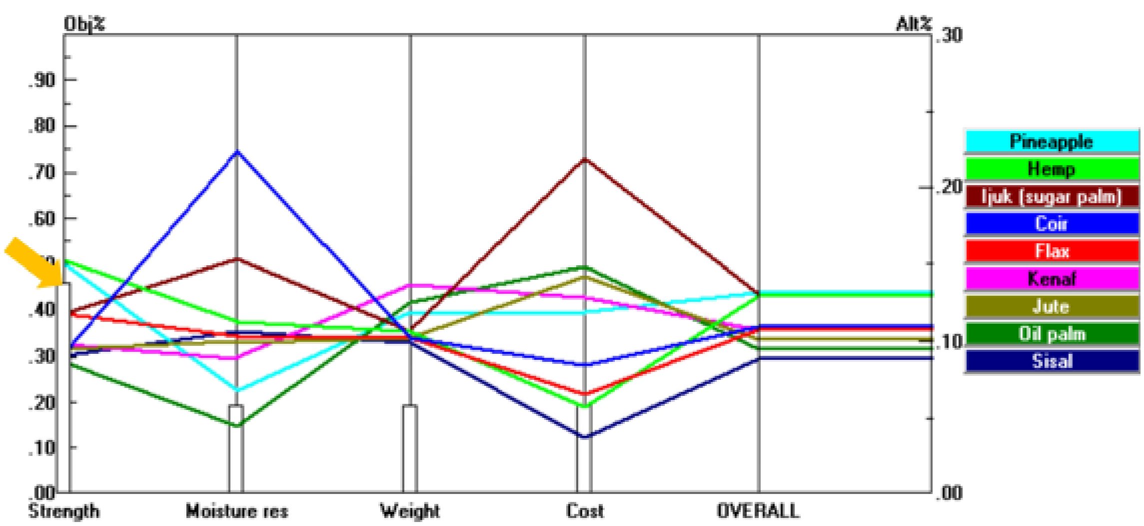


Fig. 11. Performance of natural fiber for each sub-criterion under 'Cost' node

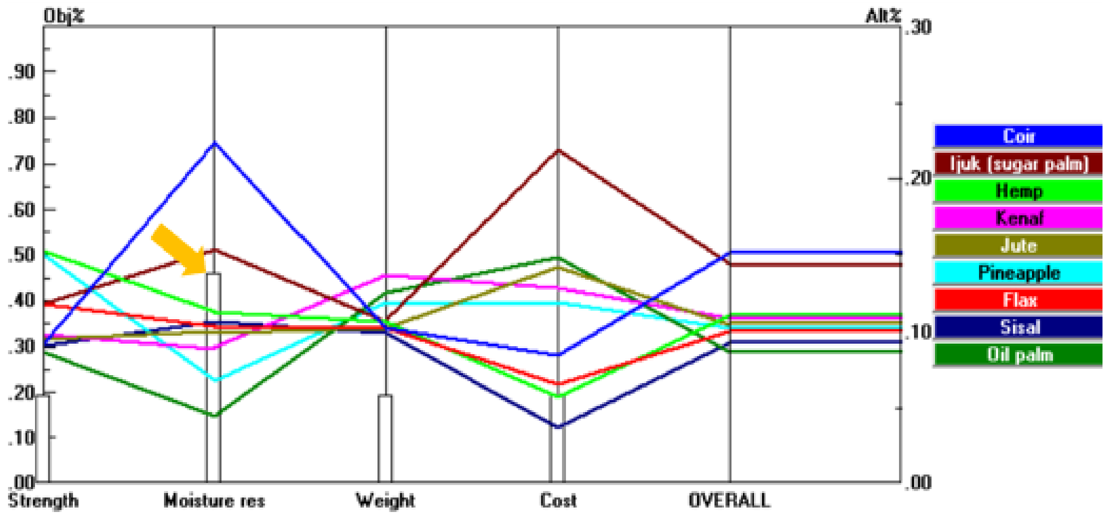
A generalization could be made that classes of fiber do not give any effect to their ranks. Ijuk is a tree fiber naturally grown on sugar palm trees is at the top rank followed by coir, a fruit fiber. At the bottom rank, sisal is a leaf fiber, while kenaf at the second last rank is a bast fiber. It is also important to note that weights obtained for sub-criteria indicate their priority value. Certain attributes have higher priority, *i.e.* more important than other attributes. From the analysis of fibers' performance with respect of main criteria (Fig. 7), Coir significantly scored the highest for moisture resistance, while for Cost main criteria, Ijuk obtained the highest score. For other main criteria, the priority scores of each fiber are about the same. Priority scores with respect to each sub-criterion under moisture resistance (Fig. 9) revealed that coir scored the highest priority for both sub-criteria. Analyzing natural fiber alternatives performance with respect of each sub-criterion of Cost (Fig. 10), ijuk scored the highest priority for raw cost and availability but obtained very low score for production rate. Jute get the highest score for production rate but low score for the other two subcriteria. Coir obtained low score for all three sub-criteria. Weightage for raw cost and availability are higher than production rate contributed to the higher score obtained by ijuk. It can be concluded that Cost and its sub-criteria are the leading indicators that drove ijuk to obtain the highest priority ranking with respect to the goal of study.

Sensitivity Analysis

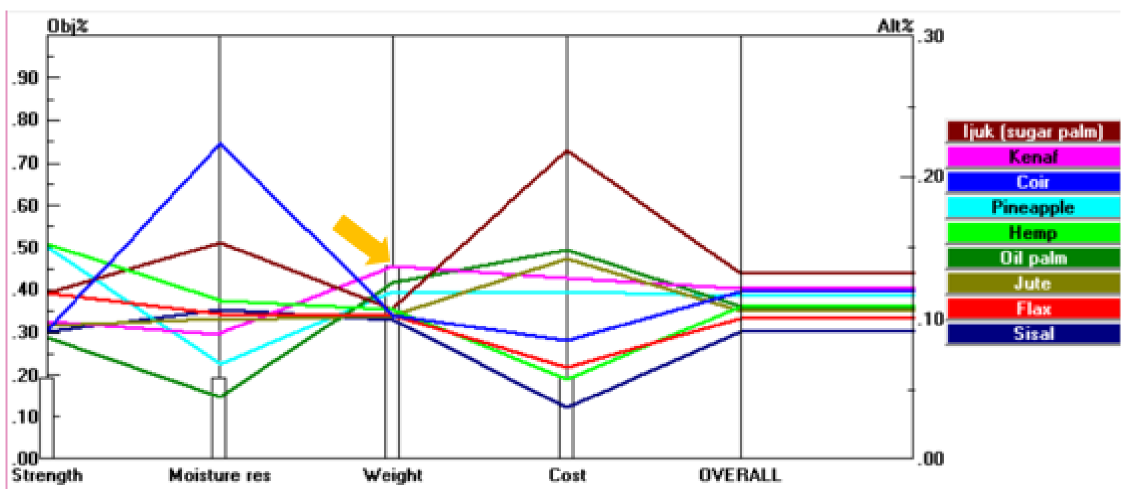
The last process of implementing AHP through Expert Choice 11.5 software is the sensitivity analysis. Sensitivity analysis is an important phase in AHP to verify that the results are robust and applicable (Saaty and Vargas 2013). Sapuan *et al.* (2011) specified that the results could be verified through sensitivity analysis by analyzing the effect of different weights of criteria defined earlier in the study. Mansor *et al.* (2013) correspondingly reported that the results of priority scores among the alternatives materials are very much dependent on the main criteria's priority vectors assigned. Therefore, varying the values, by either increasing or decreasing them, will produce different results of the alternatives' ranking and the overall final decisions. Further, by performing sensitivity analysis, constancy of ranking results can also be observed in the case of selecting the most suitable natural fiber as a reinforcement in green biocomposites for food packaging design. In this study, six simulated circumstances were tested on the performance sensitivity provided by the Expert Choice 11.5 software, and the results were compared with the initial results obtained. All results from the six scenarios are presented in Fig. 10 (a) to (f).



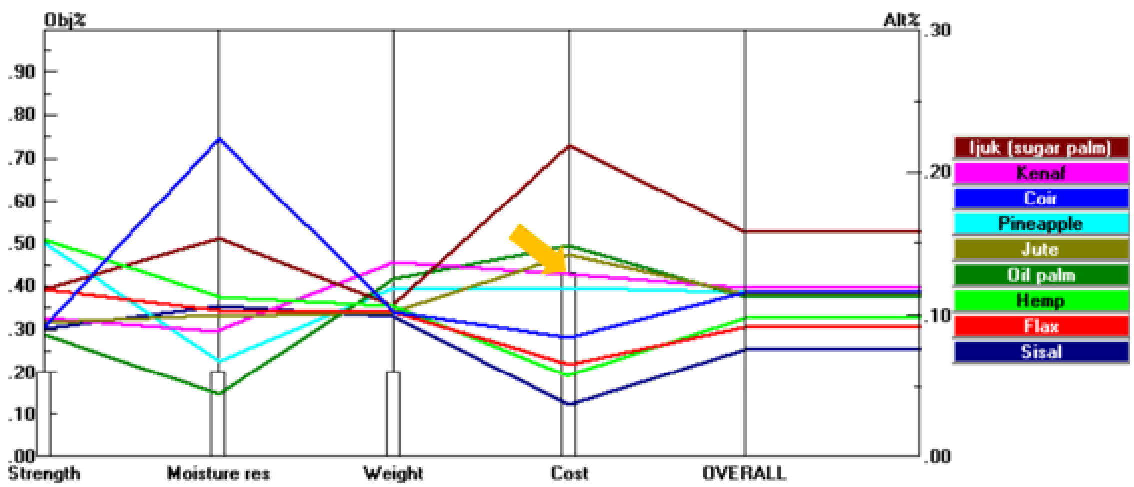
(a) Increased 20% of "Strength"



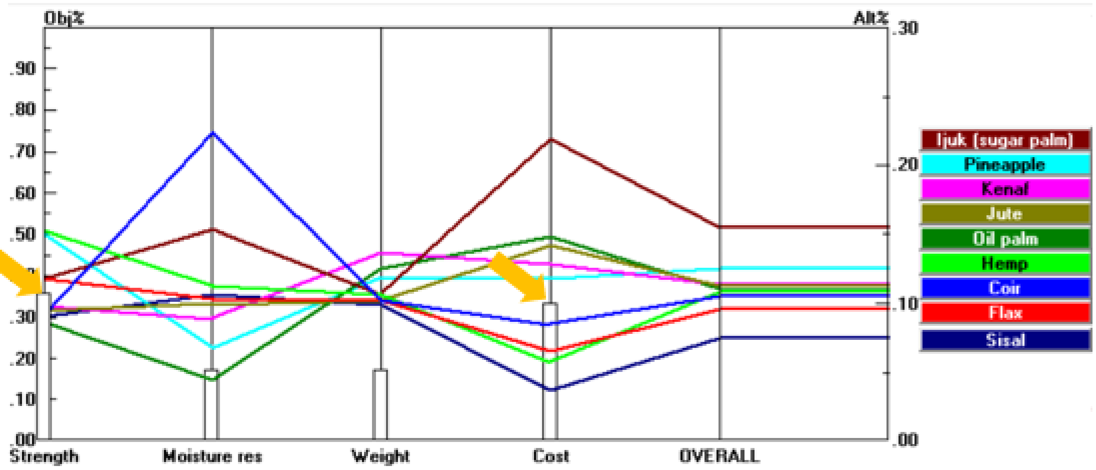
(b) Increased 20% of "Moisture Resistance"



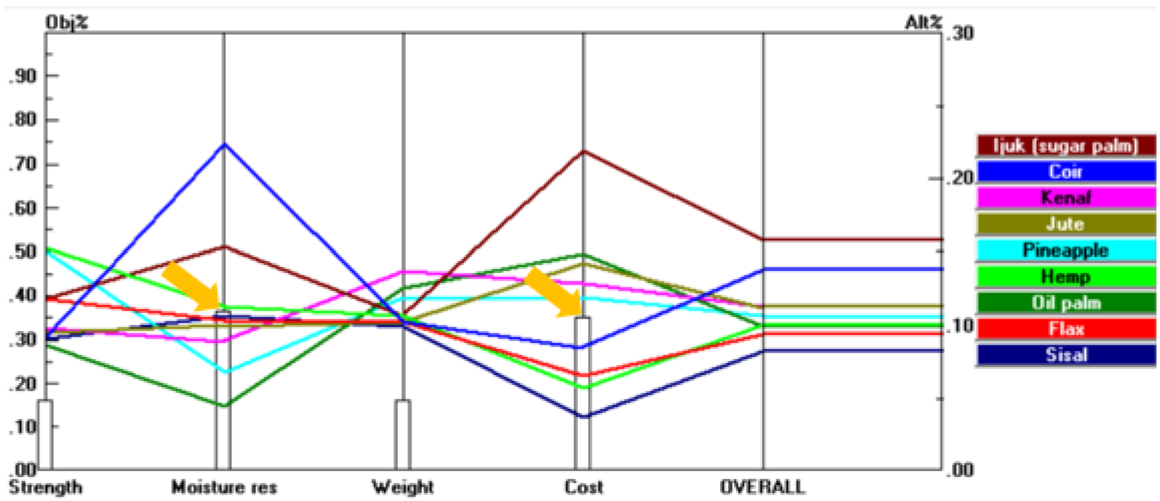
(c) Increased 20% of "Weight"



(d) Increased 20% of "Cost"



(e) Increased 10% for both “Strength” and “Cost”



(f) Increased 10% for both “Moisture Resistance” and “Cost”

Fig. 12. (a) to (f). Sensitivity analyses with six different circumstances

It was observed that *ijuk* remained at the top rank for four of the six scenarios tested. Though for 20% increased of the importance values for “Strength,” *ijuk* fell at the third rank after pineapple and hemp. Food packaging products need strong materials to hold contained food, but they do not need to be as strong as other high-performance product application, as reported by Mastura *et al.* (2018) and Mansor *et al.* (2013). By contrast, in the scenario of increased importance of “Moisture Resistance” by 20%, *ijuk* was at the second rank after coir with a small priority difference. Moisture resistance is crucial for food packaging materials to ensure the safety of food and longer shelf-life (Marsh and Bugusu 2007; Siracusa *et al.* 2008; Siracusa 2012; Karpušenkaitė and Varžinskas 2014; Amberg-Schwab *et al.* 2015). Two other scenarios examined a condition where “Strength” and “Moisture Resistance” were paired with “Cost,” and both pairs each increased by 10%. The scenarios related with “Cost” would be important because they would influence the total manufacturing cost in the production of food packaging products. Lower manufacturing cost will always be desirable to any company, provided the product's functionality is achieved (Ehrlenspiel *et al.* 2007). *Ijuk* turned out to be at the top rank for both of scenarios. All sensitivity analysis results are summarized in Table 6.

Table 6. Summary of Sensitivity Analysis Based on Six Circumstances

Rank	Original results	20% Increment of "Strength"	20% Increment of "Moisture Resistance"	20% Increment of "Weight"	20% Increment of "Cost"	10% Increment of "Strength" and "Cost"	10% Increment of "Moisture Resistance" and "Cost"
#1	***Ijuk***	Pineapple	Coir	***Ijuk***	***Ijuk***	***Ijuk***	***Ijuk***
#2	Coir	Hemp	***Ijuk***	Kenaf	Kenaf	Pineapple	Coir
#3	Kenaf	***Ijuk***	Hemp	Coir	Coir	Kenaf	Kenaf
#4	Pineapple	Coir	Kenaf	Pineapple	Pineapple	Jute	Jute
#5	Hemp	Flax	Jute	Hemp	Jute	Oil palm	Pineapple
#6	Jute	Kenaf	Pineapple	Oil palm	Oil palm	Hemp	Hemp
#7	Oil palm	Jute	Flax	Jute	Hemp	Coir	Oil palm
#8	Flax	Oil palm	Sisal	Flax	Flax	Flax	Flax
# 9	Sisal	Sisal	Oil palm	Sisal	Sisal	Sisal	Sisal

Ijuk was selected as the most suitable natural fiber for reinforcement in green biocomposites for food packaging application. In addition, it was also observed that kenaf and coir frequently appeared in the top three ranks. On the other hand, sisal, flax, and oil palm were mostly at the bottom three for all scenarios. It was concluded that sisal was the least preferred natural fiber as reinforcement in green biocomposites for the specific design objective.

Despite the strongly verified results obtained, the authors believe that this process of natural fiber selection could have been more comprehensive with additional details from other factors. It is important that the development of the requirement criteria encompass various aspects in making decision. The AHP method only prioritizes requirements and does not identify or detect the success-critical factors and their corresponding requirements (Ahmad *et al.* 2010). Consequently, in the selection process of natural fiber, decision makers must develop the selection criteria as accurate as possible according to the specific requirement because this will influence the results of the selection.

Fiber harvest time, extraction method, aspect ratio, and the fiber's pre-treatment method and storage procedures are other additional data that would be worthy to measure (Pickering *et al.* 2016). The mechanical properties of a fiber that is used as reinforcement in polymer composites can be contributed by many factors including fiber-matrix adhesion, the volume fraction of the fibers, the fiber aspect ratio (l/d), and the fiber orientation (Su *et al.* 2018). Other than that, the type of surface treatment and employment of nano-technology to ensure excellent interfacial bonding with biopolymers matrices may also alter the final selection results (Saba *et al.* 2017).

The main challenges in this selection process were that natural fibers' characteristics data and related information are not yet available in any established materials commercial database. Gathering a dataset for natural fiber alternatives is crucial, because "trustworthy and accountable sources on data of natural fibers properties play a significant part in the selection process," as Sapuan *et al.* (2011) mentioned in their report.

CONCLUSIONS

1. This study provides a systematic procedure to efficiently aid designers or material engineers in making decisions on the best natural fiber to produce new innovative green biocomposite materials for the food packaging application. There were four main selection criteria and 13 sub-criteria in the process of making decisions on the most suitable natural fiber out nine alternatives considered.
2. The analytic hierarchy process (AHP) rating mode approach was demonstrated as a convenient method to gather experts' opinion to solve decision problem in material selection process.
3. The AHP-based software, Expert Choice 11.5 was utilized and revealed that *ijuk* was the best natural fiber with a priority score of 0.14 (14%), followed by coir with the score of 0.125 (12.5%) and kenaf with a score of 0.116 (11.6%). The sensitivity analysis performed increased the confidence level of the results obtained
4. Six different scenarios in the sensitivity analysis were conducted to further validate the outcome. *Ijuk* was at the top of the rank in four out of the six scenarios tested, and it remained at the top three for two other scenarios. Therefore, *ijuk* was selected as the most suitable natural fiber for reinforcement in green biocomposites for food container design.
5. For future further development, other details, such as specific properties, fiber processing and time, and fiber treatment, could be included to obtain a more comprehensive selection criteria list and thus receive more comprehensive results.

ACKNOWLEDGEMENTS

The authors wish to express a special thanks to Professor Manuel Serafin Plasencia from the Department of Basic Sciences, Vicerrectorado "Luis Caballero Mejías," UNEXPO Caracas for the advice on the AHP Rating Mode solution regarding the results of the experts' survey. Also, the authors extend the highest appreciation to both the Public Service Department (JPA) of Malaysia for the study sponsorship to the main author and to the Universiti Putra Malaysia Grant Scheme HiCOE (Grant No. 6369107) from the Ministry of Education Malaysia for the financial support provided.

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Article submitted: June 27, 2019; Peer review completed: September 2, 2019; Revised version received: and accepted;: October 3, 2019; Published: November 1, 2019.
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APPENDIX I

Survey Scores Values, Their Idealized Priority Values and Weightings of Criteria

Expert	Tensile Strength		Elongation at break		Young's Modulus		Cellulose		Lignin		Fibre's Length		Microfibril Angle		Moisture Content		Hemicellulose		Density		Raw cost		Availability		Production rate	
	SS	IP	SS	IP	SS	IP	SS	IP	SS	IP	SS	IP	SS	IP	SS	IP	SS	IP	SS	IP	SS	IP	SS	IP	SS	IP
E1	9	1.000	9	1.000	9	1.000	8	0.712	8	0.712	9	1.000	9	1.000	8	0.712	7	0.498	7	0.498	8	0.712	7	0.498	8	0.712
E2	9	1.000	7	0.498	9	1.000	8	0.712	6	0.344	8	0.712	7	0.498	8	0.712	4	0.162	7	0.498	8	0.712	8	0.712	7	0.498
E3	9	1.000	9	1.000	9	1.000	1	0.059	1	0.059	9	1.000	1	0.059	1	0.059	1	0.059	9	1.000	9	1.000	9	1.000	1	0.059
E4	8	0.712	7	0.498	7	0.498	8	0.712	7	0.498	7	0.498	6	0.344	8	0.712	8	0.712	8	0.712	7	0.498	8	0.712	8	0.712
E5	8	0.712	8	0.712	8	0.712	5	0.237	5	0.237	7	0.498	5	0.237	7	0.498	5	0.237	8	0.712	8	0.712	9	1.000	7	0.498
E6	5	0.237	4	0.162	8	0.712	6	0.344	4	0.162	3	0.112	6	0.344	8	0.712	4	0.162	5	0.237	6	0.344	3	0.112	4	0.162
E7	8	0.712	8	0.712	7	0.498	8	0.712	7	0.498	8	0.712	8	0.712	8	0.712	8	0.712	8	0.712	8	0.712	8	0.712	7	0.498
E8	8	0.712	8	0.712	8	0.712	9	1.000	4	0.162	3	0.112	7	0.498	9	1.000	8	0.712	5	0.237	9	1.000	9	1.000	9	1.000
E9	8	0.712	5	0.237	5	0.237	6	0.344	6	0.344	7	0.498	6	0.344	6	0.344	6	0.344	4	0.162	7	0.498	5	0.237	8	0.712
E10	7	0.498	7	0.498	9	1.000	7	0.498	6	0.344	6	0.344	5	0.237	8	0.712	6	0.344	7	0.498	9	1.000	9	1.000	9	1.000
E11	7	0.498	5	0.237	3	0.112	5	0.237	5	0.237	7	0.498	7	0.498	5	0.237	5	0.237	7	0.498	7	0.498	2	0.079	3	0.112
E12	6	0.344	8	0.712	6	0.344	6	0.344	6	0.344	4	0.162	4	0.162	9	1.000	6	0.344	8	0.712	8	0.712	7	0.498	8	0.712
E13	7	0.498	7	0.498	7	0.498	6	0.344	6	0.344	6	0.344	6	0.344	7	0.498	6	0.344	7	0.498	7	0.498	8	0.712	7	0.498
E14	5	0.237	6	0.344	5	0.237	7	0.498	7	0.498	9	1.000	7	0.498	8	0.712	8	0.712	8	0.712	9	1.000	9	1.000	9	1.000
E15	8	0.712	8	0.712	8	0.712	8	0.712	7	0.498	7	0.498	5	0.237	7	0.498	7	0.498	7	0.498	7	0.498	7	0.498	7	0.498
E16	9	1.000	5	0.237	9	1.000	9	1.000	9	1.000	9	1.000	9	1.000	9	1.000	5	0.237	8	0.712	8	0.712	9	1.000	5	0.237

*** SS : Original survey score, IP: Idealized priority value**

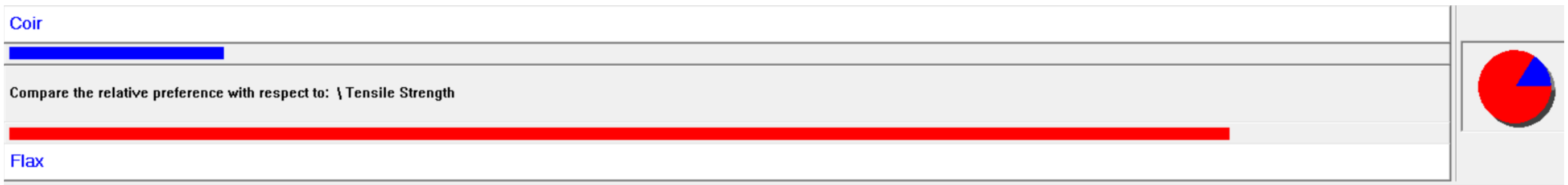
GEOMETRIC MEAN (	***0.604***	***0.482***	***0.549***	***0.442***	***0.328***	***0.458***	***0.360***	***0.542***	***0.329***	***0.505***	***0.662***	***0.548***	***0.440***
Normalized GM	***0.0966***	***0.0771***	***0.0879***	***0.0707***	***0.0526***	***0.0733***	***0.0575***	***0.0867***	***0.0526***	***0.0809***	***0.1060***	***0.0877***	***0.0705***
Global ranking	**2**	**7**	**3**	**9**	**12**	**8**	**13**	**5**	**11**	**6**	**1**	**4**	**10**

APPENDIX II

Pairwise comparison judgement of alternatives with respect to each sub-criterion

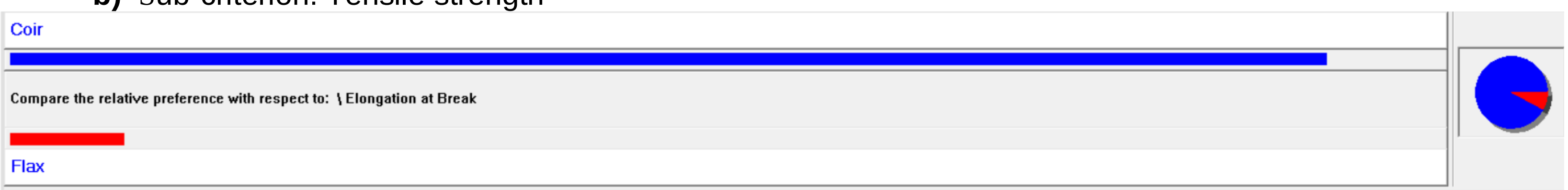
1) Main criterion: Strength

a) Sub-criterion: Tensile strength



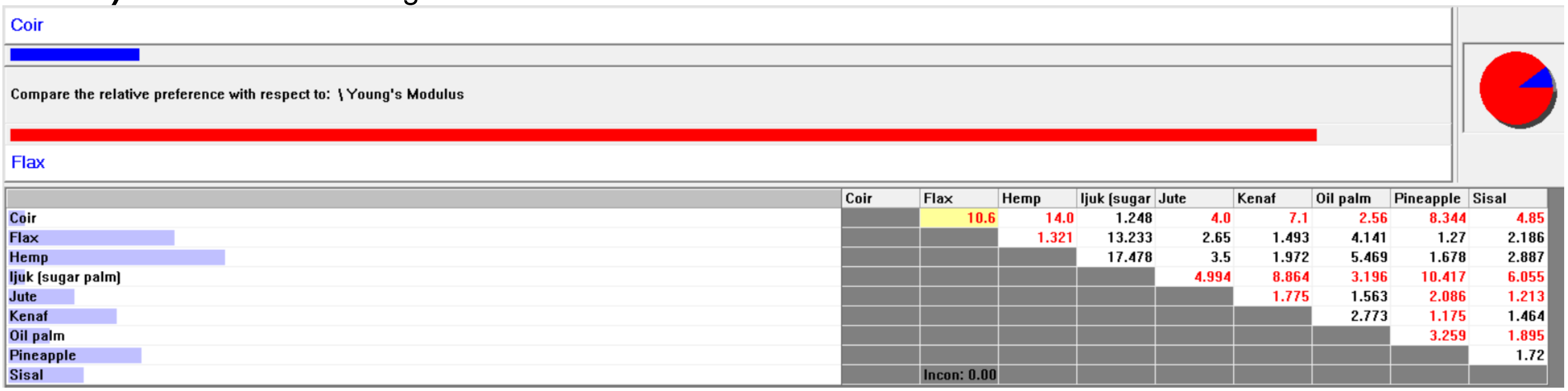
	Coir	Flax	Hemp	Ijuk (sugar	Jute	Kenaf	Oil palm	Pineapple	Sisal
Coir		5.74	4.29	1.261	3.506	4.183	1.331	5.257	2.743
Flax			1.338	4.552	1.637	1.372	4.311	1.092	2.093
Hemp				3.402	1.224	1.026	3.222	1.226	1.564
Ijuk (sugar palm)					2.78	3.318	1.056	4.619	2.175
Jute						1.193	2.633	1.5	1.278
Kenaf							3.142	1.257	1.525
Oil palm								3.949	2.06
Pineapple									
Sisal		Incon: 0.06							

b) Sub-criterion: Tensile strength



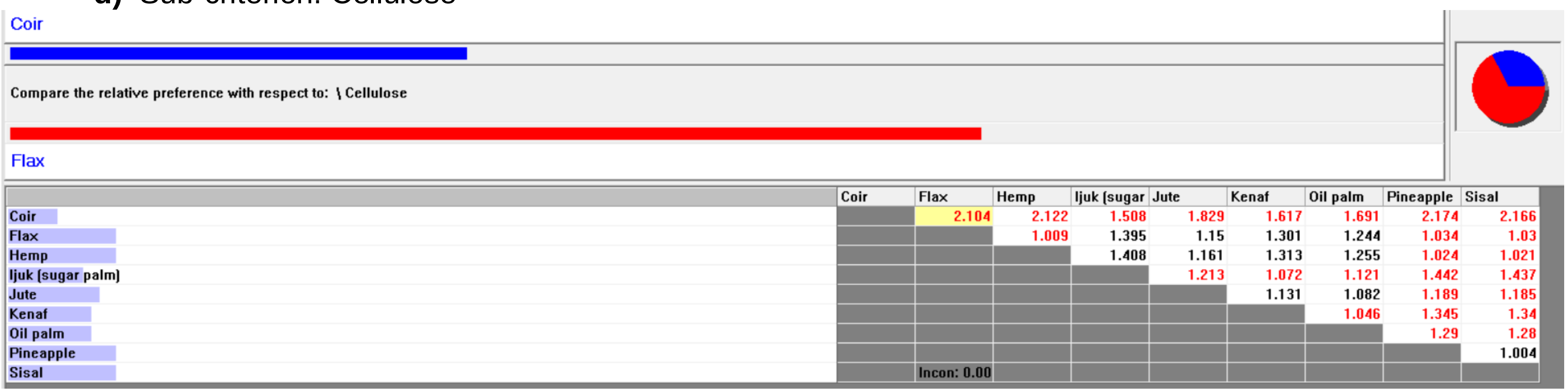
	Coir	Flax	Hemp	Ijuk (sugar	Jute	Kenaf	Oil palm	Pineapple	Sisal
Coir		12.273	14.211	1.392	15.429	9.31	1.915	3.195	3.195
Flax			1.158	8.818	1.257	1.318	6.409	3.841	3.841
Hemp				10.211	1.086	1.526	7.421	4.447	4.447
Ijuk (sugar palm)					11.086	6.69	1.376	2.296	2.296
Jute						1.657	8.057	4.829	4.829
Kenaf							4.862	2.914	2.914
Oil palm								1.669	1.669
Pineapple									1.0
Sisal		Incon: 0.00							

c) Sub-criterion: Young's modulus



	Coir	Flax	Hemp	Ijuk (sugar	Jute	Kenaf	Oil palm	Pineapple	Sisal
Coir		10.6	14.0	1.248	4.0	7.1	2.56	8.344	4.85
Flax			1.321	13.233	2.65	1.493	4.141	1.27	2.186
Hemp				17.478	3.5	1.972	5.469	1.678	2.887
Ijuk (sugar palm)					4.994	8.864	3.196	10.417	6.055
Jute						1.775	1.563	2.086	1.213
Kenaf							2.773	1.175	1.464
Oil palm								3.259	1.895
Pineapple									1.72
Sisal		Incon: 0.00							

d) Sub-criterion: Cellulose



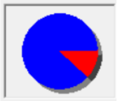
	Coir	Flax	Hemp	Ijuk (sugar	Jute	Kenaf	Oil palm	Pineapple	Sisal
Coir		2.104	2.122	1.508	1.829	1.617	1.691	2.174	2.166
Flax			1.009	1.395	1.15	1.301	1.244	1.034	1.03
Hemp				1.408	1.161	1.313	1.255	1.024	1.021
Ijuk (sugar palm)					1.213	1.072	1.121	1.442	1.437
Jute						1.131	1.082	1.189	1.185
Kenaf							1.046	1.345	1.34
Oil palm								1.29	1.28
Pineapple									1.004
Sisal		Incon: 0.00							

e) Sub-criterion: Lignin

Coir

Compare the relative preference with respect to: \ Lignin

Flax



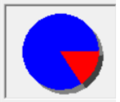
	Coir	Flax	Hemp	Ijuk (sugar	Jute	Kenaf	Oil palm	Pineapple	Sisal
Coir		7.636	3.426	1.375	3.971	1.843	1.267	3.126	2.43
Flax			2.229	10.496	1.923	4.143	6.029	2.443	3.143
Hemp				4.71	1.159	1.859	2.705	1.096	1.41
Ijuk (sugar palm)					5.458	2.533	1.741	4.296	3.34
Jute						2.155	3.135	1.27	1.634
Kenaf							1.455	1.695	1.318
Oil palm								2.468	1.918
Pineapple									1.287
Sisal		Incon: 0.00							

f) Sub-criterion: Fiber length

Coir

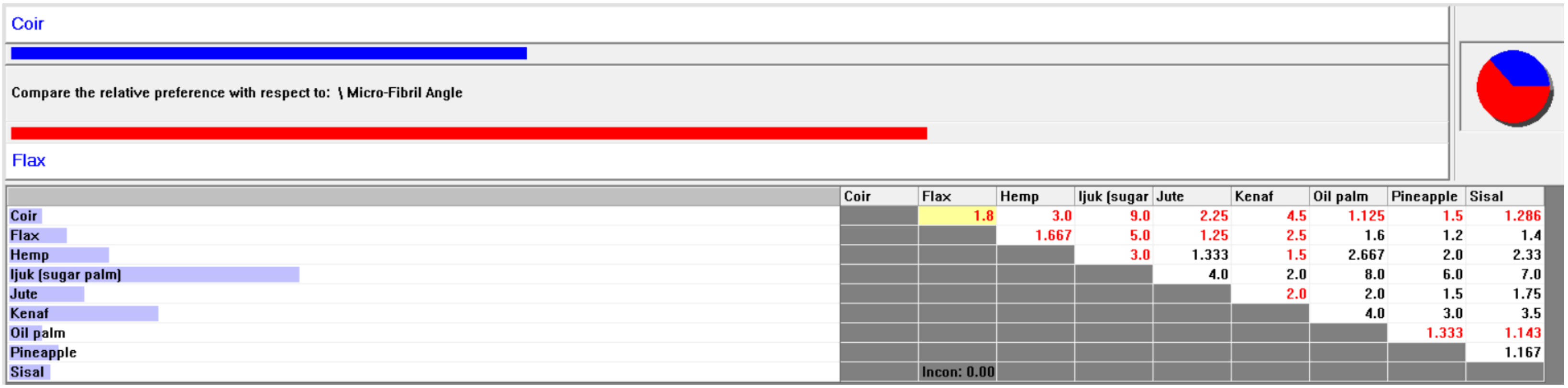
Compare the relative preference with respect to: \ Fibre Length

Flax



	Coir	Flax	Hemp	Ijuk (sugar	Jute	Kenaf	Oil palm	Pineapple	Sisal
Coir		5.324	2.833	14.0	1.399	5.882	1.353	2.833	10.588
Flax			15.083	2.63	7.449	1.105	3.935	15.083	1.989
Hemp				39.667	2.025	16.667	3.833	1.0	30.0
Ijuk (sugar palm)					19.588	2.83	10.348	39.667	1.322
Jute						8.23	1.893	2.025	14.815
Kenaf							4.348	16.667	1.8
Oil palm								3.833	7.826
Pineapple									30.0
Sisal		Incon: 0.00							

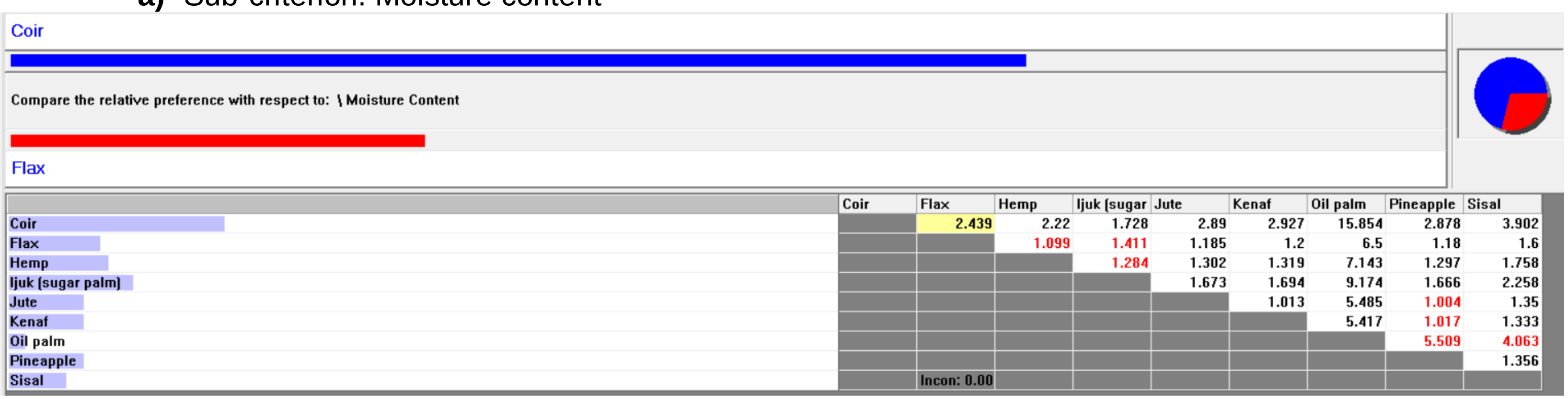
g) Sub-criterion: Micro-fibril angle



	Coir	Flax	Hemp	Ijuk (sugar	Jute	Kenaf	Oil palm	Pineapple	Sisal
Coir		1.8	3.0	9.0	2.25	4.5	1.125	1.5	1.286
Flax			1.667	5.0	1.25	2.5	1.6	1.2	1.4
Hemp				3.0	1.333	1.5	2.667	2.0	2.33
Ijuk (sugar palm)					4.0	2.0	8.0	6.0	7.0
Jute						2.0	2.0	1.5	1.75
Kenaf							4.0	3.0	3.5
Oil palm								1.333	1.143
Pineapple									1.167
Sisal		Incon: 0.00							

2) Main criterion: Moisture resistance

a) Sub-criterion: Moisture content



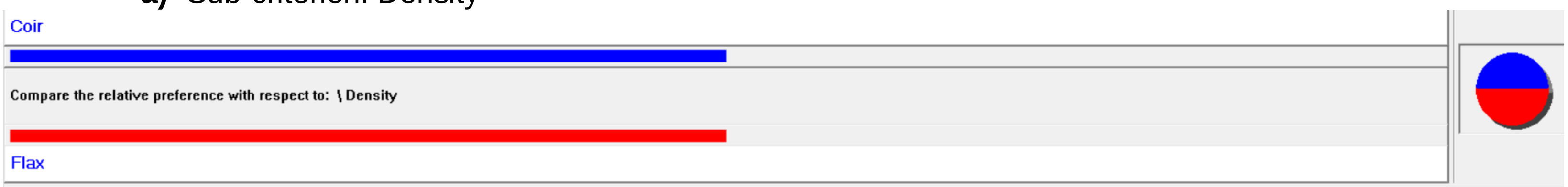
	Coir	Flax	Hemp	Ijuk (sugar	Jute	Kenaf	Oil palm	Pineapple	Sisal
Coir		2.439	2.22	1.728	2.89	2.927	15.854	2.878	3.902
Flax			1.099	1.411	1.185	1.2	6.5	1.18	1.6
Hemp				1.284	1.302	1.319	7.143	1.297	1.758
Ijuk (sugar palm)					1.673	1.694	9.174	1.666	2.258
Jute						1.013	5.485	1.004	1.35
Kenaf							5.417	1.017	1.333
Oil palm								5.509	4.063
Pineapple									1.356
Sisal		Incon: 0.00							

b) Sub-criterion: Hemicellulose

	Coir	Flax	Hemp	Ijuk (sugar	Jute	Kenaf	Oil palm	Pineapple	Sisal
Coir		1.851	1.707	1.153	1.638	2.065	2.404	4.474	1.201
Flax			1.084	1.605	1.13	1.115	1.299	2.417	1.541
Hemp				1.48	1.042	1.209	1.408	2.621	1.422
Ijuk (sugar palm)					1.42	1.79	2.084	3.879	1.041
Jute						1.261	1.468	2.732	1.364
Kenaf							1.164	2.167	1.719
Oil palm								1.861	2.002
Pineapple									3.725
Sisal		Incon: 0.00							

3) Main criterion: Weight

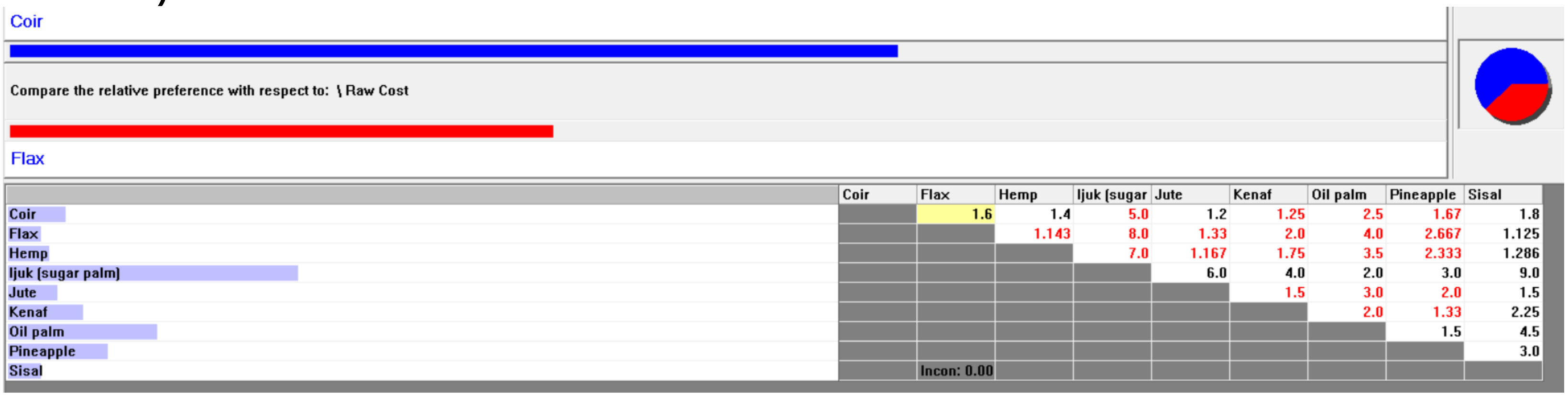
a) Sub-criterion: Density



	Coir	Flax	Hemp	Ijuk (sugar	Jute	Kenaf	Oil palm	Pineapple	Sisal
Coir		1.0	1.037	1.049	1.0	1.333	1.217	1.167	1.036
Flax			1.037	1.049	1.0	1.333	1.217	1.167	1.036
Hemp				1.011	1.037	1.286	1.174	1.125	1.074
Ijuk (sugar palm)					1.049	1.271	1.174	1.113	1.086
Jute						1.333	1.217	1.167	1.036
Kenaf							1.095	1.143	1.381
Oil palm								1.044	1.261
Pineapple									1.208
Sisal		Incon: 0.00							

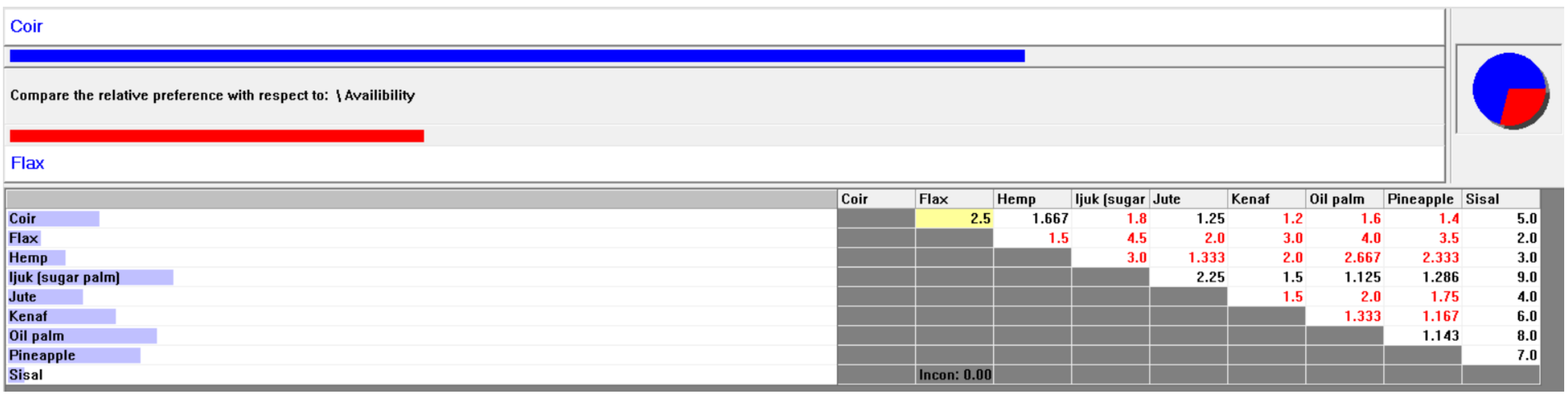
4) Main criterion: Cost

a) Sub-criteria: Raw cost



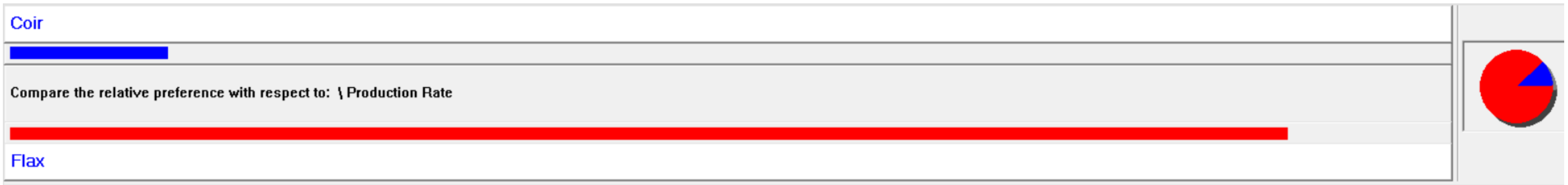
	Coir	Flax	Hemp	Ijuk (sugar	Jute	Kenaf	Oil palm	Pineapple	Sisal
Coir		1.6	1.4	5.0	1.2	1.25	2.5	1.67	1.8
Flax			1.143	8.0	1.33	2.0	4.0	2.667	1.125
Hemp				7.0	1.167	1.75	3.5	2.333	1.286
Ijuk (sugar palm)					6.0	4.0	2.0	3.0	9.0
Jute						1.5	3.0	2.0	1.5
Kenaf							2.0	1.33	2.25
Oil palm								1.5	4.5
Pineapple									3.0
Sisal		Incon: 0.00							

b) Sub-criterion: Availability



	Coir	Flax	Hemp	Ijuk (sugar	Jute	Kenaf	Oil palm	Pineapple	Sisal
Coir		2.5	1.667	1.8	1.25	1.2	1.6	1.4	5.0
Flax			1.5	4.5	2.0	3.0	4.0	3.5	2.0
Hemp				3.0	1.333	2.0	2.667	2.333	3.0
Ijuk (sugar palm)					2.25	1.5	1.125	1.286	9.0
Jute						1.5	2.0	1.75	4.0
Kenaf							1.333	1.167	6.0
Oil palm								1.143	8.0
Pineapple									7.0
Sisal		Incon: 0.00							

c) Sub-criterion: Production rate



	Coir	Flax	Hemp	Ijuk (sugar	Jute	Kenaf	Oil palm	Pineapple	Sisal
Coir		8.3	2.14	2.5	23.0	9.7	25.0	1.351	3.78
Flax			3.879	20.75	2.771	1.169	20.75	11.216	2.196
Hemp				5.35	10.748	4.533	5.35	2.892	1.766
Ijuk (sugar palm)					57.5	24.25	1.0	1.85	9.45
Jute						2.371	57.5	31.081	6.085
Kenaf							24.25	13.108	2.566
Oil palm								1.85	9.45
Pineapple									5.108
Sisal		Incon: 0.05							