Bulacan Agricultural State College
Research Journal

Volume 16, December 2019, pp. 1-12 | ISSN 1656-2496

DEVELOPMENT OF LOW-COST BIOCOMPOSITE EGG TRAY

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Abstract

Biocomposite egg tray using rice straw as substitute fiber material and waste paper was developed and tested. Tensile and compressive strengths, moisture content and water absorbency were investigated with different fiber ratios (70, 60 and 50 wt%). Tensile and compressive strengths increased with decreasing fiber content. Higher tensile and compressive strengths were observed in the 50 wt% fiber with loading at 9.3467 MPa and 0.4042 MPa. Moisture and water absorption increased with increasing fiber content. Highest values were observed at 70 wt% fiber with an average value of 6.61% and 42.71% for moisture and for water absorption respectively. Developed biocomposite egg trays had lower production costs compared with existing egg tray with Php 1.29 to Php1.38 difference per piece. Hence, this egg tray has a potential to be commercially produced.

Keywords: biocomposite, egg tray, low cost, alternative materials

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Introduction

Philippines is primarily an agricultural country with a land area of 30 million ha, 47% of which is agricultural. Agricultural waste is one the largest part of the nation wide's waste problems. The total area devoted to agricultural crops is 13 million ha distributed among food grains, food crops and non-food crops (Zafar, 2018).

Rice is one of the major foods, with per capita consumption of 65 kg per year (Escriba & Porcar, 2009), accounting for 20% of global consume calories. According to Ibrahim (2018), that in the near future, rice production is expected to increase significantly in order to feed the rising human population. Paddy rice culture produces 660 million tons of rice, along with 800 million dry tons of agricultural residues, which is mainly rice straw (Escriba & Porcar, 2009). Rice straw is a rice by-product produced when harvesting paddy. Rice straw mainly consist of carbohydrate components such as hemicelluloses, cellulose, and lignin (Cheng et.al., 2004) and has good resistance to bacterial decomposition (Summers, *et.al*., 2003). The straw fibers have better properties than any other natural cellulose fiber obtained from an agricultural by product (Wang, 2006).

With these characteristics, rice straw and waste paper materials can be turned to a bio-composite packaging material. On the other hand, paper waste is ruining the environment. In fact, the annual per capita consumption of paper in the Philippines is 13 kg, which is still much below the per capita paper consumption of developed countries (ADB, 2004). Bio-composite material can be useful packaging material and through this, proper waste management will be implemented. The associated problem involved with proper disposal of wastes and the conservation of the global environment can be effectively managed by reducing agricultural waste and waste paper generated in the planet (Aquino *et.al.,* 2013).

The use of bio-composites for food packaging applications could help to provide new food packaging materials with improved mechanical, barrier, antioxidant, and antimicrobial properties (Valdes *et.al*., 2014). Properties of packaging materials such as strength, flexibility, transparency and gas permeability is important whether packaging is suitable for the intended purpose (Molenveld, 2007). Making bio-composite materials into egg trays may improve its strength. A study about increasing the strength of packaging materials for eggs which are extremely fragile product is important because even with the best handling methods, serious losses can result from shell damage. According to Lim (2018), 20% of the egg trays used for delivering eggs are already used making them pliable and cannot properly hold the eggs and also around 2-3 % accounts to breakage due to use of old trays.

Turning waste paper materials to different packaging materials is important to effectively manage the associated problem involved with its disposal and also to conserve our forest reservation. Hence this bio-composite egg tray blended with rice straw will be significant in promoting environment-friendly endeavours and will motivate other researchers. This study will be helpful to bring into a durable bio-composite egg tray that will lessen the cost of inputs by using waste materials. It will also serve as benchmark for researchers on the subject of promoting waste reduction.

The study aimed to develop a biocomposite egg tray which is cheaper than the existing egg tray in the market using farm waste like rice straw and waste papers. Scope was limited to the evaluation of egg trays' tensile and compressive strengths, moisture content and water absorbency only.

Materials and Method

The experimental design was Complete Randomized Design (CRD) with three treatments (ratio of rice straw) and three replications (Table 1). Ratio was based from the preliminary testing wherein it was observed that there was a difference with the existing egg tray when it comes to strength if it was replaced with rice straw as partial substitute fiber for egg trays.

Table 1. Treatment Formulation

TREATMENT	Percentage Weight (%)	
	Rice Straw	**Waste Paper**
A	70	30
B	60	40
C	50	50

Figure 1. Egg tray molder

Rice straw was mixed with waste paper material. One hundred grams (of starch 100 g) was added into 200 g of mixture of rice straw and waste paper and cooked for at least 10 min until the starch become sticky. For molding, using the fabricated molder (Figure 1), 392.4 N- force (40 kg * 9.81 kg-ms^{-2}) was used to make sure of material compaction. It was dried after molding for at least three (3) days to remove the moisture content of the bio-composite material. For layering, corn starch mixed with boiling (approximately 100°C) water was applied to the egg tray using a brush then dry it again for further removal of moisture. Then, the bio-composite material was evaluated for its mechanical properties using Universal Testing Machine (UTM) as well as its economic benefits by comparing to existing egg tray.

Mechanical properties evaluation

The tensile characteristics of egg tray and paper-products were important in their ability to resist tearing or ruptures that are typical to the distribution environment of paper egg trays (Amoo *et.al.,* 2017). Tensile strength was calculated by dividing the load at break by the original minimum cross-sectional area (equation 1). The result was expressed in MPa and reported to three significant figures.

$$\text{Tensile Strength} = \frac{(\text{load at break})}{((\text{original width})(\text{original thickness}))} \qquad \text{(Equation 1)}$$

Compressive strength is the ability of material or structure to carry the loads on its surface without any crack or deflection (Corrosionpedia, 2019). A material under compression tends to reduce the size, while in tension, size elongates. Compressive strength was calculated by dividing the maximum load applied to the specimen during the test by the cross-sectional area and reported in units of megapascal (MPa) in SI units (equation 2).

$$\text{Compressive Strength} = \frac{(\text{maximum load applied})}{(\text{cross-sectional area})} \qquad \text{(Equation 2)}$$

Moisture content is the amount of moisture in the sample given as a percentage of the sample's original weight (Miller, 2019). Moisture determination is one of the most important and most widely used measurements in the processing, packaging and testing of foods (Pomeranz & Meloan, 1994). Three (3) replicates per samples were prepared. Each of the samples was dried at 105 °C for 72 h (Kumar *et.al.,* 2014). Moisture content was determined using equation 3.

$$\text{Moisture Content} = \frac{\text{Weight initial- weight final}}{\text{Weight final}} \times 100 \qquad \text{(Equation 3)}$$

Water absorbency is a measure of the amount of water absorbed by the bio-composite material (Pira, 2019). Three (3) replicates per samples were prepared. Each of the samples was soaked in a bath with distilled water. Distilled water was used because it is virtually no solids, minerals or trace elements (Bai, 2013) that can affect the water absorption of the material. The amount of water absorbed (% WA) were determined using equation 4.

$$\% \text{ WA} = \frac{\text{Weight final- Weight initial}}{\text{Weight initial}} \text{ x } 100 \qquad \text{(Equation 4)}$$

The economic benefits of such bio-composite egg tray was evaluated and assessed by comparing the cost of the existing egg tray using rice straw as raw material. This benefit was expressed numerically as the amount of money that will be saved or generated using equations 5 and 6.

$$\frac{\text{Price}}{\text{pc}} \text{ of biocomposite egg tray} = \frac{\text{Value with assumed mark-up price}}{\text{240 days / 60 egg trays per day}} \qquad \text{(Equation 5)}$$

$$\text{Savings} = \text{Price of existing} - \text{Price of fabricated bio-composite egg tray} \qquad \text{(Equation 6)}$$

Results and Discussion

The fabricated bio-composite egg tray from rice straw and waste paper is shown in Figure 2. Rice straw fibers from 70 wt % to 50 wt % fiber loading were very visible due. Based on observation, 70 wt % fiber loading has the most visible rice straw fibers compare to the other treatments.

Figure 2. Fabricated bio-composite egg trays.

The specimen with a high tensile strength essentially means that it can resist a lot of tension before it breaks (Jones, 2017). During the investigation (Table 4), the maximum tensile strength of 9.3467 MPa was noticed for 50 wt % of fiber and minimum of 3.3933 MPa for fiber with 70 wt %, respectively. On the other hand, treatment B with 60 wt % resulted to 7.1267 MPa. Tensile strength of the bio-composite material increases when the percentage weight of fiber decreases. Same trend were observed on the study of Punyamurthy *et.al.* (2014) wherein the tensile strength of the bio-composites decreases with increase in fiber loading.

Table 4. Comparisons of tensile strength and moisture content of the bio-composites with different fiber loading.

TREATMENTS	AVERAGE TENSILE STRENGTH (MPa)	AVERAGE MOISTURE CONTENT (%)
A (70:30)	3.3933	6.6141
B (60:40)	7.1267	5.2694
C (50:50)	9.3467	4.6568

The performance of bio-composites depends on the properties of the natural fibers used in them. However, the properties of natural fibers that result from the chemistry of the cell wall components make some main problems in bio-composites (Kispotta, 2011). The result of lower tensile strength at the 70 wt % could also be affected by the fiber composition in the bio-composite. According to Subramaniam 2018, fiber/matrix bonding, chemical treatments, surface modification of fibers, fiber orientation, and type of matrix are the factors influences the tensile strength. Yatim *et.al*., (2003) stated that since the natural fiber is hydrophilic and most polymers is hydrophobic, bio-composites itself have significant problems of compatibility between the bio-fibers and the matrix and this lead to poor interfacial bonding between them. Additionally, bio-fibers have high sensitivity to moisture content which is difficult to control because bio-fibers are from the hydrophilic group. Moisture is trapped in composites and affects their mechanical properties at long term conditions. On the other hand, the moisture absorbed by bio-fiber may cause the fiber surface like a separating agent, while if the fibers are not dehumidified, the mechanical properties of bio-fibers could be effected (Wang *et.al.,* 2006).

Moreover, Table 4 also displays the maximum moisture content of 6.61 % for 70 wt % of fiber and 4.66 % was minimum with 50 wt % of fiber, while 60 wt % results was 5.27 %. Bio-composites with 70 wt % fiber got the highest moisture content. The bio-composite material MC decreases in the 60 wt % and 50 wt % of the fiber loading.

Generally, the performance of paper-based packaging materials, such as tensile strength are strongly affected by the moisture content of the packaging materials which is also directly influenced by the environmental conditions (Mohanty & Swain, 2017). According to Rhim (2010), further sorption of water vapor may bring swelling and conformational change on the macromolecular structure of the material and may result decreased in mechanical strength. The decrease in tensile strength by the presence of moisture of bio-composite material is mainly due to the development of hydrogen bonds between hydrophilic hydroxyl groups of cellulose fiber in the paper and rice straw matrix consequently result in decreased mechanical strength (Rhim, 2010).

Table 5 shows the compressive strength of the bio-composite material with different fiber loading. This also displays that the compressive strength values of the sample having 50% weight of rice straw were maximum at 0.4042 MPa and were minimum at 70% weight with 0.3942 MPa while 60wt % has strength of 0.3991 MPa, respectively.

Table 5. Comparison of the compressive strength and moisture content of the bio-composites with different fiber loading

TREATMENTS	AVERAGE COMPRESSIVE STRENGTH (MPa)	AVERAGE MOISTURE CONTENT (%)
A (70:30)	0.3942	7.8073
B (60:40)	0.3991	6.9780
C (50:50)	0.4042	5.7099
EXISTING	0.0008	2.9406

Based on the testing, existing egg tray results to 0.0008 MPa which essentially means that bio-composite egg tray exhibits higher compressive strength than the existing. According to Amoo, et.al. (2017), local paper egg trays are discovered to be made of comparatively lower fiber quality. It clearly indicates that bio-composite materials typically have higher tensile strengths than compressive strengths (Corrosionpedia, 2019). Composites loaded in compression may buckle, kink or crush. According to Wu *et.al.,* (2018), when composites are subjected to a compression loading, the fiber and the resin assume the force, which will affect the compression strength of composites in common, therefore, the tensile and compression properties of composites exhibit a difference. In addition, a difference between the tensile and compressive properties of fiber and composites exists due to fiber buckling and production problems, which have been confirmed in many papers, with some authors having studied the tensile and compressive properties from the fiber viewpoint (Wu *et.al.*, 2018).

On the other hand, Table 5 also shows the maximum moisture content of 7.81 % for 70 wt % of fiber and 5.71% was minimum with 50 wt % of fiber, while 60 wt % results was 6.98%, respectively. Bio-composites with 70 wt % fiber got the highest moisture content. The moisture content of the composites increased as the filler loading increased, but the composites had the similar level of compressive strength. The compression strength of composite is strongly dependent on the effectiveness of the matrix in supporting the fiber against buckling (John and Reid, 1969). As cited by Cheng et.al. (2004), with decreasing degree of saturation it results to increase surface tension and compressive stress.

Result displays that the water absorption (WA) values of the samples having 70 wt % of rice straw fiber are maximum at 42.71 % while they are minimum at 37.19 % for the samples having 50 wt % the rice straw fiber while 60 wt % has a value of 39.86 %, respectively (Table 6). Water absorption amount of the bio-composites significantly increased with increasing the fiber loading. This was mainly result due to those free OH groups come in contact with water and hydrogen bonding which results gaining of weight in the bio-composites (Ismail & Ishak, 2018).

Table 6. Comparisons of WA of the bio-composites with different fiber loading

TREATMENTS	WATER ABSORBENCY (%)
A (70:30)	42.7133
B (60:40)	39.8600
C (50:50)	37.1933

The higher the fiber loading is, the more hydrophilic sites exist in the composites and the higher water absorption of the composites (Ismail & Ishak, 2018). In addition, composites had higher moisture absorption rate at cornstarch- based. According to Pandian *et.al*., (2014), the water absorption behavior of the composites mainly depends on the voids present in the composites, interfacial adhesion between the fiber and matrix, and type of fibers reinforced that may lead to increase rate and amount of water absorbed by the composite. On the other hand, this phenomenon can be explained by the hydrophilic nature of rice straw fibers, due to the fact that they are cellulose fibers (Khandanlou et.al. 2014).

Result shows in terms of production cost of the different treatments of bio-composite egg trays. The costs of materials are based on the retail prices available in the market (Table 7). According to Santiago (2019), owner of DKG Junkshop located at Malipampang, San Ildefonso, Bulacan waste paper price was Php 1.5 kg^{-1}. In addition, rice straw price range is Php 0.4 kg^{-1} around Pampanga and San Ildefonso area (De Lara, 2019).

It also shows that treatments have different prices in making the bio-composite egg tray. However, it further shows that 50 wt % fiber loading also has the higher price compare to the other treatments but this treatment results a good mechanical strength among the other treatments. On the other hand, the bio-composite with lesser amount of fiber loading has a cost of Php 8.23 selling price, assuming with 30% mark-up. And comparing it to existing, existing egg tray cost is Php 10.00 per tray with 30 slots. Assuming that there is one laborer working for 8 h and 60 trays he produced in one day. The money that will be saved is Php 1.77-1.84 in the bio-composite egg tray. With this, natural fiber such as rice straw can be used as a substitute for paper fiber in making an egg tray.

Table 7. Production cost and price of different mixture of bio-composites per egg tray production

PARTICULARS	COST OF USAGE		
	A (70:30)	**B (60:40)**	**C (50:50)**
Variable Cost (Php)	**4.15**	**4.17**	**4.20**
Corn Starch	0.30	0.30	0.30
Rice Straw	0.06	0.05	0.04
Waste Paper	0.09	0.12	0.15
Electricity	0.38	0.38	0.38
Labor	3.33	3.33	3.33
Fixed Cost (Php)	**2.13**	**2.13**	**2.13**
TOTAL PRODUCTION COST (Php)	**6.28**	**6.30**	**6.33**
SELLING PRICE (assume 30% mark-up)	8.16	8.19	8.23
PRICE PER PIECE (Php)	**8.16**	**8.19**	**8.23**

ASSUMPTIONS:
Production time= 8 hrs/ day
Daily production=60 trays/ day
Blender= 4 kW/h
Consumption= 0.07 kW/h
Production=240 days/ yr
Yearly production=14,400 trays/yr
Blender capacity= 8 min/tray
Electric cost= Php. 5.43 kW/h

Summary and Conclusion

Tensile strength of the biocomposite material, as tested using Universal Testing Machine (UTM), increases when the percentage weight of fiber decreases. The maximum tensile strength of 9.3467 MPa was noticed for 50 wt % of fiber and minimum of 3.3933 MPa for fiber with 70 wt %, respectively. On the other hand, 60 wt % results to 7.1267 MPa. Using UTM, result showed that compressive strength values of the sample having 50% weight of rice straw were maximum at 0.4042 MPa and were minimum at 70% weight with 0.3942 MPa while 60wt % has strength of 0.3991 MPa and 0.0008 MPa for existing egg tray.

Through oven drying the result of moisture contents of the bio-composite material with the maximum moisture content of 6.61 % for 70 wt % of fiber and 4.66 % was minimum with 50 wt % of fiber, while 60 wt % results was 5.40 %. The result of moisture content of bio-composite in compressive test indicated the maximum moisture content of 7.81 % for 70 wt % of fiber and 5.71% was minimum with 50 wt % of fiber, while 60 wt % results was 6.98%. Bio-composites with 70 wt % fiber got the highest moisture content. In terms of water absorbency, result displays that water absorption (WA) values of the samples having 70 wt % of rice straw fiber are maximum at 42.71 % while they are minimum at 37.19 % for the samples having 50 wt % the rice straw fiber while 60 wt % has a value of 39.86 %. It also means that amount of fiber loading does significantly affect the water absorption of the bio-composites.

Bio-composite egg tray has a lower price compare to the existing egg tray. 70 wt %, 60 wt % and 50 wt % prices were Php. 8.16, Php. 8.19 and Php. 8.23, respectively. Savings for this bio-composite egg tray ranges from Php.1.77- 1.84 per piece. With this, natural fiber such as rice straw can be used as a substitute for paper fiber in making an egg tray.

The rice straw fibers in the right proportion can be used as substitute fiber material in making a bio-composite and in modifying the existing egg tray. Mechanical properties of bio-composites increase when rice straw is being incorporated into it. The rice straw helps in stress transfer within the bio-composites, while the presence of natural fiber loads increases water absorption and moisture content capacity of bio-composites affecting the tray's mechanical properties making it slightly weaker. With this, development of bio-composite egg tray, has higher compressive strength compare to the existing egg tray with lower price. Based on the result, the development of bio-composite egg tray can be substituted by rice straw fiber with better mechanical strength and used as an alternative. Natural fibers are renewable, economical, eco-friendly and cause no health hazards.

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Acknowledgement

Gratitude and appreciation are given to the faculty members of Agricultural and Biosystems Engineering whose technical expertise shared to the realization of this paper.