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Assessment of Fermented Rice Straw as Nutritive Substances for Bio-based Plant Pot

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Abstract
This research aims to develop bio-based nurseries or plant pots that contain soil nourishment from agricultural waste, namely rice straw. Tapioca starch glue as a binder was mixed with rice straw and then pressed by a hydraulic compression machine to form the sheet. To promote soil nourishment, the straw was fermented. The fermentations with and without enzyme assistance were compared as well as the fermentation time. The tensile strength of the specimens was assessed through a tensile test, revealing a surprising increase in strength with fermentation. The key distinction between the specimens with and without enzyme assistance was the time it took to reach the maximum value. Without the presence of enzyme, the specimens reached a maximum tensile strength of 0.67 MPa after 7 days of fermentation. For fermentation with enzyme assistance, this value increased to 0.81 MPa but required 14 days of fermentation to reach its maximum point. Not only the fermentation duration but also the inclusion of enzymes showed a slightly impact on water absorption and water swelling. Spectrophotometry was employed to analyze the value of phosphorus (P) and potassium (K), while the amount of nitrogen (N) was determined by the Kjeldahl method. As expected, soil nourishment can be promoted by fermentation and boosted by enzymes. The sheet from straw fermented with the enzyme at 21 days gives the highest soil nourishment, i.e., 17.90%w/w for total K_2O, 0.40%w/w for total P_2O_5, and 1.89%w/w for total N.

Keywords: Plant pot, Rice straw, Fermentation, Soil nourishment, Enzyme

1. Introduction

In modern agriculture and farming, plastic is the preferred material for plant pots and nursery pots due to its durability, accessibility, and affordability. However, once the seedlings are planted in the ground, these pots become waste that is challenging to decompose. Plastic takes over a century to break down, and it cannot be easily recycled due to its diminished strength and contamination. Consequently, these pots are usually disposed of through incineration or landfills, which contributes to pollution and exacerbates global warming. To address this issue, it is crucial to manufacture plant pots and nursery pots from natural materials instead of relying on plastic.

Biobased plant pots can be made using materials derived from renewable sources or obtained as by-products of productive activities like agriculture, animal husbandry, fishing, tannery, and others (Schettini et al., 2013). The main goal of these alternative pots is their ability to naturally decompose instead of adding to the waste in landfills. Several plant pots made from compressed fibers, which were mentioned earlier among other materials, have been extensively studied and are currently available for purchase in the market such as Cowpots (composted cow manure and natural fibre), Coirpot (coir fibres), and Fertilpots (wood fibre and peat) (Nambuthiri, Fulcher, Koeser, Geneve, & Niu, 2015).

Millions of tons of rice are grown annually in Thailand, with Chiang Rai having high rate of rice cultivation among northern provinces in 2018 (Office of Agricultural Economics, 2022). As a result, utilizing rice straw, a natural byproduct of agriculture waste, to produce pots has emerged as an idea. Rice straw contains fibers that enhance the pot's strength (Sopunna, Pasom, Woradong, & Chaiwangrach, 2015), making it ideal for use. Additionally, these pots can be transferred to the soil without the need for removal, providing an appropriate planting time for seedlings. Furthermore, the pots eventually decompose into fertilizer, making them an environmentally friendly alternative. Some attempts have been made to create containers using rice straw, resulting in patents such as US7681359B2 (Van de Wetering & Athalage, 2010). The market has witnessed the introduction of a commercial product made from rice straw material, known as the StrawPot, developed by Ivy Acres. Numerous researchers have assessed the performance of these StrawPots and have found them to be decomposable, making them suitable substitutes for plastic pots (Conneway et al., 2015; Evans, Taylor, & Kuehny, 2010; Sun et al., 2015). Furthermore, they have demonstrated no adverse effects on plant establishment and the growth of plants after transplantation (Sun et al., 2015).

Rice straw, which is plentiful as an organic waste product, can be transformed into fertilizer via composting. Tiquia and Tam (2002) note that composting is an economical method for treating various organic waste types. The concept of making compost is the first idea for using effective microorganisms (EM) in environmental management. Crop residue and animal waste have been successfully composted to create organic fertilizers. Essentially, this solution containing microorganisms was created for the purpose of being used in natural or organic agricultural practices.

This study aims to develop nursery or plant pots from rice straw to be more useful by adding nutrients from the fermentation process. However, the effect of fermentation on pot quality must be evaluated. To resolve this doubt, a comparison of the effects of EM-assisted and non-EM-assisted fermentation was studied in this work.

2. Materials and Methods

2.1 Materials preparation

All the raw materials were provided from local areas in Phayao, Thailand. Rice straw was harvested and collected from the rice field area in Dok Khamtai subdistrict. It was divided into 3 groups. The first group was used without further fermentation (UF). For the fermented straw, it was soaked in the water and followed by piled up on open air for 7, 14, and 21 days. Then, the water fermented straw (WF) was dry in hot air oven at 90°C for 24 h. The last group is enzyme assisted fermentation straw (EF) where the EM was added during the fermentation. The dried fermented straws were ground until less than 0.5 cm and bound together with tapioca starch glue in various ratios of 1:2, 1:3, 1:4 and 1:5. The mixture was placed in a 300×300×5 mm metal frame sandwiched with metal plates and then pressed at 10.85×104 N/m^2 for 2 min (Sopunna et al., 2015) and baked at 90°C for 24 h. All types of straws were forming as sheets with the same procedure.

2.2 Characterization

2.2.1 Tensile testing

The test specimens were cut from the sheets into the size of 150 mm×25 mm with a gauge length of 100 mm. A universal testing machine (Instron Model 5566) equipped with 1 kN load cell was employed for the test. The test was performed at a constant crosshead speed of 5 mm/min. The average tensile strength, elongation at break and Young's modulus were calculated from at least 5 specimens.

2.2.2 Chemical analysis

The concentrations of total N were analyzed by Kjeldahl technique (Tecator™ 2006 Digestion Block and Kjeltec™ 2100 Distillation Unit) (Kathong & Ruangviriyachai, 2014). Phosphorus contents were measured by Vanadomolybdate method using spectrophotometer at 420 nm absorbance (Kathong & Ruangviriyachai, 2014) (Thermo Scientific™ GENESYS™ 30). The amount of potassium used calcium carbonate in hydrochloric as suppressor (Department of Agriculture, 2016) and determined by spectrophotometer at 722 nm absorbance.

2.2.3 Water absorption and swelling

The sample for water absorption test is done by cutting the test specimen into dimensions of 5×5 cm. The dried sample is weighed (W_1) before being dipped in water. Then, the specimens were immersed in water for 1 h and taken out of the water and weighed after soaking (W_2). The obtained data were used to find the percentage of water absorption as follows (Piyang, Chaichan, & Sagulsawasdipan, 2018):

$$\%\text{Water absorption} = [(W_2-W_1)/W_1] \times 100 \quad (1)$$

For the swelling test, the specimen was cut to a size of 5×5 cm, and the thickness of the specimen was measured while drying (T_1). The specimen was immersed in water at 20±2°C for 1 h, then the specimen was lifted and blotted with a damp cloth on the surface. After that, the test specimen was placed on a non-absorbent material for 1 h and finally the specimen thickness was measured at the same location (T_2). Swelling percentage can be calculated from the equation below (Piyang et al., 2018):

$$\%\text{Swelling} = [(T_2-T_1)/T_1] \times 100 \quad (2)$$

2.2.4 Statistical analysis

The average value difference was analyzed using Two-way analysis of variance (ANOVA) at a significance level of α = 0.05 using the statistical analysis program SPSS (Statistical Package for the Social Science version 21). For multiple comparisons, Tukey's test ($p < 0.05$) was performed to check the difference between treatment means.

3. Results and Discussions

3.1 Forming ability

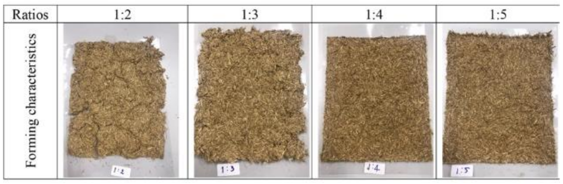

Figure 1. Characteristic of sheets produced from rice straw mixed with tapioca starch glue at various ratios.

The forming ability of straws mixed with tapioca starch glue in various ratios was shown in Figure 1. Sheets produced by 1:2 and 1:3 ratios observed cracks within the sheet and uneven thickness indicating insufficient binder. For the 1:5 ratio, it was found that there was too much binder which was observed from the material overflowing from the edge of the sheet (flash). Therefore, the sheets produced from the ratio of 1:4 are selected for the next step.

3.2 Tensile properties

The mechanical properties of samples were determined via tensile methods in term of tensile strength, elongation at break and Young's modulus. The incorporation of enzyme and fermentation time showed the significant interaction on tensile strength and Young's modulus, but elongation at break. The tensile strength, and Young's modulus of sheets made from fermented straw (whether WF or EF) were observed to be higher overall, except for the sheet made from EF after 7 days and presented in Figure 2. The mechanical properties of EF after 7 days of fermentation were found to be comparable to those of UF, with no significant differences. The initial enzyme activity could potentially explain the fermentation delay. Initially, the biomass entered a lag phase as the microorganisms adjusted to the new conditions, which was then followed by an exponential growth phase according to the growth curve (Glissmann & Conrad, 2000).

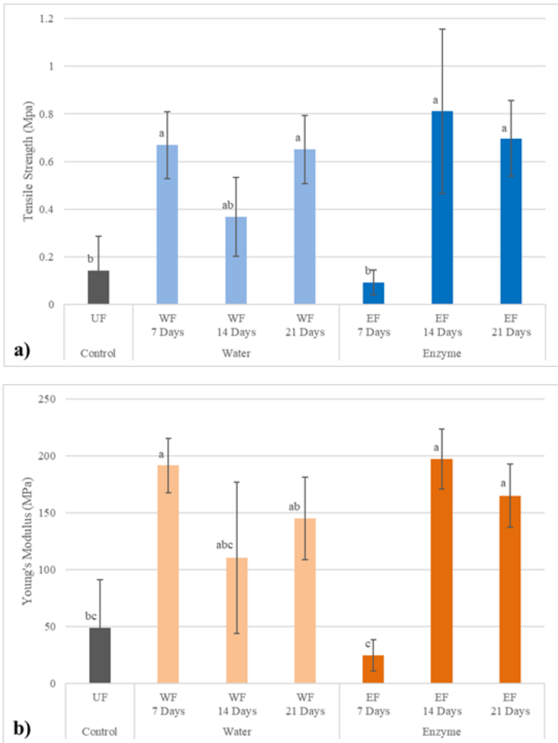

Figure 2. Comparison the mechanical properties of fermented rice straw sheets with and without enzyme assistance (a) Tensile strength, and (b) Young's modulus. Different letters within bars

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indicate significant difference ($p \leq 0.05$) according to Tukey's multiple comparisons test.

The elongation at break did show significant interaction, only fermentation time effect on this property and show in Figure 3.

However, the analysis conducted using a one-way ANOVA indicated that there were no significant alterations in the elongation at break because of fermentation time until 21 days. Regardless of the effect of enzyme, the result showed a slight increase as a function of time but there were no statistically differences among treatments. Moreover, the elongation at break after 21 days of fermentation was significantly higher when compared to control.

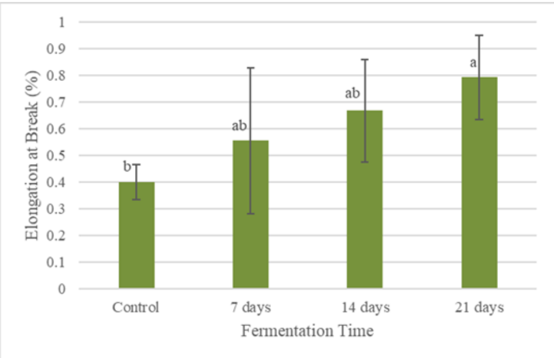

Figure 3. Effect of fermentation time on the elongation at break of sample. Different letters within bars indicate significant difference ($p \leq 0.05$) according to Tukey's multiple comparisons test.

The change in surface morphology might be the reason for mechanical properties development. When a surface is rough, it creates a more favorable environment for wetting, allowing for better mechanical interlocking, which in turn results in improved mechanical properties. The roughness of rice straw is intensified by fermentation (Kumari & Singh, 2022; Liang et al., 2010; Xia et al., 2018), especially when enzymes are added, resulting in a rougher texture than when water is the only medium used (Kumari & Singh, 2022). The increase in surface area of rice straw is due to the degradation of lignin and hemicellulose (Kumari & Singh, 2020).

The main difference between the sheets produced from WF and EF was the duration of fermentation necessary to attain sheets with varying degrees of mechanical properties. In general, the mechanical characteristics of sheets produced via water fermentation alone resulted in the greatest strength after 7 days, with a maximum modulus of 191 MPa, a tensile strength of 0.67 MPa and an elongation at break of 0.69%. The enzyme-assisted fermented sheets achieved their maximum values after 14 days, with the highest modulus, tensile strength, and elongation at break measurements being 197 MPa, 0.81 MPa, and 0.76%, respectively. This difference can be attributed to the previously mentioned delay in the fermentation process.

3.3 Chemical properties

Since the main purpose of using fermented straw is to add nutrients to plant pots, therefore, the changes in N, P and K due to the fermentation process were determined. Table 1 compared the N, P and K values of sheets produced from UF, WF and EF at different fermentation times.

Table 1. Comparison of nitrogen, phosphorus, and potassium content in the samples.

Sample	Total K_2O (%w/w)	Total P_2O_5 (%w/w)	Total N (%w/w)
UF	1.37 ± 0.01^g	0.31 ± 0.00^f	0.69 ± 0.00^g
WF 7 Days	4.57 ± 0.03^f	0.32 ± 0.00^e	0.76 ± 0.02^f
WF 14 Days	11.09 ± 0.07^d	0.34 ± 0.00^c	1.11 ± 0.02^d
WF 21 Days	15.06 ± 0.00^b	0.37 ± 0.00^b	1.65 ± 0.04^b
EF 7 Days	7.79 ± 0.09^e	0.33 ± 0.00^d	0.91 ± 0.00^e
EF 14 Days	13.13 ± 0.12^c	0.37 ± 0.00^b	1.33 ± 0.02^c
EF 21 Days	17.90 ± 0.03^a	0.40 ± 0.00^a	1.89 ± 0.02^a

Mean ± standard deviation. Means in the same column with different letters (a–g) are significantly different ($p < 0.05$).

The results clearly show that the fermentation process greatly affects the N, P and K values as indicated by Tukey's test. The employment of water fermentation only led to a notable rise in all three measurements, which was even more pronounced with an extended fermentation time. The incorporation of enzymes into the fermentation process further intensified these values. At the same fermentation period, the enzyme-assisted fermentation demonstrated a higher value compared to the water fermentation sample. The main function of the EM is to provide microorganisms to the system and to produce useful nutrients (Jusoh, Manaf, & Latiff, 2013). The process of fermentation using only water for 21 days resulted in total N, P_2O_5, and K_2O values of 1.65%, 0.37%, and 15.06% by weight, respectively. However, when EM was added to the mixture for a shorter period of 7 days,

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the values of N, P, and K increased compared to the fermentation with water alone. Enzymatic fermentation for 21 days resulted in even higher values, with total N increasing to 1.89%w/w, total P_2O_5 to 0.40%w/w, and total K_2O to 17.90%w/w. Furthermore, even after molding and heat treatment, the fermented straw demonstrated substantially greater values of N, P, and K in comparison to non-fermented straw. Hence, it can be deduced that the process of straw fermentation, particularly when combined with EM, can enhance the nutritional properties of plant pots, and this benefit persists even after potting procedures that involve heat treatment. As per the Royal Gazette, non-liquid organic fertilizers are required to contain a minimum of 1.0% total N by weight, 0.5% total P_2O_5 by weight, and 0.5% total K_2O by weight. Alternatively, the total macronutrient content should not be less than 2.0% by weight. Therefore, the N, P, and K values obtained from all specimens in this study meet the criteria for being classified as organic fertilizer.

3.4 Water absorption and swelling

The fermentation process might affect water absorption and swelling. Fermentation not only changes the texture of the straw but also results in increased porosity in the straw (Kumari & Singh, 2022). These pores directly affect the adsorption and swelling values as shown in Table 2. It was expected that the sheets made from longer fermentation time had more water absorption and swelling and were higher than UF. Notably, the sheets produced from EF exhibited higher in number on water absorption and swelling values compared to those obtained from WF at all fermentation durations. The increase in both values may be attributed to a decrease in cellulose crystallinity that occurs during the fermentation process (Xia et al., 2018).

Table 2. Comparison of %water absorption and %swelling in the samples.

Sample	%Water Absorption	%Swelling
UF	58.00	56.25
WF 7 Days	60.00	60.78
WF 14 Days	68.00	61.54
WF 21 Days	70.00	65.45
EF 7 Days	67.00	68.75
EF 14 Days	71.00	70.59
EF 21 Days	78.47	77.59

4. Conclusion

The properties of rice straw nursery plant pots can be altered through the process of fermentation. Over time, fermentation increases the levels of N, P, and K. When combined with an EM enzyme, the fermentation process results in even greater improvements compared to non-enzyme fermentation. The tensile strength and Young's modulus can be improved due to both fermentation time and incorporation of enzyme with reaching the maximum in 14 days for enzyme fermentation and 7 days for non-enzyme fermentation. However, elongation at break was increased to the maximum value at 21 days of fermentation regardless of enzyme assistance. Furthermore, the inclusion of enzymes during fermentation and longer fermentation period leads to an increase in water swelling and water absorption.

In summary, to maximize the nutritional benefits of the material, fermenting rice straw for a duration of 21 days with the aid of enzymes before using it as a material for bio-based plant pots can significantly enhance its nourishing properties, making it suitable as an organic fertilizer.

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Conflict of Interest

The authors do not report any financial or personal connections with other persons or organizations, which might negatively affect the contents of this publication and/or claim authorship rights to this publication.

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