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Characterization of Sugarcane and Coconut Leaf Sheath Biodegradable Seedling Bag with Slow-Release Phosphate

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Sustainable practices in agriculture are crucial for supporting the growth of human population without impacting the environment. However, excessive usage of seedling polybags has led to environmental pollution due to the increased waste of plastics. Usually, after the seedling is moved into pots or planting holes, polybags are thrown away and this may damage the root system from growing healthily. Besides, soils may lack nutrients that the plant seedlings need. Therefore, the solution for this issue is to develop a biodegradable seedling bag (BSB) that is made from natural fiber waste with slow-release phosphate function for increasing the survival of seedlings. Sugarcane bagasse fiber (SBF) and coconut leaf sheath fiber (CLSF) were used as the reinforced materials to slow-release fertilizer (SRF) matrix. SRF consists of a mixture of glycerol, water, cassava starch, vinegar, and fertilizer (phosphoric acid). Then, SBF was added to the SRF mixture and spread on top of the CLSF surface using the hand lay-up technique before being dried in the oven. Then, it was compressed using cold compression molding press machine. Three compositions with different ratios of CSLF, SBF and SRF were formulated. Then, BSBs were tested to identify the water contact angle, water absorption, biodegradability, chemical interaction, and tensile properties. The best composition of BSB consists of the highest fibers (CLSF and SBF) content, which gave the highest physico-mechanical and chemical properties except tensile elongation at break. Application of BSB may reduce seedling shock because of pot transferring, increase root growth and early shoot growth, accelerate ground cover for erosion protection and improve seedling survival. The development of BSB may help promote circular economy via reutilization of waste biomass. Thus, minimizes the environmental impact caused by utilization of non-biodegradable plastic and phosphate fertilizer.

Keywords: Biodegradable seedling bag; slow-release fertilizer; sugarcane bagasse; coconut leaf sheath; slow-release phosphate

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The need for a productive food production system and for global food security must be addressed considering the growing demands of the global population. Therefore, it is essential to utilize chemicals such as fertilizers and pesticide to increase crop productivity. However, possible loss of fertilizer to the environment via percolation, volatilization, and run-off may occur due to low retention in soils with a low cation exchange capacity. The availability of nutrients may remain low despite a high application rate of fertilizer, causing a loss of agricultural productivity [1]. Furthermore, fertilizer may enter agroecological systems and releases phosphate that may cause eutrophication and further damage to the aquatic system. Slow-release fertilizer (SRF) is a new kind of fertilizer that is needed to promote sustainable agriculture since its slow-release nutrient function allows for high utilization efficiency and minimal environmental damage.

The majority of SRFs on the market are commercially produced fertilizers that have been coated with a hydrophobic substance to slow the rate of nutrient release [2]. These SRFs cannot be widely used because of the high preparation costs. Another issue is the buildup of coating residue made of petrochemicals in the soil that can also leach into the environment. In this research study, cassava starch, commercial fertilizer, and short fiber of sugarcane bagasse fiber (SBF) were mixed and coated on the surface of template made from long fiber of coconut leaf sheath fiber (CLSF) to make a biodegradable seedling bag (BSB). The implementation of SRF may prevent any potential negative impacts to the environment by improving the nutrition of crops and reduce labor costs by lowering the frequency of water irrigation [3].

In the agriculture industry, the seedlings are propagated from seeds and grown in seedling

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polybags made of polyethylene in nurseries and horticulture until the time comes to transplant the seedlings into the ground or larger containers. The sturdy, lightweight plastic is capable of holding water and soil, allowing the plants to develop in controlled conditions throughout their early growth stages. However, these polybags are made from petroleum-based plastic, which contributes to environmental pollution and may expand the issue of plastic waste if the polybags are not disposed of properly. In some cases, despite the fact that polybags are made to reduce transplant shock, improper handling or cutting of the bag during the transplant process can still harm the roots and put the plant under stress. In addition, the process transplant can be a labor-intensive process, particularly in large scale business. Therefore, the usage of biodegradable plastic instead of petroleum-based polybag as seedling bag's material may promote environmental sustainability and reduce time requirements and personnel expenses during the transplant process.

In this study, we used a combination of short fiber of SBF and long fiber of CLSF as the reinforced materials in BSB, which is part of agricultural waste that will help creates a stable structure for the seedling bag and as a template to hold the slow-release of phosphate, increase the survival rate of seedlings, minimizing root damage, and eliminating the need to remove the pot. Water would be absorbed by BSB, causing natural degradation and slow-release of fertilizer without harming the environment. The fiber-reinforced BSB may withstand the watering phase and allow root penetration by the seedlings before planting into the ground [4].

Additionally, the usage of fertilizer is intended for increasing crop production but may be ineffective because seedlings absorption of nutrients may be slow. The rapid loss of the fertilizer to the environment may be due to its high quantity and low rates of utilization by the plants [2]. These excessive or improper applications of traditional fertilizer can lead to the accumulation of toxic substances in the soil. This will lead the nutrient run-off into nearby water bodies, causing eutrophication. This process can impact the local biodiversity by altering the nutrient balance in nearby ecosystems. Inefficiency of traditional fertilizer not only wastes resources but also exacerbates environmental pollution after the transplant process of seedlings to ground. In order to address these limitations, biodegradable materials are used in composite to accelerate the rate of biodegradation, but excessive degradation may adversely impact the seedlings due to the loss of support structure. There is limited report on the development of bioplastic seedling bag or plant container utilizing agricultural waste, such as coconut leaf sheath fiber (CLSF) and sugarcane bagasse fiber (SBF) combined with starch-based slow-release fertilizer. Therefore, this study emphasizes the medium degradation rate and slow-release nutrient functions of the seedling bag to further benefit the seedling during the early development.

EXPERIMENTAL

Preparation of CLSF and SBF

CLSF and BSF wastes were cleaned from any dirt and moisture by carefully rinsing with tap water before being placed in a high-temperature oven at 100 °C for 24 h to stop the growth of fungus. The alkali treatment was performed using 5% concentration of sodium hydroxide (NaOH). Both fibers were soaked in NaOH solution for 8 h at room temperature. Next, the fibers were rinsed with distilled water to remove the excess NaOH solution. Then, the fibers were dried in a high-temperature oven at 100 °C for 24 h to ensure complete removal of moisture from the fibers, preventing mold and mildew growth in the fibers and ensuring consistency and stability of the fibers by having uniform controlled drying process. CLSF was used in the form of long fiber, and SBF was used in the form of short fiber. Therefore, SBF was crushed using a mill pulverizer to obtain short fiber with a length of less than 1 mm. Lastly, SBF was washed with distilled water and dried in the oven at 100 °C for 2 h. Next, SBF and CLSF were weighed according to various compositions of BSB (Table 1). Meanwhile, CLSF was compressed using a cold compression molding press machine at 100 °C and 200 kg/cm^2 for 10 min.

Preparation of Slow-Release Fertilizer (SRF)

SRF is a combination of water, glycerol, vinegar, cassava starch and fertilizer. Firstly, the SRF was prepared by mixing an aqueous glycerol solution (made of 180 ml of water and 45 ml of glycerol) with cassava starch and vinegar at 100 ºC and 1500 rpm using a magnetic stirrer for 45 min until the mixture becomes gelatinized. Next, 10 grams of complehumus fertilizer (Zeenex Agroscience Sdn. Bhd.) is added to the cooled SRF and mixed well at 100 ºC and 1500 rpm for 25 min until has a consistent colloid-like mixture before being weighted according to total SRF amount of the BSB's composition. Finally, the SBF with various weights (10, 20, and 30 grams) were added into the SRF mixture and mixed well at 100 ºC and 1500 rpm for 25 min before it is cooled for 30 min at room temperature. The hand lay-up process created the seeding bag composite. The details of each material used are shown in Table 1.

Preparation of Biodegradable Seedling Bag (BSB) Composite

The BSB composite was prepared using the hand lay-up method in the fabricated mild steel mold (160 × 160 × 3) mm. First, the compressed CLSF was lay-up evenly in the mold before the mixture of SRF was spread evenly on top of the CLSF surface. Next, the layered SRF on top of CLSF was dried in oven at 100 ºC for 30 min. The layering of SRF mixture process was repeated on the other side of CLSF's surface. Next, the composite sample was dried in oven at 120 ºC for another 2 h. Finally, the composite sample was compressed using the cold compression molding press machine for 5 min to ensure the thickness consistency at 3 mm in accordance with ASTM D638 [5]. It was left to rest for 24 h before being sliced with a heavy-duty cutter according to sample size for each characterization procedure.

Water Contact Angle

The wettability and hydrophobicity of BSB were determined using water contact angle in accordance with ASTM D5946 [6]. The water contact angle of BSB sample sized (20 × 20) mm was measured using the Image Analysis Workstation and VCA-3000S TM platform. The BSB composite sample was placed on a contact angle goniometer stage before a water droplet from a syringe containing ±5.0 µL of distilled water was dropped on top of the BSB surface in ambient conditions. The measurement of five different spots on the BSB surface was carried out to determine the average value of the water contact angle for each composition.

Water Absorption and Thickness Swelling

Water absorption for BSB was determined according to ASTM D570 [7]. The BSB composite sample with a dimension of (76.2 × 25.4 × 3) mm was oven-dried at 50°C for 24 h and cooled to room temperature before the dry weight of the film is weighed. Next, the dried BSB was placed in a closed container for immersion in distilled water for 120 min.

At each interval of 15 min, the BSB film is taken out, dried with a cloth, the weight is recorded, and it is then put back into the water. After 120 min, the same procedures were repeated, and the weight was measured once more. Subtracting the weight gain post-immersion from the percentage of water absorption obtained from Equation (1) yields the amount of water absorbed. Meanwhile, the thickness swelling was determined using Equation (2).

$$\text{Water absorption (\%)} = \frac{W_{A1} - W_{A0}}{W_{A0}} \times 100 \quad (1)$$

where W_{A0} is the BSB's initial dry weight and W_{A1} is the bag's weight after soaking in distilled water for 2 h with intervals of every 15 min. Next, equation (2) below is used to calculate thickness swelling,

$$\text{Thickness swelling (\%)} = \frac{T_1 - T_0}{T_0} \times 100 \quad (2)$$

where T_0 represents the biodegradable seedling pot's initial thickness and T_1 represents the thickness of the bag after 2 h with 15 min intervals in distilled water.

Soil Burial Test

Excellent BSB should allow root growth by deteriorating the walls over time in order to aid the plant seedlings in growing well after transplanting in soil. The BSB biodegradation was evaluated using a solid burial test method. The BSB sample (20 × 20) mm was buried in the soil at 6 cm depth for 7, 14, and 21 days. The sample was then weighed before being buried in the ground. At each interval time frame (7, 14 and 21 days), each sample was retrieved, cleaned, and dried at room temperature before being weighted. The BSB weight before and after soil degradation test were recorded accordingly, and the data were used to determine the weight loss percentage as shown in Equation (3),

$$\text{Weight loss (\%)} = \frac{W_1 - W_0}{W_0} \times 100 \quad (3)$$

Table 1. Composition of materials in biodegradable seedling bag (BSB)

BSB composition (CLSF: SBF:SRF)	CLSF (g)	SBF (g)	Starch (g)	Water (ml)	Glycerol (ml)	Vinegar (ml)	Fertilizer (g)	Total SRF (g)
1:1:18	10	10	45	180	45	45	10	180
2:2:16	20	20	45	180	45	45	10	160
3:3:14	30	30	45	180	45	45	10	140

where W_0 represents the BSB's initial dry weight before being buried in the ground and W_1 represents the weight of the biodegradable seedling bag after completing their period of burial.

UV–Vis Spectroscopy

Spectrophotometer (PerkinElmer's, LAMBDA 750 UV/Vis/NIR) was used for the UV-Vis spectroscopy to determine the amount and presence of phosphate that the SRF released after being buried for 7, 14, and 21 days in the soil. The soils for each BSB composition were collected after 7, 14 and 21 days. Next, 180 μm sieve shaker was used to get fine fraction from the soil. Then, 5 g of fine soil was mixed with 33 ml distilled water in a centrifuge tube before putting it in a benchtop centrifuge machine. This procedure was done to separate the mixture's liquid and solid. After that, the mixture was then filtered using filter paper to remove the excess sediment. Lastly, the phosphate concentration in the filtered solution was analyzed by colorimetry using a UV-Vis spectrophotometer and the absorbance at 420 nm was recorded.

Fourier Transform Infrared (FTIR) Spectroscopy

The intermolecular bonding of BSB was evaluated using a Fourier transform infrared (FTIR) spectroscopy (Perkin Elmer's Spectrum 400 FTIR). All spectra were recorded based on an average of 16 scans, a wavenumber range of 4000—400 cm^{-1}, and a spectral resolution of 4 cm^{-1}.

Tensile Test

Tensile properties which are tensile strength, tensile modulus, and elongation were measured using an Instron Universal Testing Machine according to ASTM D638 [5]. The initial grip separation was set at 25 mm, and the crosshead speed was 2 $mm.min^{-1}$. The BSB sample (63.5 × 9.53 × 3.0) mm was cut into dumbbell shaped. Tensile and elongation tests were replicated five times on each variation of the BSB composition at 23±2 °C and 50±5% relative humidity.

RESULTS AND DISCUSSION

Reaction in SRF and BSB

During the synthesis process of SRF, all components (i.e., glycerol, vinegar, and starch) were dissolved in water. The CLSF and SBF remained insoluble and suspended in the soluble mixture. Cassava starch and glycerol were mixed with water to form a colloid substance that serves as a matrix and humectant, respectively. The presence of cassava starch and glycerol improved the consistency and flexibility of SRF, respectively. The soluble mixture in SRF may have been dehydrated during the drying process. The close arrangement of all soluble compounds allows the formation of hydrogen bonds between the hydroxyl, carboxyl, and phosphoryl groups, promoting the slow-release of the phosphate nutrient from the SRF. Lastly, the short fiber of SBF may have absorbed the phosphate nutrient-rich colloid and enhanced its ability to hold the nutrient as a physical barrier, further delaying the release of nutrient into the soil. Further dehydration during the mixing process thickens the SRF and SBF mixture to a consistency of a colloid substance before spreading it on the surfaces of CLSF.

Water Contact Angle

Figure 1 illustrates an upward trend of water contact angle of BSB. With water contact angles of less than 90º, all the BSBs exhibited hydrophilic characteristics except for the sample content ratio of CLSF:SBF:SRF (3:3:14) that has the lowest content of SRF mixture (which contains water, glycerol, vinegar, cassava starch and fertilizer) but has the highest content of BSF and CLSF. This may be due to the Cassie-Baxter state on the surface of the fibers that was treated with alkali before mixing with starch-based matrix (SRF). The alkali treatment commonly removes non-cellulosic components in fiber like hemicellulose and lignin, resulting the modification on the surface morphology and surface energy of the fibers. The surface roughness may increase, and surface irregularities can be removed during the alkali treatment, which promotes the interfacial adhesion between the cellulose and matrix, and further improving the barrier properties of BSB [8]. Meanwhile, the surface energy may have been increased by the exposure of the hydroxyl groups on cellulose and at the same time, the removal of non-cellulosic components may have decreased the surface energy. The balance between these effects may influence the wetting properties and provide the opportunities for the Cassie-Baxter state to occur from the repulsion of water from the surface of BSB. All these effects can increase the hydrophobicity and cause the BSB to have higher water contact angle.

The water contact angle of BSB was also influenced by the amount of SRF matrix. The decrease in the amount of SRF helped increase the hydrophobicity of the BSB. It was due to the inclusion of cassava starch, glycerol, and vinegar (acetic acid), which directly influence the hydrophilicity of the matrix. The cassava starch's amylose and amylopectin, which contains a lot of hydroxyl (–OH) groups, enabled the polar-polar interaction with water molecules. Furthermore, glycerol is hygroscopic, which easily binds or absorbs water molecules [9]. As a result, the lower content of cassava starch and glycerol in SRF increased the hydrophobicity and water contact angle of BSB. Meanwhile, vinegar can act as a cross-linking agent that helps enhanced intermolecular interactions and created a smoother surface, in which the cloud increased the water contact angle of BSB.

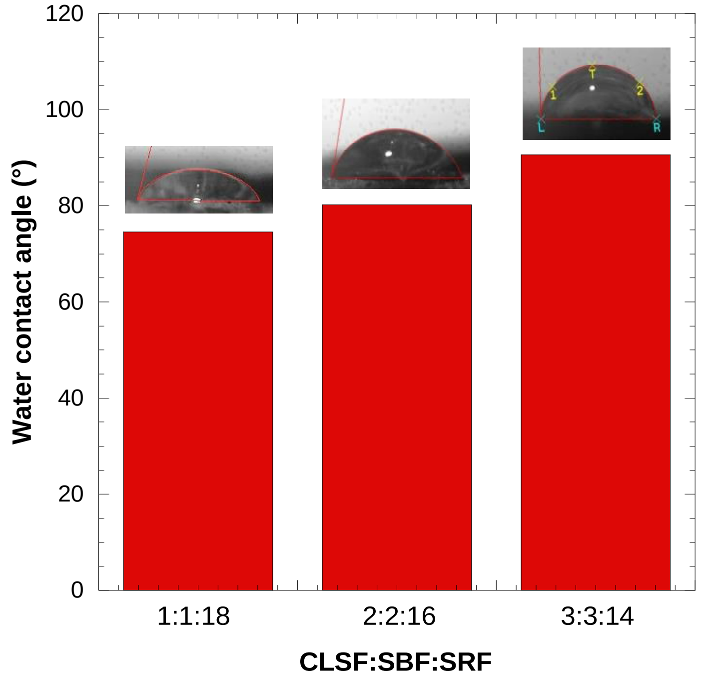

Figure 1. Water contact angle (°) of BSB with various composition ratio of CLSF:SBF:SRF

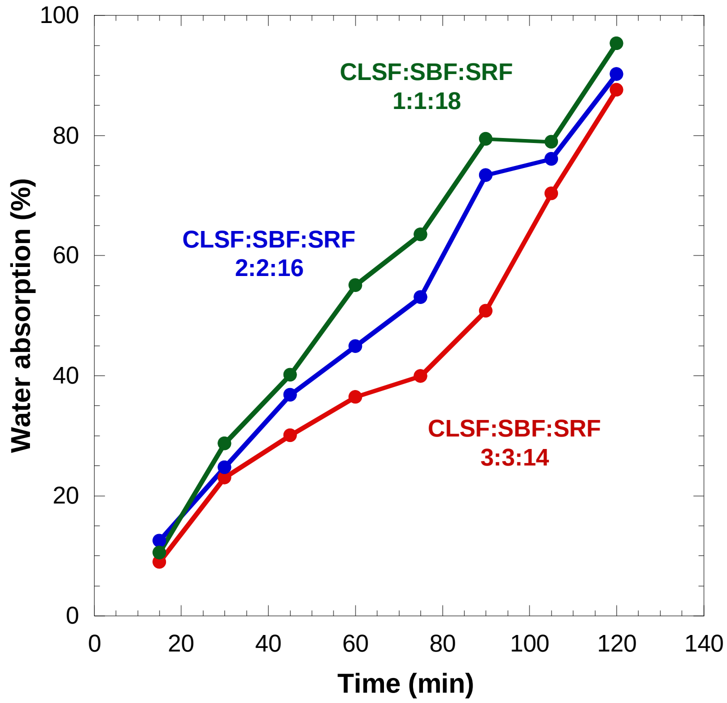

Figure 2. Water absorption (%) of BSB with various composition ratio of CLSF:SBF:SRF as a function of time (min)

Water Absorption and Thickness Swelling

Generally, adding chemicals or employing chemically modified starch in biocomposite can reduce water absorption significantly. Figures 2 and 3 show the water absorption and thickness swelling of BSB immersed in distilled water for 120 min, respectively. The water absorption percentages and thickness swelling of all BSBs increase dramatically with immersion time. However, increasing fiber (SBF and CLSF) content in BSBs leads to a decrease in water absorption and thickness swelling. This was due to the decreased proportion of the starch-matrix relative to fiber. Since the higher fiber content in the matrix, the lower water absorption, and swelling tendencies occur due to the decrease of water interaction behavior of cellulose within SRF matrix [10].

The incorporation of a higher fiber content in SRF matrix can enhance the interfacial bonding between the fiber and the matrix. Improvement of the interfacial bonding reduced the pathways for water molecules to diffuse into the matrix, resulting in decreased water absorption and thickness swelling. Higher content of fiber also enhanced the structural integrity of BSB, which reduced the tendency of the BSB to swell when exposed to water.

For all BSB compositions, water absorption and thickness swelling generally increase with immersion time. The inclusion of glycerol and cassava starch can increase thickness swelling and water absorption over time. Cassava starch is initially very hydrophilic due to its numerous hydroxyl (−OH) for binding with water molecules. The starch may continue to hydrate and gelatinize which further contributes to water absorption and thickness swelling.

On the other hand, glycerol naturally has the capacity to absorb water and retain moisture from the surrounding environment by forming hydrogen bonds with water molecules. This effectively reduces the availability of water absorption by the matrix and minimizes the thickness swelling. Moreover, glycerol also acts as a plasticizer in the SRF matrix and improved the BSB's flexibility by reducing its crystallinity. This plasticizing effect has made the BSB matrix denser and less permeable to water molecules. However, in course of time, this plasticizing effect can have the reverse effect. When further exposed to water, this may cause the BSB to swell, which allows rapid diffusion of water molecules that leads to increased water absorption and thickness swelling.

Biodegradability

Figure 4 shows the weight loss evolution of BSB within 21 days. Generally, incorporating fiber dispersed within the biocomposite can be favorable in many aspects. Fiber that has undergone chemical treatment can impart chemical resistance to microbial degradation. The higher content of fiber in biocomposite, the greater fiber can provide chemical stability and lessen the rate of deterioration, which will result in a reduced weight loss in the soil-buried test. Furthermore, chemical modified fiber improves the structural integrity of the biocomposite by creating the physical barrier within the BSB matrix. This barrier may prevent soil microorganisms and enzymes from accessing the bioplastic substance, slowing down the degradation and eventually limiting weight loss of BSB.

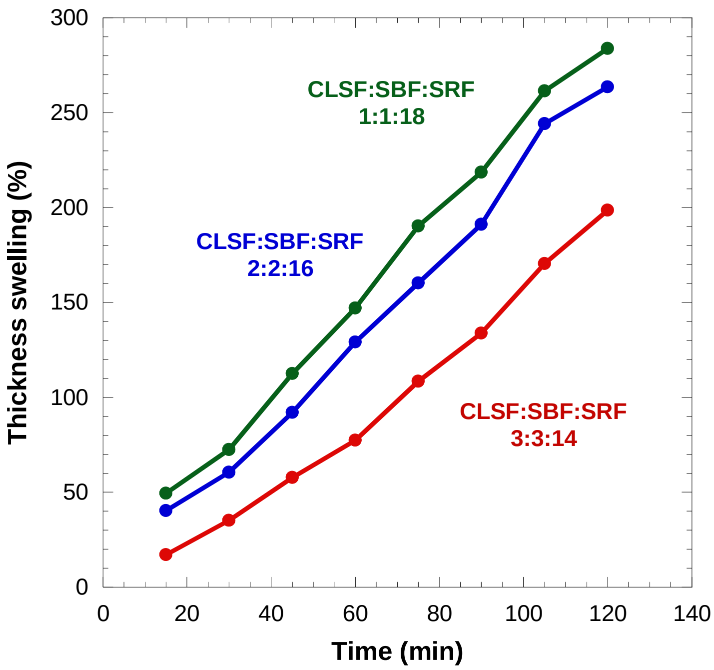

Figure 3. Thickness swelling (%) of BSB with various composition ratio of CLSF:SBF:SRF as a function of time (min)

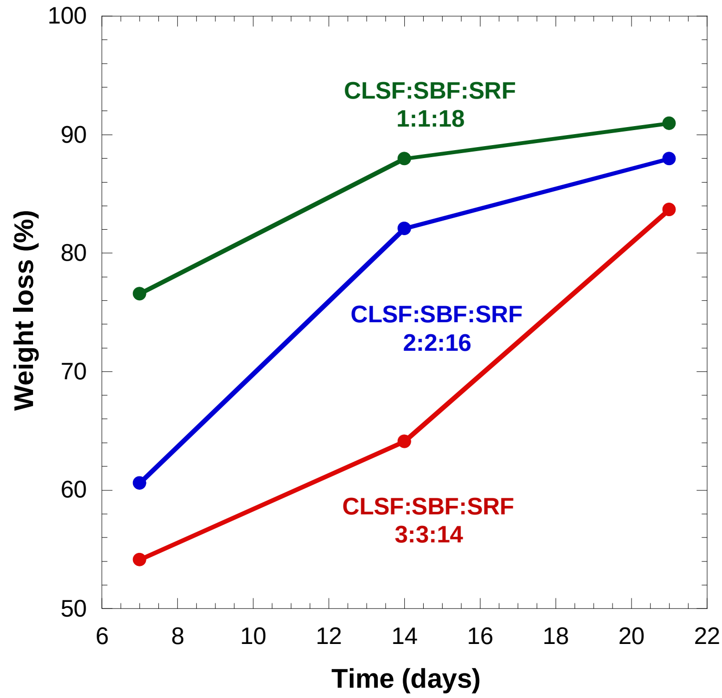

Figure 4. Weight loss (%) of BSB with various composition ratio of CLSF:SBF:SRF as a function of decomposition time (days)

On the contrary, weight loss increased over time due to inclusion of starch, glycerol, and vinegar in the SRF matrix. Starch-rich matrix can accelerate decomposition of biocomposite by microbial enzymes due to its long chain of carbohydrate molecules that serves as a carbon source for soil microorganisms [11]. At the same time, moisture content can be absorbed from the soil environment and accelerates the microbial activity. Glycerol and vinegar (acetic acid) aid in promoting microbial colonization and enzymatic degradation by lowering the pH to create the acidic condition and further contribute to weight loss of biocomposite. This is clearly shown in physical observation during the recovery of the BSB samples, which shows that the matrix decayed before the fibers. The decayed starch matrix in SRF appeares mushy or gelatinous, which feels damp or wet to touch and produces unpleasant odor. As the starch matrix breaks down, the structural integrity of the SRF matrix is compromised which causes it to lose its original shape and form. Meanwhile, the embedded SBF in SRF becomes more exposed but CLSF fiber retains their structure and firmness compared to decayed starch. Only the highest content of fiber is able to maintain it structural integrity (sample's shape) up to 21 days, while the other composition's structure disappeares.

UV–Vis Spectroscopy

UV-Vis spectrophotometer is used to verify the release of phosphate in soil. Figure 5 shows the phosphate release of BSB with different composition ratio of CLSF:SBF:SRF. The peak at 420 nm is recorded because this peak refers to phosphate peak. The results prove that the incorporation of higher content of fiber (SBF and CLSF) in the biocomposite is better in holding and slow releasing the phosphate inside the fertilizer into the soil compared to the other composition. The fiber increases the surface area and porosity of the biocomposite, which provides physical protection to the nutrient from rapid leaching into the soil by encapsulating the nutrient within the biocomposite matrix. This will prevent premature release and ensure sustained nutrient release over time. Besides that, the capability of fiber to retain moisture within the biocomposite matrix will provide a favourable condition for microbial activity, which enhances the solubility, dispersion, and sustained nutrient release over time. The starch molecule may be decomposed by microbes and weakens the physical integrity of the encapsulated phosphate, allowing more water absorption and the release of phosphate via the water leaching process.

In addition, the inclusion of starch, glycerol, and vinegar (acetic acid) in SRF matrix provides a chemical structural framework that may have encapsulated the phosphate ion to effectively restricts the movement of nutrient and leads to a controlled and slow-release of nutrient. Apart from that, when the SRF matrix comes to contact with soil moisture, the matrix absorbed the water and swelled as it became a hydrated matrix. This hydrated matrix acts as a barrier that prevented the rapid diffusion of the nutrient and thus slowing the release of the nutrient into the soil. However, to a certain extent, the amount of starch, glycerol, and vinegar in SRF matrix can have the reverse effect, leading to rapid hydration and excessive swelling of the matrix. This effect can initiate the biocomposite matrix to disintegrate and facilitate rapid dissolution and release of nutrients into the soil.

Fourier Transform Infrared (FTIR) Spectroscopy

Figure 6 shows the FTIR spectrum of BSB that contains cassava starch, glycerol, vinegar, fertilizer, SBF and CLSF. The FTIR spectrum revealed the presence of a clear transmittance band attributed to various functional groups of BSB. Vibrational bands that correlate to cassava starch, phosphate nutrient (fertilizer) and fibers were observed. The presence of vibrational bands of cassava starch at 3264, 2929, and 1636 cm^{-1} were attributed to O−H stretching, C−H stretching and O−H bending, respectively [9, 12, 13]. These strong and broad bands of O−H stretching vibration refers to hydroxyl groups and bound water in the cassava starch and in the hydrated phosphate. The higher of SBF content in BSB, the higher intensity of O−H vibration peak at 1636 cm^{-1}. It is associated with an increase in hydrogen bonds between the SBF with the water molecules or −OH group in the SRF matrix. In addition, a band at 2929 cm^{-1} corresponds to the asymmetric stretching vibration of the aliphatic C−H group (CH_2). Meanwhile, the vibration bands of fiber located at 1534 and 1443 cm^{-1} were associated with the C=C and CH_2 symmetric scissoring, respectively [9, 14]. Lastly, the vibration bands in the range of 1400−800 cm^{-1} originated from the P−O stretching vibration [12, 15]. The band at 1032 cm^{-1} and a shoulder at 1060 cm^{-1} were associated to the stretching of P−O vibrations. However, it can be observed that the bands were located at slightly lower wavenumber values. Besides that, the intensity of P−O vibration band at 1032 cm^{-1} decreased with the decrease of SRF content in BSB. This can be concluded that the amount of phosphate in the BSB was influenced by the amount of SRF because the phosphate tends to bind with the starch-based matrix compared to fiber.

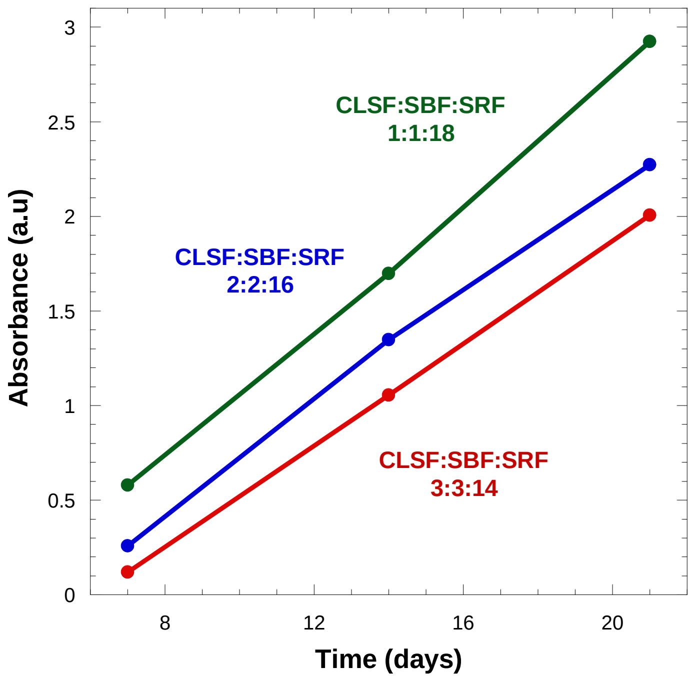

Figure 5. Phosphate release of BSB with various composition ratio of CLSF:SBF:SRF

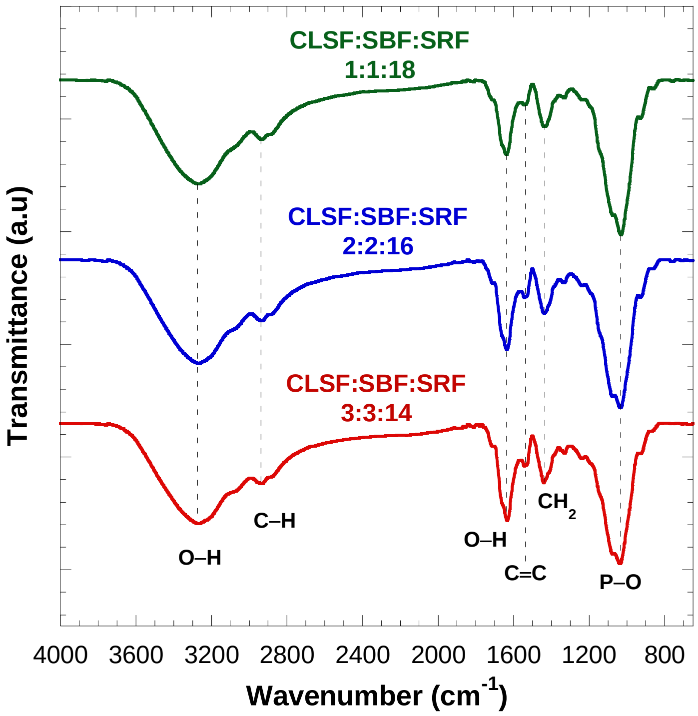

Figure 6. FTIR spectra of BSB with various composition ratio of CLSF:SBF:SRF

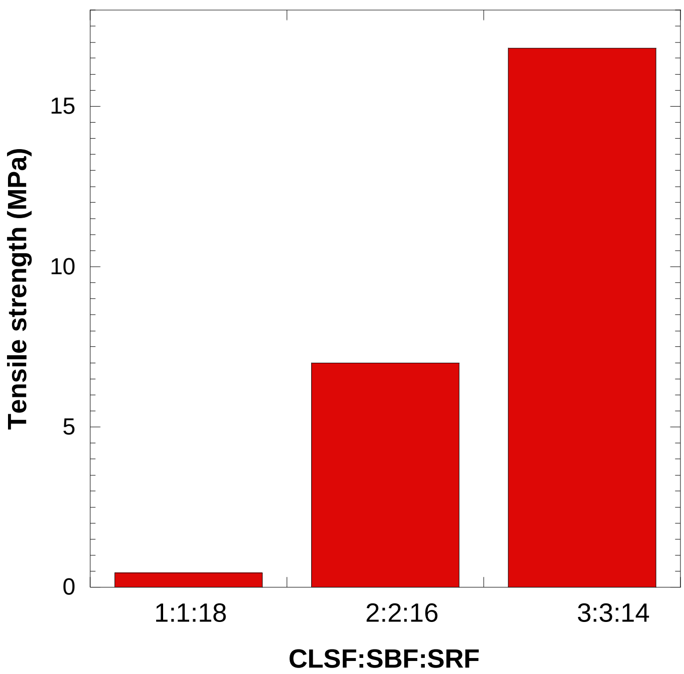

Figure 7. Tensile strength (MPa) of BSB with various composition ratio of CLSF:SBF:SRF

Tensile Properties

The tensile strength, tensile modulus, and elongation at break of BSB are shown in Figures 7, 8 and 9, respectively. The tensile strength and tensile modulus of BSB increased with the increase of fibers (CLSF and SBF) content in BSB. It was due to the alkali treatment that induced structural changes in fibers by removing non-cellulosic such as lignin, hemicellulose, pectin, and waxes. These non-cellulosic components were flaw points in the fiber structure, which can decrease the ability to evenly distribute load within the biocomposite under tensile stress. Thus, by removing these components from fibers, it may increase the load-bearing capacity by enhancing the stress transfer from the matrix to the reinforcing fibers. This may lead to a higher tensile strength and tensile modulus but may decrease in elongation at break.

In addition, the alkali treatment can increase the crystallinity of the fibers, restricting the movement of polymer chains during deformation. These effects made the biocomposite become stiffer and enhanced its resistance to deformation and elongation under tensile load. Thus, this increased the tensile strength and tensile modulus but decreased the elongation at break.

Moreover, the treated fiber may also benefited from having a rougher and textured surface. Hydroxyl groups may have been induced on the fiber surface, creating a stronger hydrogen bond with the matrix. This effect may have increased the surface area and enhanced the adhesion between the fiber and biocomposite matrix. Greater adhesion between the fiber and matrix led to greater uniform load distribution and prevented fiber pull out and debonding during loading, resulting in improved tensile strength and tensile modulus but decreased the elongation at break.

Additionally, starch, vinegar and glycerol also influenced the mechanical properties. Starch molecules provide the hydrogen bonds with fiber and with the other components in biocomposite matrix. These hydrogen bonds contributed to the cohesion and integrity of the matrix and led to better mechanical properties such as tensile strength and tensile modulus but decrease the elongation at break. Meanwhile, vinegar or acetic can enhance the intermolecular interactions between the biocomposite chains. This can increase the interfacial adhesion and dispersion of other components in the matrix and improves tensile strength and tensile modulus. Furthermore, the inclusion of glycerol in the formulation can improve the biocomposite's flexibility and toughness. It is because glycerol acts as a plasticizer and enhanced the mobility of biocomposite chains, reduced brittleness, and prevented crack propagation. This can lead to an increase in the tensile strength and tensile modulus. However, excessive content of starch, vinegar and glycerol can weaken the intermolecular interactions, reduce chain entanglements, and lead to a decrease in elongation at break. Overall, the right ratios for each component in BSB will significantly influence the mechanical properties of BSB.

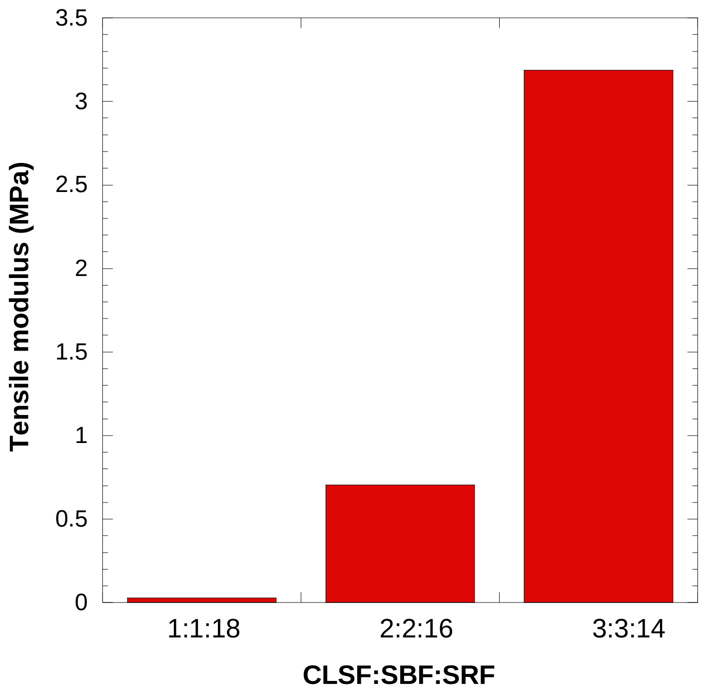

Figure 8. Tensile modulus (MPa) of BSB with various composition ratio of CLSF:SBF:SRF

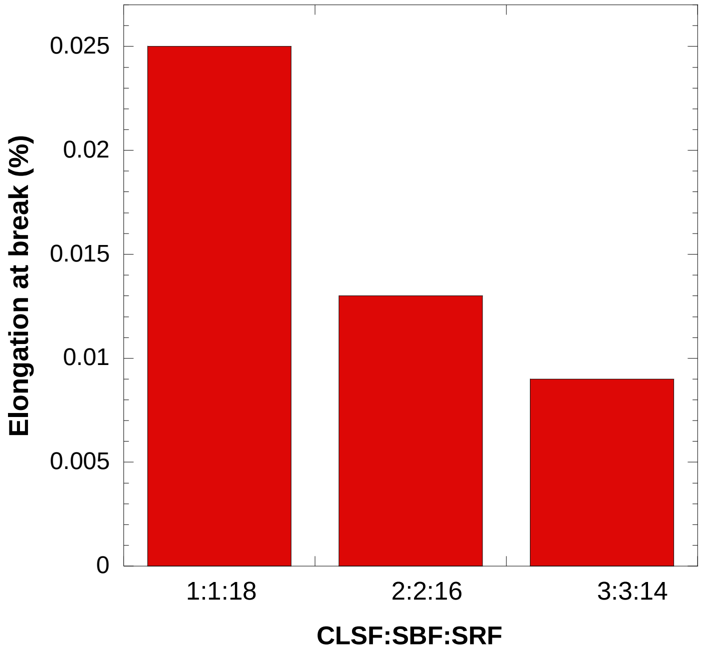

Figure 9. Elongation at break (%) of BSB with various composition ratio of CLSF:SBF:SRF

CONCLUSION

The BSB has been successfully developed using short fiber of SBF, long fiber of CLSF, cassava starch, glycerol, and vinegar. Content of fibers (CLSF and SBF) in the BSB showed significantly different physico-mechanical, wettability, water absorption, biodegradability, and phosphate release properties between various biocomposite. The rise of fiber content resulted in significantly increased the water contact angle, tensile strength and tensile modulus but concurrently decreased the water absorption, biodegradability, phosphate slow-release, and elongation at break properties. It is worth noting the chemical reactions in SRF matrix and FTIR spectrums data reflected the results water contact angles, water absorption, phosphate slow-release and mechanical properties. The optimum BSB composition is the one with the highest amount of fibers, which are SBF and CLSF. This could retard the biodegradation of biocomposite better than formulation without the combination of short and long fiber in the biocomposite. Therefore, this research has demonstrated the ability of BSB in the agriculture practices and the same time, BSB can reduce seedling shock because of pot transferring, root growth, early shoot growth, speeds ground cover for erosion protection and improve seedling survival. Next, the research directions will focus on developing comprehensive methods and tests for measuring the plant growth and effectiveness of BSB with slow-release nutrients, ultimately leading to improved agricultural practices and enhanced crop yields. BSB will influence sustainable agriculture development that protects the environment while promoting a circular economy by reusing natural waste materials.

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