Cassava Starch-Based Biodegradable Foam Composited with Plant Fibers and Proteins

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Abstract: The development of starch foam trays has attracted an increasing amount of attention. However, starch foam trays exhibit poor physical and mechanical properties, and low water and oil resistance. This research aimed to improve the properties of baked composite cassava starch foam tray (CSF) by adding the leaf sheath of betel nut palm, coconut husk or kraft fibers, sunflower meal protein and gluten protein at concentrations of 0, 5 and 10%. All formulations of the CSF trays formed well-shaped trays. The addition of 10% kraft fiber and 10% gluten protein to the CSF trays exhibited the best properties for maximal flexural strength (4.8 MPa) and compressive strength (1.74 MPa). The water and oil absorptions of the trays were reduced by 43% and 72%, respectively. Moreover, composite CSF trays blended with 10% kraft fiber and 10% gluten protein were used as packaging for minimally processed durian (MPD) and kept at 4°C for 5 days. Results showed that compressive strength of the composite CSF slightly decreased from 1.74 to 1.51 MPa, while water and oil absorptions did not change during storage of MPD.

Keywords: Betel nut palm, Coconut husk, Gluten protein, Kraft fiber, Sunflower meal protein.

1. INTRODUCTION

The development of starch-based biodegradable packaging to replace expanded polystyrene foam (EPS foam) has attracted an increasing amount of attention due to its swelling properties, low cost, non-toxicity, renewability and biodegradability [1]. EPS foams may require several years to degrade and can cause serious environmental pollution [2]. Therefore, consumers are increasingly interested in environmentally friendly packaging, and for this reason, starch foam packaging is a great alternative to EPS foam. Starch foam trays are typically produced by a process consisting of swelling, gelatinization, and dehydration [3]. Shogren *et al.* [4] showed that shaped starch foams could be produced by baking starch/water batters in heated, closed molds. The foaming process of the starch batter in a hot baking mold can be divided into several steps. First, water is used to plasticize the starch to make it soft and rubbery. Next, the high temperature causes rapid evaporation of the water. Finally, the steam generated from the water of the starch batter acts as the blowing agent to create foam inside the mold, resulting in the expanded structure of starch foam. Unfortunately, starch-based foams tend to exhibit certain performance limitations, including poor mechanical properties and sensitivity to water [4]. To overcome these disadvantages, the use of composites from agricultural materials can aid in the development of low-cost products with better performance [3]. Interestingly, inexpensive materials derived from plant proteins and fibers might be potential additives that can improve cassava starch foam trays. Plant proteins have the ability to interact with neighboring molecules to form strong cohesive and visco-elastic foams [5]. Sunflower meal and gluten protein are by-product form oil industry. Globulins (60%) constitute the majority of sunflower meal protein, while glutenins (47%) and gliadins (34%) are the main groups of gluten proteins. Gliadin is a single-chain peptide containing intramolecular disulfide bonds that play a role in film formation, strength and elasticity [6]. Fiber is used as a material in the manufacture of low-cost packaging for its improved mechanical resistance to tearing and tension forces [7]. In our previous studies, cassava starch foam trays blended with kraft fiber, chitosan, plant proteins, or palm oil were monitored [8,9]. Although the strength of cassava starch foam was increased by adding kraft fiber or plant proteins, its water absorption and water solubility properties need to be improved. One interesting point of the combination of cassava starch with fibers and proteins might aid in the modification and enhance performance of starch foam trays. Thus, the goal of the present work was to investigate the physical and mechanical property improvements exerted by incorporating three types of fibers (leaf sheath of betel nut palm, coconut husk and kraft fiber), two proteins (sunflower meal protein and gluten protein) and composite cassava starch foam (CSF) trays blended with fiber and protein for

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packaging low moist food (minimally processed durian, MPD).

2. MATERIALS AND METHODS

2.1. Materials

Cassava starch was obtained from Ocean Foods Co., Ltd. (Thailand). Kraft fiber from eucalyptus (length (l) = 13.5 mm and diameter (d) = 0.1 mm) was kindly provided by the Thai Kraft Paper Co., Ltd. (Thailand). Fiber from the leaf sheath of betel nut palm (l = 7.8 mm and d = 0.1 mm) and coconut husk (l = 15.5 mm and d = 4.5 mm) was prepared in the Phytobioactive and Flavor Laboratory, King Mongkut's University of Technology Thonburi, Bangkok, Thailand. Sunflower meal protein was generously provided by Flower Food Products Co., Ltd. (Thailand). Gluten protein and sodium chloride (NaCl) were obtained from Sigma Chemical (Missouri, USA). Expanded polystyrene foam trays were obtained from J.T. Pack of Food Co., Ltd. (Thailand). Fresh cut durians were purchased from a local market in Thailand.

2.2. Starch Batter Preparation and Baking Process

The starch batter was prepared by adding 100 mL water to 80 g cassava starch. The leaf sheath of betel nut palm, coconut husk, kraft, sunflower meal protein and gluten protein (0, 5 and 10% by weight of starch) were mixed with 80% (w/v) cassava starch. The formulation was homogenized using a blender (8011BU, Waring, USA) at 18,000 rpm for 5 min. Eighty grams of starch batter with additive was poured into a hot baking mold with a size cavity measuring 180 mm in length, 105 mm width, and 10 mm in depth. The mold was heated and maintained at 200±5°C for 5 min. Before the properties of foam trays were investigated, they were equilibrated at a temperature of 25±2°C and a relative humidity of 75% using a saturated solution of NaCl in a polyethylene box for 1 week [10]. The properties of the cassava starch foam trays were measured and compared with commercial EPS foam trays.

2.3. Morphology by Scanning Electron Micrographs (SEM)

The cassava starch foam (CSF) was cut to a size of approximately 3 mm with a razor blade and mounted on SEM stubs using double-sided tape. The samples were coated with a thin layer of gold under vacuum for cross-sectional visualization. The morphology of the cassava starch foam was examined with a scanning electron microscope (SEM) (JOEL, JSM 5410LV, Japan) using an operating voltage of 15 kV.

2.4. Density

The density was determined by the sand displacement method described by Cinelli *et al.* [11]. Samples were weighed and placed in a 25-mL cylinder with a known volume of sand added to the cylinder. The total volumes of the foams and sand were recorded after tapping the graduated cylinder for 1 min. The foam density was calculated as the relationship between weight and volume according to Eq. (1).

$$\text{Density} = M/V \quad (1)$$

where M is the weight of the foam and V is total volume of the foam.

2.5. Flexural Strength

Flexural tests were performed to determine the mechanical properties of the foams using a textural analyzer (TA Plus, LLOYD Instruments, UK) with a 500-N load cell. To prepare samples for mechanical testing, the starch foams were cut to a size of 25 mm × 100 mm. The flexural tests were performed using three-point bending tests according to ASTM D790-10 [12] with a span setting of 50 mm and a crosshead speed of 2.5 mm/min. The foam specimens were deformed until the sample broke.

2.6. Compressive Strength

Compressive tests were performed using a textural analyzer (TA Plus, LLOYD Instruments, UK) with a 500-N load cell according to ASTM D1621-10 [13]. The starch foam tray was placed on a flat plate and compressed to 10% of its original diameter at a loading rate of 2.5 mm/min using a metal probe.

2.7. Water Absorption

Water absorption was measured using a modified method of Salgado *et al.* [14]. Samples were weighed and then soaked in distilled water at 4, 25 and 60°C for 30 min. After removing the excess water by centrifugation, the samples were reweighed. The quantity of absorbed water was calculated from the weight difference and expressed as the mass of absorbed water per mass of original sample according to Eq. (2).

$$\text{Water absorption} = [(W_2 - W_1)/W_1]\ 100 \quad (2)$$

where W_1 and W_2 are the weights of the foam before and after soaking in water, respectively.

2.8. Oil Absorption

The oil absorption of the starch foams was determined using a slightly modified version of the method described by Karnnet *et al.* [15]. Each sample was cut to a size of 100 mm × 100 mm and placed on a white paper. A tube 25 mm in diameter and more than 25 mm in height was placed over each sample, and then 5 g of sand was poured into the tube. Next, 1.1 mL of palm oil was added dropwise into the sand, and the tube was then covered with a glass lid. This test method was performed at 25–29°C and 75% relative humidity for 7 days. The oil absorption was calculated according to Eq. (3).

$$\text{Oil absorption} = (W_2 - W_1)/A \qquad (3)$$

where W_1 and W_2 are the weight of the foam before and after oil absorption, respectively, and A is the surface area of the foam.

2.9. Preliminary Test of Foam Trays for Packing Minimally Processed Durian

The best composite CSF tray (10% kraft fiber + 10% gluten protein) was preliminary tested as food packaging and it was compared with EPS foam trays. Minimally processed durian (MPD) pulps were packed in composite CSF trays and EPS foam trays. The foam trays contained MPD were stored at 4°C for 5 days. The appearance and compressive strength of the foam trays was evaluated before and after the storage condition.

2.10. Experimental Design

The chosen combinations of fibers and proteins to test between the CSF and composite CSF trays were designed as a Randomized Complete Block Design (RCBD). All experimental data were analyzed using SAS statistical software (SAS Institute, 1990). Duncan's Multiple Range Test (DMRT) ($p < 0.05$) was used to detect differences among the foam property mean values.

3. RESULTS AND DISCUSSION

3.1. The Effect of Fiber on the CSF Trays

Scanning electron micrographs of cross-sections of the CSF are shown in Figure **1**. CSF had a sandwich-type structure with dense outer skins of small cells composing the surface of the foam. Because the starch batter was in direct contact with the hot mold, rapid gelling and drying of the starch paste occurred and prevented extensive expansion, as previously shown by Salgado *et al.* [14]. The interior of the CSF contained large cells with thin walls due to the amount of water venting outside the mold and consequent cell rupture [16]. The SEM of the fiber-containing CSF showed that the fibers were trapped in gelatinized starch and became a part of the CSF cell wall (Figures **1b-g**). With the addition of fiber, it was observed that both the outer and inner skin of the starch foam had accumulated fiber, resulting in an increased viscosity and decreasing expandable structures. In this case, the increased viscosity of the batter prevented the steam from bubbling during the expansion while being baked.

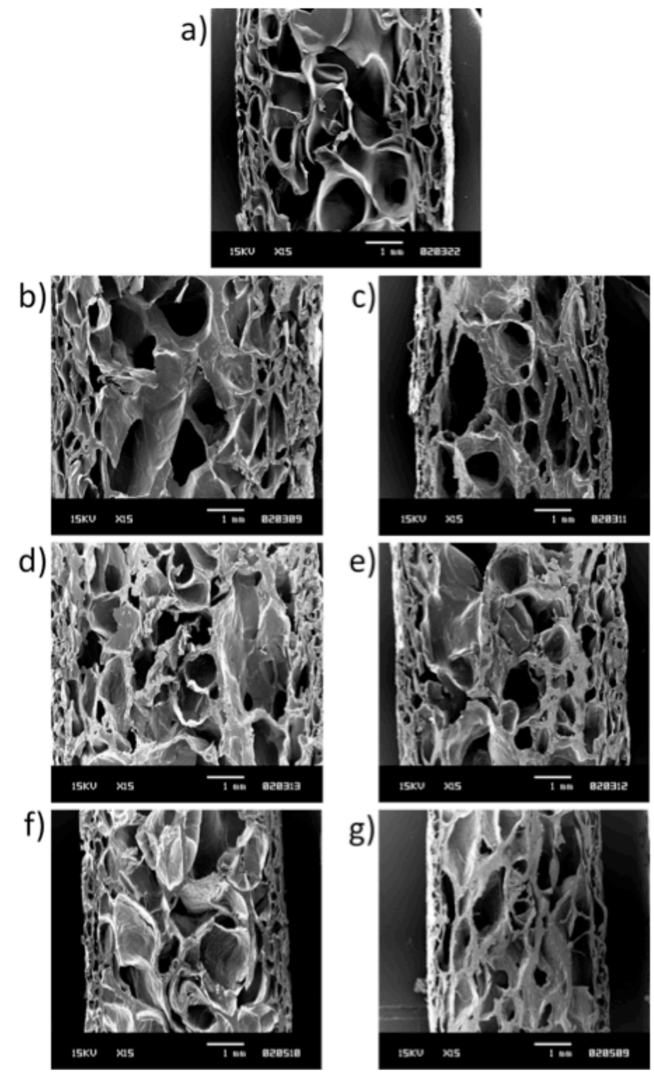

Figure 1: SEM micrographs of (**a**) cassava starch foam and cassava starch foam blend with (**b**) 5% leaf sheath of betel nut palm, (**c**) 10% leaf sheath of betel nut palm, (**d**) 5% coconut husk, (**e**) 10% coconut husk, (**f**) 5% kraft fiber and (**g**) 10% kraft fiber.

The density of the CSF (control) and the CSF blended with leaf sheath of betel nut palm, coconut husk or kraft fiber is presented in Table **1**. The foam density ranged from 0.18 to 0.36 g/cm^3. Notably, the addition of any fiber type caused the blended CSF to have a higher density than the control. These findings were similar to the data obtained by SEM (Figure **1**). The cell size for each cassava starch foam tray blended with the three fiber types was decreased with increasing fiber content. As a result of the small cell size, thick cell wall, high density and presence of reinforcing fibers, the fiber-reinforced CSF appeared to exhibit the most improvement in strength [10]. The CSF blended with the leaf sheath of betel nut palm showed a greater density than samples containing the coconut husk or kraft fibers. The changes in density might depend on the type, length and diameter of the fiber [17]. The addition of fibers with a high aspect ratio could be attributed to an increase in the viscosity of the starch batter, as a result of the fibrous network formation that increases its surface area [10].

The compressive strength of the CSF control and CSF blended with fiber conditioned at 75% RH before testing is shown in Table **1**. The compressive strength of the CSF foam was 1.15 MPa, which is lower than the strength of the CSF blended with all of the fibers. The addition of fiber had a significant reinforcement effect on the CSF due to the adhesion between the fiber and the starch matrix, resulting in the CSF blended with fiber exhibiting higher strength than the control [10]. The CSF blended with 10% kraft fiber showed much greater compressive strength than both the CSF blended with 10% leaf sheath of betel nut palm and 10% coconut husk. The higher degree of reinforcement observed for the CSF containing kraft fiber might be due to the length and diameter of this fiber [17]. The addition of a high aspect ratio (l/d) fiber could result in an increase in the viscosity of starch-based batters due to fibrous network formation [4].

To determine water absorption, the CSFs were submerged in distilled water for 30 min and the percentage of water absorbed was calculated and presented in Table **1**. The highest water absorption level was for the control CSF (448%), possibly due to the high number of hydroxyl groups that could strongly interact with the water molecules [18]. The CSF blended with leaf sheath of betel nut palm, coconut husk or kraft fiber exhibited less water absorption than the control CSF due to the bonding between amylose polymer chains and fiber, thereby preventing the water molecules from forming hydrogen bonds with the polymer chains [19]. When the fiber content of the CSF was increased, the water absorption decreased due to the lower hydrophilic character of fiber compared to starch.

3.2. The Effect of Protein on the CSF Trays

Figure **2** shows the scanning electron micrographs of cross-sections of the CSF control and the CSF blended with sunflower meal protein or gluten protein. The outer skin of the CSF blended with protein was dense, due to contact with the hot mold. The interior of the CSF blended with protein exhibited several cavities, likely caused by air bubbles. When the protein content was increased, the inner structure of the CSF blended with protein exhibited a more dense structure. This may be due to the increased viscosity of the batter preventing expansion while the hot mold is baking [14].

Table 1: Density, Compressive Strength, and Water Absorption of Cassava Starch Foam (CSF) Trays Blended with Natural Fibers

Type and amount of fiber	Density (g/cm^2)	Compressive strength (MPa)	Water absorption (%)
Cassava starch foam tray (CSF)	0.18 ± 0.01^{e}	1.15 ± 0.01^{d}	448.80 ± 14.84^{a}
CSF + 5% leaf sheath of betel nut palm	0.29 ± 0.01^{cb}	1.51 ± 0.09^{b}	423.67 ± 29.22^{ab}
CSF + 10% leaf sheath of betel nut palm	0.36 ± 0.02^{a}	1.50 ± 0.07^{b}	363.69 ± 26.13^{c}
CSF + 5% coconut husk	0.28 ± 0.01^{c}	1.42 ± 0.09^{bc}	420.31 ± 20.82^{ab}
CSF + 10% coconut husk	0.30 ± 0.02^{cb}	1.53 ± 0.09^{ab}	397.76 ± 33.20^{bc}
CSF + 5% kraft	0.23 ± 0.01^{d}	1.28 ± 0.05^{cd}	380.09 ± 13.10^{c}
CSF + 10% kraft	0.30 ± 0.01^{b}	1.61 ± 0.04^{a}	361.04 ± 5.02^{c}
F-test	**	**	**
C.V. (%)	4.90	6.16	5.59
LSD	0.02	0.16	39.12

Average ± standard deviation.
^{a,b,c}Different superscripts in the same column indicated that means were significantly different.

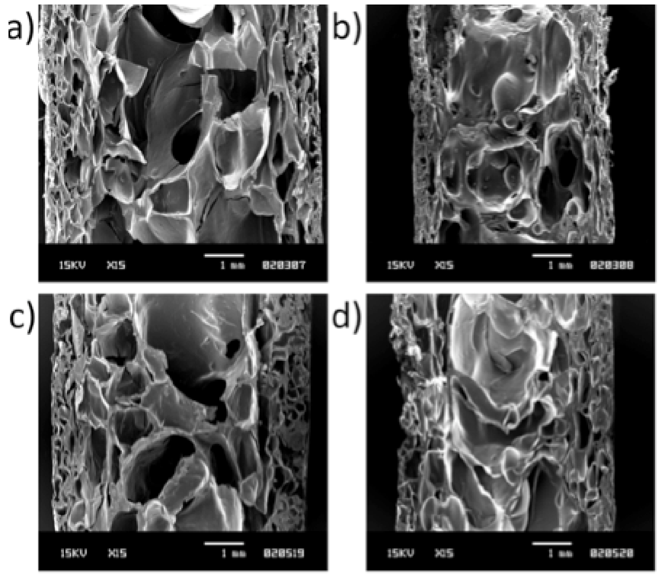

Figure 2: SEM micrographs of cassava starch foam blend with (**a**) 5% sunflower protein, (**b**) 10% sunflower protein, (**c**) 5% gluten protein and (**d**) 10% gluten protein.

The densities of the CSF blended with sunflower meal protein or gluten protein are presented in Table **2**. Overall, the foam density increased with increasing protein content. The density of the CSF blended with 5-10% proteins was approximately 0.27–0.31 g/cm^3, which is a higher density than the control (0.18 g/cm^3). This was likely due to the increased viscosity and resistance of the protein during expansion, leading to difficulty in swelling during foam formation and resulting in a density that is higher than CSF alone [14, 20]. The addition of 10% gluten protein into CSF resulted in a highest density (0.31 g/cm^3). This finding was in agreement with data obtained from SEM, which showed that a high protein content yielded less expansion of the CSF. However, the compressive strength of the CSF blended with sunflower meal protein and gluten protein was slightly decreased from 1.15 (control) to 1.07-1.09 MPa and 0.88-1.14 MPa, respectively. The reason for the lower compressive strength might be the reduction of internal hydrogen bonding between the polymer chains, resulting in increased molecular space [21, 22].

The water absorptions of the CSF control and CSF blended with sunflower meal protein or gluten protein are presented in Table **2**. The addition of 10% gluten protein to the trays made of CSF led to a reduction in water absorption from 448% to 364%. Our findings agree with Salgado *et al.* [14], who found that the water absorption and water content of cassava starch trays decreased with the addition of proteins. The lowest water absorption was observed in the CSF blended with 10% gluten protein (364%). The reason for the lower water absorption was due to the formation of intermolecular bonds between glutenin and gliadin in the gluten protein, which could not be solubilized in water [6].

3.3. Composite CSF Blended with Kraft Fiber and Gluten Protein Characteristics

The results demonstrate that the water absorption of CSF was improved by adding kraft fiber and gluten protein. The addition of kraft fiber could improve the compressive strength, which conferred higher compressive strength than the leaf sheath of betel nut palm and coconut husk. The SEM micrographs also confirmed that there was good adhesion between the starch matrix and the kraft fibers. Therefore, the composite CSF blended with kraft fiber (5 and 10%) and gluten protein (5 and 10%) was selected for subsequent composite CSF tray analysis.

Table 2: Density, Compressive Strength, and Water Absorption of Cassava Starch Foam (CSF) Trays Blended with Plant Proteins

Type and amount of protein	Density (g/cm^2)	Compressive strength (MPa)	Water absorption (%)
Cassava starch foam tray (CSF)	0.18 ± 0.01^c	1.15 ± 0.01^a	448.80 ± 14.84^a
CSF + 5% sunflower meal protein	0.27 ± 0.02^b	1.07 ± 0.06^a	424.28 ± 15.38^{ab}
CSF + 10% sunflower meal protein	0.30 ± 0.01^a	1.09 ± 0.01^a	397.36 ± 7.01^b
CSF + 5% gluten protein	0.29 ± 0.01^a	0.88± 0.07^b	427.28 ± 19.21^{ab}
CSF + 10% gluten protein	0.31 ± 0.01^a	1.14 ± 0.05^a	364.36 ± 14.29^c
F-test	**	**	**
C.V. (%)	5.07	6.78	4.03
LSD	0.03	0.13	30.20

Average ± standard deviation.
^{a,b,c}Different superscripts in the same column indicated that means were significantly different.

3.3.1. The Appearance and Morphology of Composite CSF Trays

The appearance and SEM micrographs of the CSF blended with kraft fiber and gluten protein are shown in Figure **3**. When cassava starch was blended with gluten protein and kraft fiber, the composite CSF had an irregular structure with a smaller cell size compared with the control CSF. This observation might be because the gluten and fiber in the starch batter increased the overall sample viscosity, causing the batter to be less expandable and giving rise to smaller cell sizes and thicker cell walls [10, 14]. Although the baking time employed was set at 5 min, the baking time required for the gluten protein and kraft fiber blended with CSF slightly increased due to the high water holding capacity of the fiber [3]. All of the foam trays made in this study formed well-shaped trays that lacked evident cracks (Figure **3**). The color appearance of the CSF containing kraft fiber and gluten protein was light brown due to the original color of the protein and the high temperature. These findings are in agreement with Salgado *et al.* [14], who reported that the CSF trays containing proteins presented a yellow color when pressed at temperatures between 180 and 200°C.

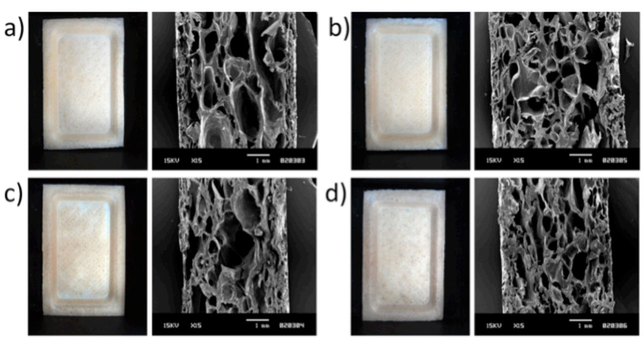

Figure 3: The appearance and SEM micrographs of cassava starch foam trays blended with (**a**) 5% kraft fiber and 5% gluten protein, (**b**) 10% kraft and 5% gluten protein, (**c**) 5% kraft fiber and 10% gluten protein and (**d**) 10% kraft and 10% gluten protein.

3.3.2. Density

The effect of adding kraft fiber and gluten protein on the density of the composite CSF trays was studied by the sand displacement method. The density of the composite CSF trays ranged from 0.183 to 0.429 g/cm^3. The kraft fiber and gluten protein content significantly increased the CSF density ($p < 0.05$). Figure **4** shows that the mixture of kraft fiber and gluten protein to the formulation foam led to an increase in density compared with the control CSF. This was probably due to the higher amount of kraft fiber and gluten protein content, which increase the viscosity of the CSF trays [5, 23]. The gluten protein content had a greater effect on the density than the kraft fiber content. Although a high gluten protein content might obstruct foam expansion, a high fiber content might act as a nucleating agent, effectively increasing the viscosity of the starch foam [17]. Although the density of the CSF blended with kraft fiber and gluten protein was high, the density value observed in this study was lower than the CSF blended with cellulose pulp and plant proteins, which had a density of 0.46 to 0.52 g/cm^3 [14]. Nevertheless, the density of the CSF blended with kraft fiber and gluten protein was higher than the density of the EPS foam (0.03 g/cm^3).

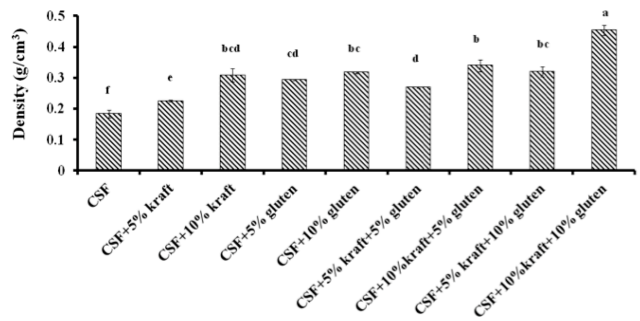

Figure 4: Density of composite cassava starch foam (CSF) trays blended with kraft fiber and gluten protein.

3.3.3. Flexural Strength

The flexural strength, as measured with the three-point bending test, was significantly affected by the kraft fiber and gluten protein content ($p < 0.05$) (Figure **5**). Gluten protein addition to the CSF increased the flexural strength because the protein matrix was affected by heat, which causes proteins to unfold, hydrogen bonds to weaken, and general rearrangement of the proteins that form the starch matrix. These changes could increase the strength and elasticity of the resulting matrix [6]. When the kraft fiber was added to CSF, the flexural strength was increased because the fibers adhered to and reinforced the starch matrix. This finding is consistent with the results of Soykeabkaew *et al.* [10], who found that stress could effectively transfer from the starch matrix to the fibers during deformation, hence giving rise to greater strength. The highest flexural strength corresponded to the CSF trays containing 10% kraft fiber and 10% gluten (4.80 MPa), with values that were greater than EPS foam trays (1.27 MPa) or cassava starch foam trays (1.80 MPa). This might be due to the relationship between the strength and density of the composite CSF trays, where the highest density presented the highest flexural strength [24].

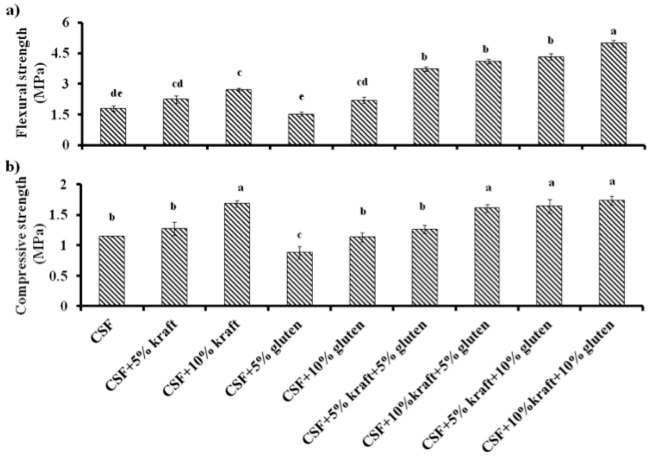

Figure 5: Flexural strength (**a**) and compressive strength (**b**) of composite cassava starch foam (CSF) trays blended with kraft fiber and gluten protein.

3.3.4. Compressive Strength

Compressive strength is a mechanical property that is important in packing materials. The higher the compression value of the foam, the more load can be supported. As shown in Figure **5**, only the fiber was observed to have a significant effect on compression. The addition of gluten protein to the CSF decreased the compressive strength, but this change was less than the concentration change observed for the gluten protein. The addition of 10% kraft fiber and 10% gluten protein to the CSF trays yielded the highest compressive strength (1.74 MPa). This might be due to their fibrous network formations [10]. In this study, the compressive strength was consistent with increasing flexural strength. The addition of plant fiber conferred a reinforcing effect on the starch foams, improving their mechanical properties. Moreover, the compressive strengths of the CSF blended with both kraft fiber and gluten protein in this study were higher (1.27-1.74 MPa) than the compressive strengths of the EPS foam trays (1.3 MPa) and the CSF blended with either kraft fiber (1.28-1.61 MPa) or gluten protein (0.88-1.14 MPa).

3.3.5. Water Absorption

The water absorption levels for the CSF control and the composite CSF blended with kraft fiber and gluten protein at different temperatures are displayed in Figure **6**. The water absorption of CSF at 4°C was lower than the water absorption of CSF at 25°C and 60°C. The water absorption increased when the temperature increased due to starch degradation, perhaps because a more open structure was formed, allowing water penetration and absorption [25]. The highest water absorption occurred at 60°C (559%) and was observed in the control CSF trays because the water molecules attached to the H-bonds and disrupted the OH-groups of starch, resulting in weakened bonds and increased water absorption [17, 26]. The composite CSF trays containing 5-10% kraft fiber and gluten protein had a low water absorption capacity. This might be due to the formation of hydrogen bonds between the fiber and the starch [19]. The lowest water absorption was observed in the CSF blended with 10% kraft fiber and 10% gluten protein tested at 4°C. The decreased water absorption of the composite CSF blended with both kraft fiber and gluten protein, a combination of additives, is thought to arise from the synergistic effect of the additives. Similar to the present findings, the addition of plant proteins to the trays made of starch and cellulose fiber led to a significant reduction in the water absorption capacity and water content of the trays [14]. Although kraft fiber and gluten protein individually could reduce the water absorption of CSF, the water absorption of the composite CSF blended with both kraft fiber and gluten protein in this study was still higher than the EPS foam trays. These results might be because cassava starch and fiber are hygroscopic materials, whereas polystyrene consists of long hydrocarbon chains [17, 23].

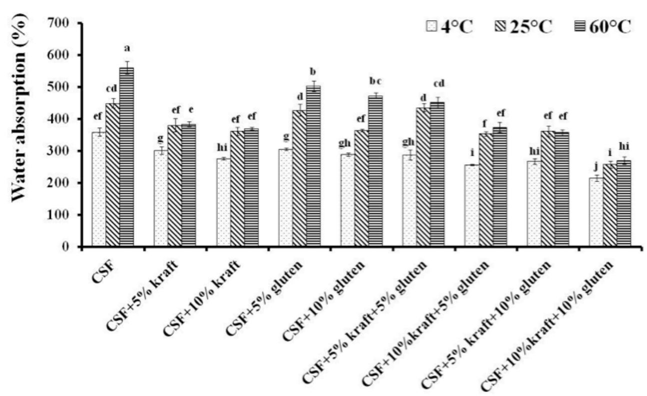

Figure 6: Water absorption at 4°C, 25°C and 60°C of composite cassava starch foam (CSF) trays blended with kraft fiber and gluten protein.

3.3.6. Oil Absorption

The oil absorption of the CSF trays was measured via direct contact between the surface of the foam and the palm oil. The oil absorption of CSF decreased with the addition of the kraft fiber and gluten protein (Figure **7**). Composite CSF trays containing 5% to 10% kraft fiber resulted in a 50% decrease in oil absorption (0.016 g/m^2), whereas the addition of 5% and 10% gluten protein reduced the oil absorption by 60% (0.013 g/m^2). Moreover, the composite CSF trays containing

10% kraft fiber and 10% gluten protein showed a reduced oil absorption of 0.009 g/m^2 (72%). This result likely occurred because the addition of kraft fiber and gluten protein to CSF gave the foam a more dense structure, preventing the oil from penetrating the starch foam. These findings are in agreement with the results reported by Butkinaree *et al.* [27], who observed that a starch coating could prevent the absorption of oil into paperboards.

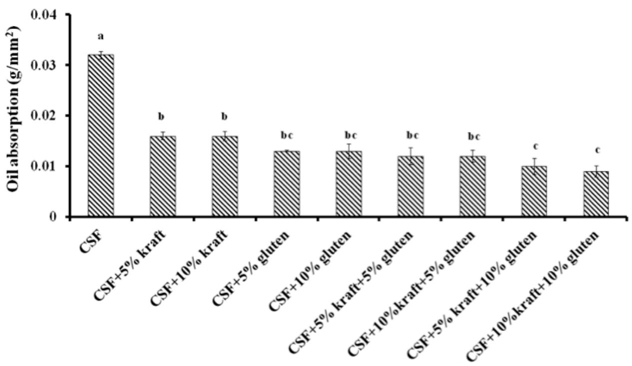

Figure 7: Oil absorption of composite cassava starch foam (CSF) trays blended with kraft fiber and gluten protein.

3.4. Preliminary Test of Composite Foam Trays as Fruit Packaging

Composite CSF blended with 10% kraft fiber +10% gluten protein was used as packaging for fresh cut durian pulps and kept at 4°C for 5 days. It was found that the compressive strength of composite CSF blended with 10% fiber and 10% protein slightly decreased from 1.74 to 1.51 MPa during storage time (Table **3**). The appearance of the composite CSF blended with 10% kraft fiber +10% gluten protein containing with fresh cut durian pulps showed softening texture at the center of the trays (Figure **8**). It might be due to the movement of moisture content from durian pulps to the composite CSF indicating that the trays were sensitive to direct contact with moist foods. However, water and oil absorption of the tested composite CSF trays remained unchanged compared with their controls (before using as fruit packaging) (data not shown).

Figure 8: The appearance of packaging produced from composite cassava starch foam trays blended with 10% kraft fiber and 10% gluten protein, **a**) before packing minimally processed durian and **b**) after packing minimally processed durian.

Table 3: Compressive Strength of Composite Cassava Starch Foam (CSF) Trays with 10% kraft fiber + 10% Gluten Protein before and after Packing Fresh Durian and kept at 4°C for 5 Days

	Compressive strength (MPa)	
	Before	**After**
EPS foam tray	1.27 ± 0.09	1.23 ± 0.08
CSF with 10% kraft fiber+10% gluten protein	1.74 ± 0.11	1.51 ± 0.20

Average ± standard deviation.

4. CONCLUSION

This study characterized the properties of composite cassava starch foam trays blended with fibers (leaf sheath of betel nut palm, coconut husk, and kraft fiber) and proteins (sunflower meal protein and gluten protein). The addition of kraft fiber and gluten protein led to a significant increase in the mechanical properties and a slight decrease in the water and oil absorption properties of cassava starch foam trays. The formulation of cassava starch foam containing 10% gluten protein and 10% kraft fiber exhibited the best properties, including maximal flexural strength and compressive strength. In addition the composite CSF also used as packaging for fresh cut durian. The results of this study demonstrate that plant fiber and protein additives represent an alternative approach for improving the water and oil absorption of starch foam trays. Although the composite CSF trays blended with plant fibers and proteins could be used to pack minimally processed of fresh cut fruit (durian), the composite foam needs further development to improve the water and oil resistance and needs further study of the possibility for packing the moist and oily foods.

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