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Characterization of cassava starch based foam blended with plant proteins, kraft fiber, and palm oil

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ABSTRACT

Cassava starch foam (CSF) trays blended with zein, gluten, soy protein, kraft fiber, and palm oil at various concentrations: 0, 5, 10 and 15% by weight of starch, were characterized. The addition of zein and gluten into CSF resulted in consolidated and homogeneous structural foams compared to its controls. Moreover, the flexural and compressive strength increased with increasing kraft, zein and gluten. CSF containing 15% kraft gave the highest flexural and compressive strength. However, the addition of palm oil into CSF gave the lowest flexural strength and compressive strength. The observed water absorption and water solubility index of CSFs blended with 15% zein and 15% gluten protein was lowest. Although kraft, zein and gluten could improve mechanical properties, water absorption and water solubility were greater than the expanded polystyrene foam (EPS). The CSF trays in this study might be an alternative for packing low water content foods.

1. Introduction

Plastic packing especially expanded polystyrene (EPS) has been used for everyday life commodities due to their low density, good thermal insulation property, reasonable strength, and low cost (Soykeabkaew, Supaphol, & Rujiravanit, 2004). However, EPS foams may require several hundred years to degrade and can cause serious environmental pollution (Hu, Chen, & Gao, 2009). Currently, the bioplastic that are environmentally friendly polymers, have been a major focus of interest, but their disadvantages are expensive and low resistance to conditions of high heat and humidity, heat distortion temperature, low flexibility, and long mold cycle time (Auras, Singh, & Singh, 2006; Lee, Eskridge, Koh, & Hanna, 2009). An alternative material for the replacement of petroleum-based and bioplastic polymers is natural polymer such as native starch.

Starch has been used to produce starch-based foam due to its swelling property with low cost, non-toxic, renewable and biodegradable (Yew, Mohd, Mohd, & Ishiaku, 2005). Shogren, Lawton, and Tiefenbacher (2002) showed that shaped starch foams could be produced by baking starch/water batters in heated closed molds. During the processing, the starch granules gelatinize and the evaporation of water causes the starch to foam out and take up the shape of the mold (Soykeabkaew et al., 2004). However, foams made from native starch are brittle, sensitive to water and require further treatments or additives to improve their strength, flexibility, and water resistance for such applications as plates and clamshells (Shogren et al., 2002). In our previous study, natural polymers of cassava starch, fiber and chitosan were used to produce starch foam trays (Kaisangsri, Kerdchoechuen, & Laohakunjit, 2012). Although density, tensile strength and elongation of cassava starch foam blended with fiber and chitosan were close to EPS foam trays, water absorption and water solubility were greater than the EPS foam trays. To overcome these weaknesses, the association of starch foam with other natural polymers is a new strategy to obtain low cost and compostable material. In this context, protein, fiber and palm oil are inexpensive and may be potential additives to improve cassava starch foams.

Proteins possess multiple function properties, such as solubility, gelation, elasticity, emulsification and cohesion–adhesion. Proteins are amphoteric molecules and they can migrate spontaneously to an air–water interface or an oil–water interface (Cuq, Gontard, & Guilbert, 1998). Once at the interface, proteins have an ability to interact with the neighboring molecules and form strong cohesive, visco-elastic foam that can withstand morphology and mechanical motions. Plant proteins also constitute an interesting source for economic biopolymers suitable for packaging (Zhao, Torley, & Halley, 2008). Previous work has shown that the addition of sunflower proteins to trays made of cassava starch led to reduction in water absorption and water content of trays, without affecting

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mechanical properties (Salgado, Schmidt, Ortiz, Mauri, & Laurindo, 2008).

Bio-based materials such as fiber-formed cellulose are being used as ingredients to improve the mechanical properties of biodegradable foams. Plant fibers have been studied in various applications and reviewed by many authors because they have excellent specific properties, such as high strength, low weight and good barrier properties (Vercelheze et al., 2012). Glenn and Orts (2001) showed that both strength and flexibility of corn starch foams were improved by incorporating softwood fiber. Furthermore, the addition of sugarcane bagasse fiber increased the strain at break values of the cassava starch foam trays (Vercelheze et al., 2012).

Palm oil is an edible vegetable oil derived from the mesocarp of the fruit of oil palms. It consists of triglycerides, which are glycerol molecules, each esterified with three fatty acids. In the effort to improve water resistance, many different hydrophobic materials and cross-linking agents were added to the batter formulations. Butkinaree, Jinkarn, and Yoksan (2008) found that increasing the stearic acid concentration could reduce water absorptivity of paperboard. Moreover, a hydrophobic additive such as beeswax could improve the water resistance of corn starch foam trays (Polat, Uslu, Aygün, & Certel, 2012).

However, the natural biopolymers have different properties affecting the properties of cassava starch foam. Thus, the aim of this study was to improve the mechanical properties and water resistance of cassava starch foam by additive agents of natural polymers including proteins, fibers, and vegetable oil.

2. Materials and methods

2.1. Materials

Cassava starch was obtained from Ocean foods Co., Ltd. (Thailand) and its moisture content was 12%. Kraft was kindly provided by the Thai Paper Co., Ltd. (Thailand). Zein, gluten, soy protein acid hydrolysate, and Tween® 20 were obtained from Sigma Chemical (MO, USA). Palm oil was obtained from Lam Soon PCL (Thailand). Expanded polystyrene foam trays were obtained from J.T. Pack of Food Co., Ltd. (Thailand).

2.2. Foam preparation

Each of the five additives (zein, gluten, soy protein, kraft fiber and palm oil) were mixed with 80% (w/v) cassava starch at 3 concentrations; 5, 10 and 15% by weight of starch, but in the preparation of starch batter containing palm oil, the palm oil was mixed with 10% Tween® 20 (w/w of palm oil content). All formulations were homogenized using a blender (8011BU, Waring, USA) at 18,000 rpm for 5 min. Eighty grams of starch batter with additive was poured to the mold in which its size cavity was 180 mm in length, 105 mm width and 10 mm in depth. The mold was heated and controlled at 200 ± 5 °C for 5 min. Before the properties of foam were investigated, foam specimens 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. Properties of CSF were compared with commercial EPS foam trays.

2.3. Cassava starch foam (CSF) tray characterization

2.3.1. Morphology by scanning electron micrographs (SEM)

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

2.3.2. Density

Foam density was determined by the sand displacement method followed by Cinelli, Chiellini, Lawton, and Imam (2006). For each specimen, cassava starch based foam was analyzed and the measurements made in triplicate. The specimen (10 mm × 10 mm) was weighed and then placed in a 25 mL cylinder and a known volume of sand was added to the cylinder. The total volumes of foams and sand were recorded after tapping the graduated cylinder for 1 min. Foam density was calculated from the mass divided by the displaced volume.

2.3.3. Flexural strength and compressive strength

A texture analyzer model TA plus (LLOYD Instruments, UK) with a 500 N load cell was used to determine the flexural strength and compressive strength of the foams. Flexural tests were performed using three-point bending tests according to ASTM method D790M-91 (1991). The foam samples were cut to 25 mm × 100 mm and were performed with a span setting of 50 mm and a crosshead speed of 2.5 mm/min. Foam specimens were deformed until the sample broke. Compressive tests were done according to ASTM method D1621-73 (1973) and a starch foam tray was placed on a flat plate and compress to 10% of its original diameter at a loading rate of 2.5 mm/min using a metal probe.

2.3.4. Water resistance

Water absorption index (WAI) and water solubility index (WSI) were measured by the AACC method 56–20 (1983). One gram of the sample was dispersed in 30 mL distilled water in a centrifuge tube and placed in a water bath at 30 °C for 30 min. The tube was centrifuged at 4000 × *g* for 30 min. The supernatant was poured into an aluminum can and dried at 105 °C for 24 h. The WAI and WSI were calculated as follows:WAI $= \frac{(W_1-W_2)}{W_1}$ where W_1 and W_2 were the weight of the foam before and after water absorption, respectively.

$$\text{WSI} = \frac{W_{A1} - W_{A2}}{W}$$

where W_{A1} was the weight of the aluminum can with supernatants after being dried at 105 °C for 24 h, W_{A2} was the weight of the aluminum can, and W was the weight of the foam before water absorption.

2.3.5. Oil absorption

Oil absorption of the starch foams was determined with slightly modified method following Karnnet, Potiyaraj, and Pimpan (2005). The sample was cut to a size of 100 mm × 100 mm. Each sample was placed on a white paper. A tube 25 mm in diameter and more than 25 mm in height was placed over each sample, then 5 g of sand was poured into the tube. After that, 1.1 mL of palm oil was dropped onto the sand and the tube was then covered with a glass lid. This test method must be performed at 25–29 °C and 75% relative humidity for 7 days. The oil absorption was calculated as follows:

$$\text{Oil absorption} = \frac{W_1 - W_2}{A}$$

where W_1 and W_2 were the weight of the foam before and after oil absorption and A was the surface area of the foam.

2.4. Statistical analysis

Statistical analysis was carried out using SAS software (SAS Institute Inc., Cary, NC, USA). Analysis of variance was used to compare the mean differences of starch foam. Duncan's Multiple Range Test

was used to detect the differences in physical and mechanical properties, water resistance, and oil resistance of starch foam trays obtained with different formulations.

3. Results and discussion

3.1. Morphology of CSF by scanning electron micrographs (SEM)

The cross-sections of polystyrene foam and CSF trays obtained by SEM are presented in Fig. 1. The EPS foam had a great arrangement of air bubbles whereas cassava starch foam had a sandwich type structure with dense outer skins with small cells comprising the surface of the foam. Since the starch batter had contact with the hot mold, rapid gelling and drying of the starch paste occurred and prevented an extensive expansion (Salgado et al., 2008; Shogren, Lawton, Doane, & Tiefenbacher, 1998). The interior of the CSF had large cells with thin walls due to the amount of water venting outside the mold and consequent cell rupture (Shogren et al., 1998).

Zein, gluten, and soy protein were mixed with cassava starch at 3 concentrations; 5, 10 and 15% by weight of starch and the SEM mixed with proteins are shown in Fig. 2. The addition of gluten and zein proteins into CSF created homogeneous structures, but not with the addition of soy protein. CSF mixed with zein protein had more dense outer skins and interiors of the foam than in CSF (with no additive). When zein protein was added at high amounts, expansion properties decreased. Similarly, the addition of gluten protein gave more dense outer skins, but the interiors of the foam had large cells with thin walls. This could be attributed to foam forming which created the formation of the starch-protein matrix that trapping gas cells (Gorton, 2009). The cross section micrograph of CSF mixed with 15% gluten protein showed a greater homogeneity than CSF without gluten protein (Fig. 2(f)). Moreover, the addition of soy protein into cassava starch foam presented a non-homogeneous structure, which might be attributed to a protein-rich phase (Tapia-Blácido, Mauri, Menegalli, Sobral, & Añón, 2007). When the soy protein concentration increased to 15%, the outer skin presented a foamy aspect and the interior had a smoother appearance (Fig. 2(i)). An increase in protein concentration probably led to an interference of proteins with the establishment of a starch network. It is known that protein-polysaccharide systems could be characterized by limited compatibility between their components, occasionally resulting in phase separation (Salgado et al., 2008).

The SEM of CSF with kraft fiber showed that kraft fiber was trapped in gelatinized starch and became a part of the cell wall of CSF mixed with kraft fiber (Fig. 3(a)–(c)). The CSF with a great kraft fiber content presented irregular structures and small air bubbles. With the addition of 15% kraft fiber, it was observed that the outer skin of starch foam had accumulated fiber, resulting in decreasing expandable structures (Fig. 3(c)). This observation might be explained that fiber in a starch batter could be responsible for an increase in the viscosity, caused the batter to be less expandable, giving rise to smaller cell size, thicker cell wall (Shogren et al., 2002; Soykeabkaew et al., 2004). This finding is in contrast with the addition of sugarcane bagasse resulting in more expanded structures, with large air cells and lower density structures (Vercelheze et al., 2012).

SEMs of CSF mixed with palm oil are shown in Fig. 3(d) and (e). The CSF mixed with 15% palm oil could not form foam because of palm oil was not inserted and made the homogenous mixture of cassava starch batter. However, the addition of palm oil into CSF resulted in the un-uniform structure throughout the foam tray and its structure seemed to lack a starch network (Shogren et al., 2002). CSFs with high palm oil concentrations resulted in more dense outer skins and the interiors of the foam because the addition of lipids in polysaccharide could increase surface irregularity and might distort and crack during drying (Yang & Paulson, 2000).

3.2. Density

Density is an important physical property of foam, which low density is ideal for these products. The density of CSF mixed with zein, gluten, soy protein, kraft, and palm oil at 5, 10 and 15% (w/w) of starch is presented in Fig. 4. The foam density increased with increasing protein content. However, the density of EPS foam, CSF, and CSF mixed with gluten, zein, soy protein was 0.03, 0.18, and 0.23–0.46, 0.29–0.34, 0.30–0.32 g/cm^3, respectively. Foam trays containing high contents of protein had a greater density which was higher than EPS foam (0.05–0.09 g/cm^3) (Glenn & Orts, 2001; Shey, Imam, Glenn, & Orts, 2006). In this study, results were in agreement with data obtained from SEM which showed that an increase in protein could decrease the expansion properties. This was probably due to the increased viscosity of high protein contents and resistance to expansion, resulting in the difficulty in swelling during foam forming. Therefore, the density of CSFs with proteins was higher than the starch foam (Salgado et al., 2008; Zhao et al., 2008).

The addition of kraft fiber into CSF at concentrations of 5, 10 and 15% showed that the greatest amount of fiber had the highest density of foam. These findings were similar to the data obtained by SEM. The density of CSFs mixed with kraft ranged from 0.22 to 0.36 g/cm^3 (Fig. 4). The high level of fiber produced greater density due to the fiber bonding to the starch matrix and thus creating a fibrous network which promoted expansion. Density has been inversely related to expansion and increasing fiber content caused an increase in density (Lee et al., 2009). However, the values of density of CSFs mixed with kraft fiber were lower than Salgado et al. (2008) who reported that cassava starch mixed with eucalypt cellulose pulp had a density around 0.46–0.52 g/cm^3. These results could be explained as foam mixed with a high content of kraft might increase in viscosity of foam batter, which caused a less expandable material, a smaller air cell size and a thicker cell wall that led to increased density (Mali, Debiagi, Grossmann, & Yamashita, 2010; Shogren et al., 1998).

Increasing palm oil into CSF resulted in a greater density of the foam (Fig. 4). The highest foam density (0.71 g/cm^3) was from CSF mixed with palm oil at 10% (w/w) of starch. However, the density of CSF mixed with palm oil ranged from 0.22 to 0.71 g/cm^3, which was higher than the density of EPS foam (0.07 g/cm^3) (Shey et al., 2006). This might be the reason that the CSF with palm oil could resist the expansion of starch foam leading to less volume of CSF, resulting the high density of the foam (Shogren et al., 2002; Polat et al., 2012).

3.3. Flexural strength

Before the flexural strength of CSF was investigated, foam specimens were kept in conditioning chambers for 1 week. The conditioning chambers, having specific RH levels of 75.3%, were prepared by filling the chambers with saturated, aqueous solutions of NaCl salts (Soykeabkaew et al., 2004). In this study, the flexural strength of EPS foam was investigated as the control for comparing to cassava starch foam, in which their values were 0.85–0.97 MPa. The EPS foam density was close to those obtained by Glenn and Orts (2001) who reported that the flexural strength of EPS foam was 1.3 MPa. Fig. 5(a) shows the flexural strength of CSF and CSF mixed with zein, gluten, kraft fiber, and palm oil. The flexural strength of CSF mixed with zein and gluten protein was increased to 1.93–4.18 MPa and 1.48–3.84 MPa, respectively, in which their values were greater than EPS foam tray (0.85 MPa). These results could be the attribution of chemical compositions of varied proteins (Salmoral, Gonzalez, & Mariscal, 2000). Moreover, the addition of

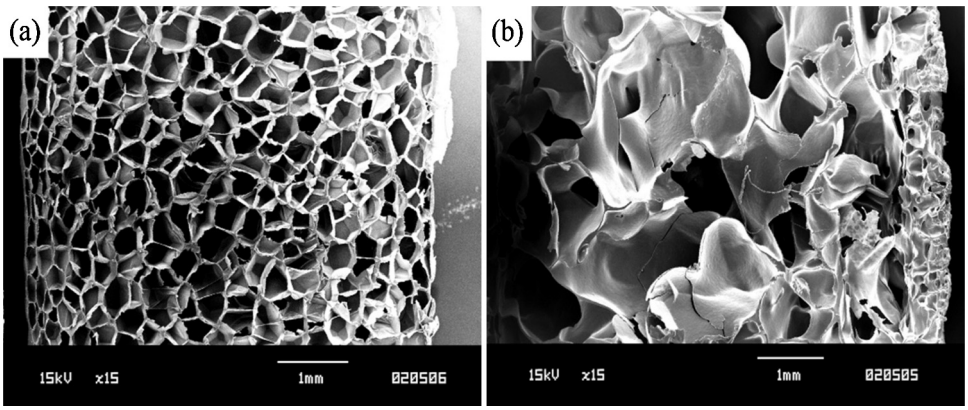

Fig. 1. Scanning electron micrographs of cross-sections of (a) expanded polystyrene foam trays, and (b) cassava starch foam trays with no additive.

zein and gluten could improve compressive strength because proteins were fully compatible with starch and cross-linked between these polymers (Cuq et al., 1998; Gáspár, Benkő, Dogossy, Réczey, & Czigány, 2005). On the other hand, the addition of soy protein into CSF gave lower flexural strength than EPS foam and CSF mixed with gluten and zein protein. This could be explained that the compositions of zein (consisting of polamines) and gluten (consisting of glutenins and gliadins), were more rubbery and flexible than soy protein (Dangaran, Tomasula, & Qi, 2009).

The flexural strength of CSF mixed with kraft fiber increased with increasing kraft fiber content, especially in CSF mixed with 15% kraft fiber which gave the highest flexural strength (5.3 MPa) (Fig. 5(a)). The reason for improvement in the flexural strength was due to the reinforcing effect of interfacial interaction between

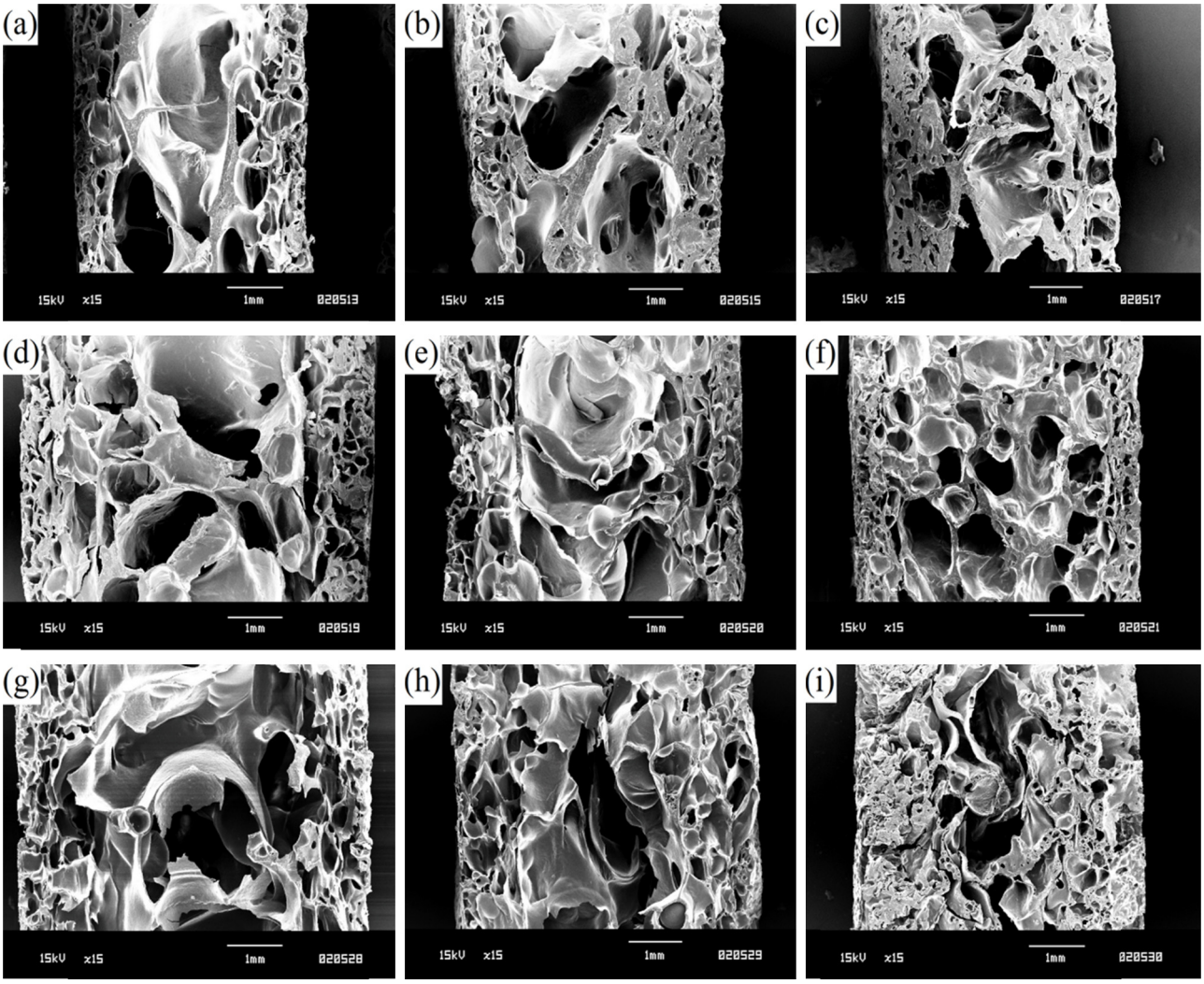

Fig. 2. Scanning electron micrographs of cross-sections of the cassava starch foam trays with different additive: (a) 5% zein protein, (b) 10% zein protein, (c) 15% zein protein, (d) 5% gluten protein, (e) 10% gluten protein, (f) 15% gluten protein, (g) 5% soy protein, (h) 10% soy protein and (i) 15% soy protein.

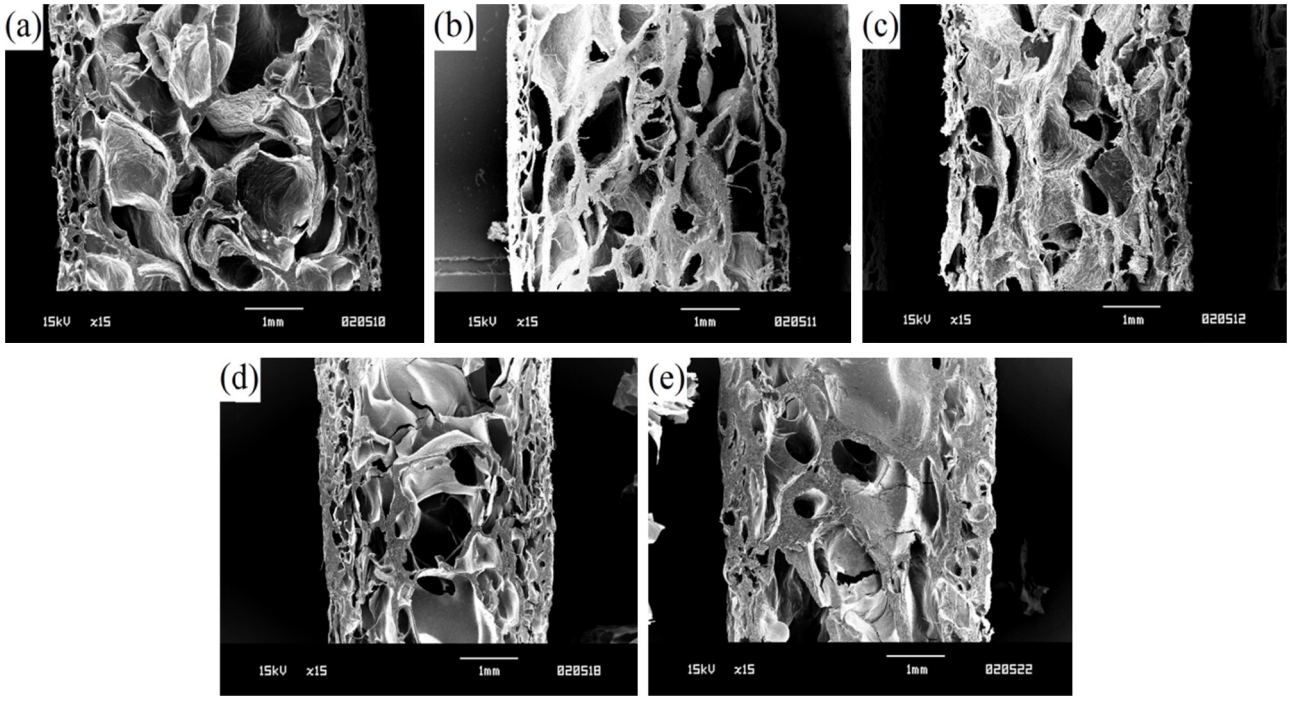

Fig. 3. Scanning electron micrographs of cross-sections of cassava starch foam trays with kraft fiber and palm oil: (a) 5% kraft, (b) 10% kraft, (c) 15% kraft, (d) 5% palm oil, (e) 10% palm oil.

fiber and starch matrix. This finding is consistent with the result of Soykeabkaew et al. (2004) who found that stress could transfer from the starch matrix to the fibers very effectively during deformation, hence giving rise to greater strength. Bénézet, Davidovic, Bergeret, Ferry, and Crespy (2012) also reported that the flexural strength of expanded starch–fiber was reinforced by hemp and cellulose fiber.

However, the addition of palm oil into CSF gave the lowest flexural strength (0.25 MPa) (Fig. 5(a)). The flexural strength of CSF mixed with palm oil slightly increased with increasing palm oil content. The low flexural strength might be the incompatibility of water and oil phases resulted in cracking the starch matrix of the foam, hence reducing the strength (Shogren et al., 2002; Yang & Paulson, 2000).

3.4. Compressive strength

The compressive strengths of CSF and CSF mixed with zein, gluten, soy protein, kraft fiber, and palm oil conditioned at 75.3% RH before testing are shown in Fig. 5(b). The EPS foam was also investigated in comparison with CSF, which its compressive strength was 1.26 MPa and the value was close to the CSF (1.15 MPa). By adding zein and gluten protein into cassava starch, the compressive strength was slightly increased when zein and gluten content was increased. Protein-polysaccharide complexes could exhibit more effective functional properties than

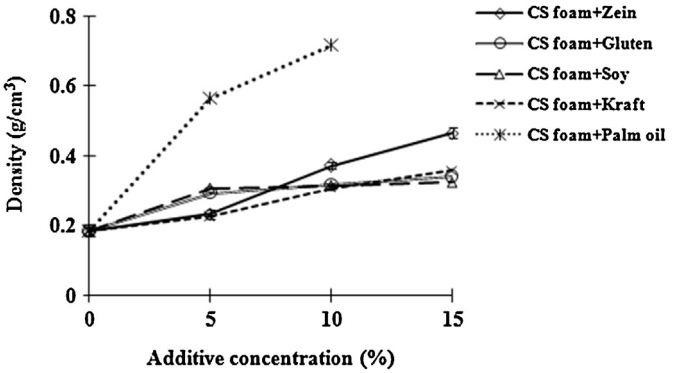

Fig. 4. Effect of zein, gluten, soy protein, kraft fiber, and palm oil on density of cassava starch foam.

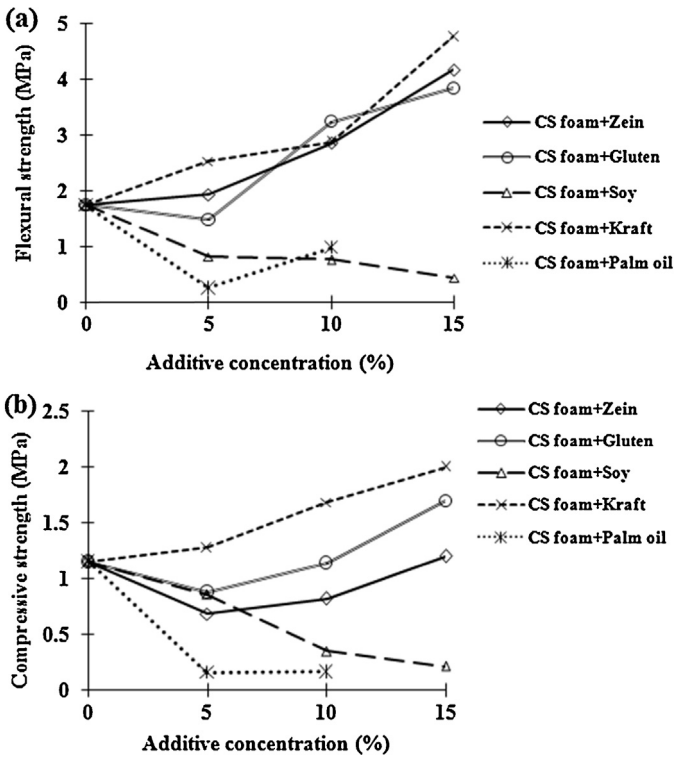

Fig. 5. Effect of zein, gluten, soy protein, kraft fiber, and palm oil on (a) flexural strength and (b) compressive strength of cassava starch foam.

polysaccharide alone (Coughlan, Shaw, Kerry, & Kerry, 2004). The protein matrix was affected by shear and heat, which caused proteins to unfold, hydrogen bonds to weaken, and general rearrangement of the proteins to form with starch. These changes could increase the strength and elasticity of the resulting matrix (Dangaran et al., 2009).

When kraft fiber was added at higher concentrations, the compressive strength of CSF mixed with kraft was increased. The addition of 15% kraft fiber into CSF gave the highest compressive strength (1.99 MPa) due to their fibrous network formations. The interfacial interaction between fiber and starch matrix had a very good result that was similar to chemical functional groups (Shogren et al., 2002; Soykeabkaew et al., 2004). In this study, the compressive strength is consistent with increasing flexural strength. These findings are consistent with the result of Salgado et al. (2008) who reported that the addition of eucalypt cellulose pulps resulted in a reinforcing effect on starch foams, improving their mechanical properties.

The addition of palm oil into CSF resulted in the lowest value of compressive strength. The compressive strength of CSF mixed with palm oil ranged from 0.15 to 0.16 MPa. Adding the palm oil into starch foam gave less compressive strength which corresponded to decreasing flexural strength. The hydrophobic nature of palm oil might prevent the formulation of the homogenous foam structure, which might explain the decline in mechanical properties (Polat et al., 2012).

Flexural and compressive strength were improved by adding kraft fiber which gave the higher mechanical properties than gluten, zein, soy protein, and palm oil. These results could be explained the good interaction between fiber and starch matrix translates into the ability for the matrix to transfer stress to the reinforcing fiber very effectively, thus imparting higher strength to the starch–fiber foam (Soykeabkaew et al., 2004).

3.5. Water absorption index (WAI)

Starch foams are susceptible to moisture when they attack water. Water molecules attack the hydrogen bonds of starch, weakening them and decreasing the functional properties of the foam (Mali et al., 2010). Therefore, water resistance is an important parameter to investigate for improving the applications of starch foam. The WAI of cassava starch foam mixed with zein, gluten, soy protein, kraft fiber, and palm oil is displayed in Fig. 6(a). The highest WAI (12.14) was observed in CSF because the water molecules could easily diffuse to H-bonds with OH-groups of glucose units along the polymer chains (Schlemmer & Sales, 2010). The addition of zein, gluten, and soy protein into CSF resulted in the decreasing WAI. The WAI of the CSF mixed with zein, gluten, and soy protein ranged from 2.79 to 4.90. The CSF mixed with 15% zein protein gave the lowest values of WAI (2.79). The reason for lower WAI might be the formation of intermolecular bonds between polamine in zein protein composition solubilized in alcohol, but not in water, and starch could lead to starch that had little or no water absorption (Cuq et al., 1998; Dangaran et al., 2009). Our findings agree with Salgado et al. (2008), who found that the addition of sunflower proteins to trays made of starch and cellulose fiber led to a significant reduction in water absorption and water content of trays.

The WAI of CSF mixed with kraft fiber decreased significantly ($p \leq 0.01$). The addition of 15% kraft fiber into CSF could decrease the WAI from 12.14 to 4.74. These results suggested that the increase in the crystalline phase (fiber) of semi-crystalline material (starch) is known to be highly linked to decrease in water absorption (Bénézet et al., 2012; Mali et al., 2010). Results were in agreement with Guan and Hanna (2006) who reported that cellulosic fiber could reduce the moisture sensitivity of starch foams.

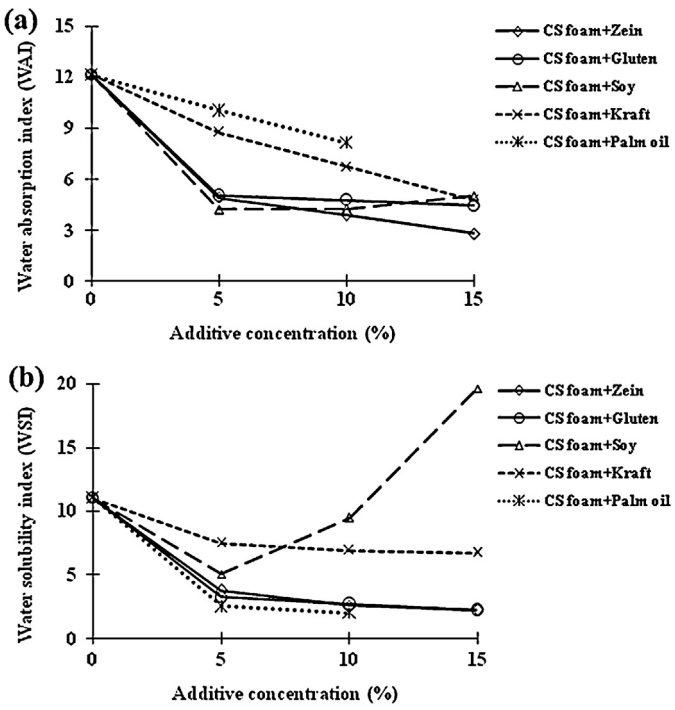

Fig. 6. Effect of zein, gluten, soy protein, kraft fiber, and palm oil on (a) water absorption index and (b) water solubility index of cassava starch foam.

Water absorption of CSF mixed with palm oil decreased with the increase of palm oil (Fig. 6(a)). When palm oil was mixed at high concentrations, the WAI of CSF slightly decreased. The WAI decreased because the addition of palm oil might increase the hydrophobicity of the foam and might induce a re-organized starch structure with less exposed hydroxyl groups (Karnnet et al., 2005; Schlemmer & Sales, 2010).

3.6. Water solubility index (WSI)

The WSI of CSF mixed with protein decreased with increasing protein concentrations (Fig. 6(b)). When protein concentrations were increased, the WSI of cassava starch foam was not different. The CSF mixed with 15% zein or 15% gluten proteins had less WSI (2.22 and 2.23%). The decreased WSI might be the covalent intermolecular bonds or numerous interactions which could lead to the foam, resulting in little or no water solubility (Cuq et al., 1998). It was also found that the WSI decreased with the addition of soy protein up to 5% and increased when the soy protein content of cassava starch foam exceeded 10%.

The increase of kraft fiber content into CSF had a slightly decreased WSI of the CSF (Fig. 6(b)). The WSI of CSF mixed with 5, 10 and 15% kraft was 7.47, 6.91 and 6.71%, respectively. The decrease in WSI was possibly due to the incorporation between the kraft fiber and starch matrix, resulting in a dense outer skin that was resistant to water molecules (Mali et al., 2010). According to Kaisangsri et al. (2012), the water solubility of CSF decreased when kraft fiber was added at high concentrations.

The WSI of CSF mixed with palm oil decreased with increasing palm oil content. The addition of 10% palm oil into CSF gave the lowest WSI (1.99%). For foam containing fatty acids of palm oil, the water solubility decreased with increased hydrophobicity of the lipids in the composite foam (Yang & Paulson, 2000).

The addition of zein and gluten protein could improve the water resistance of CSF. When zein and gluten were mixed at increased concentrations, the WSI decreased from 11.01 to 2.22 and 2.23, respectively. According to Fig. 6(b), the WSI of CSF mixed with zein

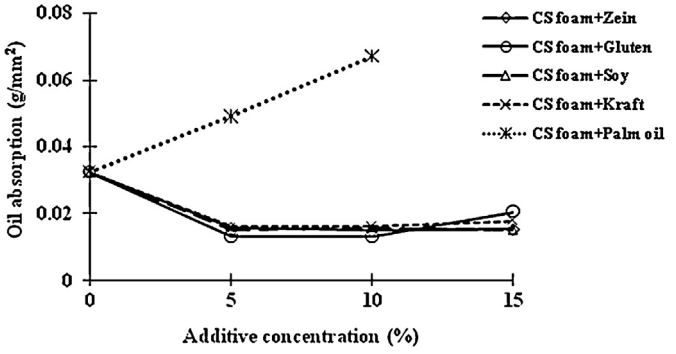

Fig. 7. Effect of zein, gluten, soy protein, kraft fiber, and palm oil on oil absorption of cassava starch foam.

and gluten protein was greater than that of CSF (with no additive). The reason for the improvement in water resistance of CSF might be the non-soluble in water of the chemical compositions of gluten and zein (Dangaran et al., 2009). Although zein and gluten could reduce water absorption and water solubility of CSF, water absorption and water solubility were still higher than in EPS foam. These results might be explained that the CSFs are hygroscopic material while polystyrene is long hydrocarbon chains that consist of thousands of styrene monomers (Lee et al., 2009).

3.7. Oil absorption

The oil absorption of CSF was measured through direct contact with the surface of the foam with palm oil. The oil absorption of CSF mixed with zein, gluten and soy protein slightly decreased with the addition of the protein (Fig. 7). The types and concentrations of proteins did not significantly affect ($p \leq 0.01$) the oil absorption of the foam. However, the addition of kraft fiber into CSF also decreased slightly in oil absorption. This could be explained by the addition of protein and kraft fiber giving more dense outer skins resulting in the prevention of the palm oil penetrating into the starch foam (Butkinaree et al., 2008). These findings were agreement with Han and Krochta (2001) who reported that the oil absorption rate decreased by whey protein isolate coating on the paper. On the other hand, the oil absorption of CSF with palm oil increased with increasing oil content. This evidence might be the addition of palm oil increased the hydrophobicity of starch foam which led to penetration of the oil into the starch foam (Butkinaree et al., 2008; Han & Krochta, 2001).

4. Conclusions

This study was conducted to improve the mechanical properties and water resistance of baked CSFs blended with natural polymers including proteins, fiber, and vegetable oil. The addition of kraft, zein, and gluten could improve flexural and compressive strength of the CSF trays. Moreover, the water absorption and water solubility index of cassava starch foams blended with zein and gluten proteins were low. Although adding palm oil into CSFs increased the water resistance, their flexural and compressive strength decreased. These findings demonstrate that CSF trays blended with kraft, gluten and/or zein could be used as an alternative to EPS foam trays for oily and less moist foods. The starch foam trays should further improve and develop their expansion, water resistance and their possible application to moist foods.

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References

American Association of Cereal Chemists Approved Methods (AACC). (1983). *Hydration capacity of pregelatinized cereal products*. Minnesota: American Association of Cereal Chemists Approved Methods.

American Society for Testing and Materials (ASTM). (1973). *Method D1621-73: Standard test method for compressive properties of rigid cellular plastics*. Philadelphia: Annual Book of ASTM Standards.

American Society for Testing and Materials (ASTM). (1991). *Method D790M-91: Standard test methods for flexural properties of unreinforced and reinforced plastics and electrical insulating materials*. Philadelphia: Annual Book of ASTM Standards.

Auras, R., Singh, S. P., & Singh, J. (2006). Performance evaluation of PLA against existing PET and PS containers. *Journal of Testing and Evaluation*, *34*, 530–536.

Bénézet, J. C., Davidovic, A. S., Bergeret, A., Ferry, L., & Crespy, A. (2012). Mechanical and physical properties of expanded starch, reinforced by natural fibres. *Industrial Crops and Products*, *37*, 435–440.

Butkinaree, S., Jinkarn, T., & Yoksan, R. (2008). Effects of biodegradable coating on barrier properties of paperboard food packaging. *Journal of Metals, Materials and Minerals*, *18*, 219–222.

Cinelli, P., Chiellini, E., Lawton, J. W., & Imam, S. H. (2006). Foamed articles based on potato starch, corn fibers and poly(vinyl alcohol). *Polymer Degradation and Stability*, *91*, 1147–1155.

Coughlan, K., Shaw, N. B., Kerry, J. F., & Kerry, J. P. (2004). Combined effects of proteins and polysaccharides on physical properties of whey protein concentrate-based edible films. *Journal of Food Science*, *69*, E271–E275.

Cuq, B., Gontard, N., & Guilbert, S. (1998). Proteins as agricultural polymers for packaging production. *Cereal Chemistry*, *75*, 1–9.

Dangaran, K., Tomasula, P. M., & Qi, P. (2009). Structure and function of protein-based edible films and coatings. In K. C. Huber, & M. E. Embuscado (Eds.), *Edible films and coatings for food applications* (pp. 25–56). New York: Springer.

Gáspár, M., Benkő, Z., Dogossy, G., Réczey, K., & Czigány, T. (2005). Reducing water absorption in compostable starch-based plastics. *Polymer Degradation and Stability*, *90*, 563–569.

Glenn, G. M., & Orts, W. J. (2001). Properties of starch-based foam formed by compression/explosion processing. *Industrial Crops and Products*, *13*, 135–143.

Gorton, L. A. (2009). Fundamental bakery dough processes. In E. J. Pyler, & L. A. Gorton (Eds.), *Baking science and technology* (pp. 89–108). Missouri: Sosland Publishing Company.

Guan, J., & Hanna, M. A. (2006). Selected morphological and functional properties of extruded acetylated starch–cellulose foams. *Bioresource Technology*, *97*, 1716–1726.

Han, J. H., & Krochta, J. M. (2001). Physical properties and oil absorption of whey protein-coated paper. *Food Engineering and Physical Properties*, *66*, 294–299.

Hu, G., Chen, J., & Gao, J. (2009). Preparation and characteristics of oxidized potato starch films. *Carbohydrate Polymers*, *76*, 291–298.

Kaisangsri, N., Kerdchoechuen, O., & Laohakunjit, N. (2012). Biodegradable foam tray from cassava starch blended with natural fiber and chitosan. *Industrial Crops and Products*, *37*, 542–546.

Karnnet, S., Potiyaraj, P., & Pimpan, V. (2005). Preparation and properties of biodegradable stearic acid-modified gelatin films. *Polymer Degradation and Stability*, *90*, 106–110.

Lee, S. Y., Eskridge, K. M., Koh, W. Y., & Hanna, M. A. (2009). Evaluation of ingredient effects on extruded starch-based foams using a supersaturated split-plot design. *Industrial Crop and Products*, *29*, 429–436.

Mali, S., Debiagi, F., Grossmann, M. V. E., & Yamashita, F. (2010). Starch, sugarcane bagasse fibre, and polyvinyl alcohol effects on extruded foam properties: A mixture design approach. *Industrial Crop and Products*, *32*, 353–359.

Polat, S., Uslu, M.-K., Aygün, A., & Certel, M. (2012). The effects of the addition of corn husk fiber, kaolin and beeswax on cross-linked corn starch foam. *Journal of Food Engineering*, *116*, 267–276.

Salgado, P. R., Schmidt, V. C., Ortiz, S. E. M., Mauri, A. N., & Laurindo, J. B. (2008). Biodegradable foams based on cassava starch, sunflower proteins and cellulose fibers obtained by a baking process. *Journal of Food Engineering*, *85*, 435–443.

Salmoral, E. M., Gonzalez, M. E., & Mariscal, M. P. (2000). Biodegradable plastic made from bean products. *Industrial Crops and Products*, *11*, 217–225.

Schlemmer, D., & Sales, M. J. A. (2010). Thermoplastic starch films with vegetable oils of Brazilian Cerrado. *Journal of Thermal Analysis and Calorimetry*, *99*, 675–679.

Shey, J., Imam, S. H., Glenn, G. M., & Orts, W. J. (2006). Properties of baked starch foam with natural rubber latex. *Industrial Crops and Products*, *24*, 34–40.

Shogren, R. L., Lawton, J. W., Doane, W. M., & Tiefenbacher, K. (1998). Structure and morphology of baked starch foams. *Polymer*, *39*, 6649–6655.

Shogren, R. L., Lawton, J. W., & Tiefenbacher, K. F. (2002). Baked starch foams: Starch modifications and additives improve process parameters, structure and properties. *Industrial Crops and Products*, *16*, 69–79.

Soykeabkaew, N., Supaphol, P., & Rujiravanit, R. (2004). Preparation and characterization of jute- and flax-reinforced starch-based composite foams. *Carbohydrate Polymers*, *58*, 53–63.

Tapia-Blácido, D., Mauri, A. N., Menegalli, F. C., Sobral, P. J. A., & Añón, M. C. (2007). Contribution of the starch, protein, and lipid fractions to the physical, thermal, and structural properties of Amaranth (*Amaranthus caudatus*) flour films. *Journal of Food Science*, *72*, 293–300.

Vercelheze, A. E. S., Fakhouri, F. M., Antônia, L. H. D., Urbano, A., Youssef, E. Y. Y., Yamashita, F., et al. (2012). Properties of baked foams based on cassava starch, sugarcane bagasse fibers and montmorillonite. *Carbohydrate Polymers*, *87*, 1302–1310.

Yang, L., & Paulson, A. T. (2000). Effects of lipids on mechanical and moisture barrier properties of edible gellan film. *Food Research International*, *33*, 571–578.

Yew, G. H., Mohd, Y. A. M., Mohd, I. Z. A., & Ishiaku, U. S. (2005). Water absorption and enzymatic degradation of poly(lactic acid)/rice starch composites. *Polymer Degradation and Stability*, *90*, 488–500.

Zhao, R., Torley, P., & Halley, P. J. (2008). Emerging biodegradable materials: Starch and protein-based bio-nanocomposites. *The Journal of Materials Science*, *43*, 3053–3071.