



## Research article

# Fabrication of edible and biodegradable cutlery from morning glory (*Ipomoea aquatic*) stem fiber-reinforced onto soy protein isolate

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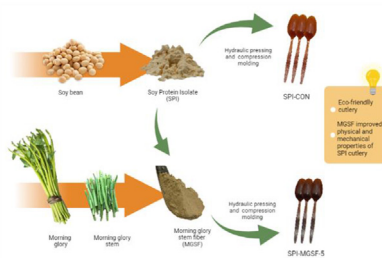
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## HIGHLIGHTS

- MGSF at 5% level improved water resistance properties than the control SPI.
- Mechanical properties were enhanced in SPI sample treated with MGSF.
- Impact strength decreased with the increments of MGSF fiber in SPI cutlery.
- SEM micrographs confirmed the uniform fiber distribution in SPI treated with 5% MGSF.
- SPI at 5% MGSF can be exploited to produce edible and eco-friendly cutlery.

## GRAPHICAL ABSTRACT



## ARTICLE INFO

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## ABSTRACT

This study aimed to investigate the preparation of soy protein isolated (SPI) cutlery incorporated with 5–20% (w/w) crude morning glory stem fiber (MGSF). SPI cutlery samples without and with MGSF were subjected to hydraulic hot press molding at 160 °C for 5 min pressing time. SPI with 5% MGSF showed decreased lightness values compared to the control SPI (without MGSF) ( $p < 0.05$ ). Flexural modulus attained in SPI with 5% MGSF was higher and subsequently showed decreases in impact strength and compression load compared to the control SPI ( $p < 0.05$ ). SPI with 5% MGSF sample showed slightly lower water absorption followed by decreases in degree of swelling and solubility with that of the control SPI ( $p < 0.05$ ). Micrographs revealed a 5% MGSF formed uniform matrix with SPI in comparison to the control and other treatments that showed cracks with the increased fiber addition. Additionally, stiffness decreased with the addition of 5% MGSF to SPI thereby increasing deflection in comparison to the control SPI and other treatments. Thus, SPI cutlery added with 5% MGSF potentially retained the physical and mechanical properties of edible and biodegradable cutlery for food applications.

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## 1. Introduction

Packaging material from plastics or synthetic composites has become a major problem for a waste management system to dispose of non-biodegradable wastes in the densely populated regions of the world (Mohanty et al., 2000). The demand for eco-friendly biocomposite packaging materials with biodegradable properties is increasingly to replace the petroleum-based synthetic polymers (Putri et al., 2020; Putri et al., 2019). Polylactic acid despite intense use in the preparation of biodegradable packaging material still belongs to synthetic polymers (Putri and Chinpa, 2020; Rajeshkumar et al., 2021). Therefore, it is a challenging task for researchers to produce value-added biodegradable disposable packaging materials from plant by-products and waste products. Biodegradable polymers can be obtained from different types of feedstock including agricultural products, such as corn or soybeans, and other sources like fishery, algae, or food waste (Kaushalya et al., 2019). Alternative materials such as plant waste by-products are being exploited to produce biodegradable packaging material and edible cutlery.

Proteins sources from plants and animals have been exploited because of their functional properties (Olatunde et al., 2021). Soy protein isolate (SPI) is extracted from soybeans as a plant by-product that exhibits excellent biodegradable and compostable properties compared to the plastic material. SPI has been employed as the key material for the development of biodegradable composites as plastic replacers (Echeverría et al., 2014). Several modifications of SPI have shown promising results to improve mechanical and thermal properties (Liu et al., 2021). Numerous products obtained from soybean include defatted soy flour, soy protein concentrate, and SPI amount 50, 70, and 90% of protein content, respectively (Saenghirunwattana et al., 2014). The thermal stability of SPI has been reported to be 244.80 °C (Qin et al., 2019). However, soy protein-based cutlery could not withstand the high mechanical strength and high moisture absorption. Therefore, the mechanical resistance of cutlery could be improved by the utilization of natural fibers from plant by-products or fresh vegetable wastes.

During the past decade, natural fibers have been extensively employed to replace synthetic fibers in composites and are a valuable addition to the green environment and economy (Rajeshkumar et al., 2021). Preparation of green composites or cutlery using plant proteins and plant fibers have several characteristic features such as low cost, lightweight, abundant and biodegradable. Soy protein supplemented with polylactic acid (PLA), corn husk fiber, and silane 1.5% have been documented to form a protein/fiber network with enhanced mechanical properties (Saenghirunwattana et al. (2014).

Morning glory (*Ipomoea aquatica*) is a vegetable with several health benefits widely consumed in Thailand (Austin, 2007; Sultana and Rahman, 2016). It is estimated that 2.60 million kg of morning glory seeds worth 207.78 million baht have been exported in the year 2020 from Thailand to the other parts of the world (Agriculture, 2020). Additionally, morning glory is referred to as water spinach has boosted the economic status of farmers for decades for maintaining the consistent fresh supply in the Thai traditional markets (Ketkrai et al., 2018). A large amount of morning glory stem is daily produced and becomes the big waste in every part of Thailand. Morning glory stem fiber has been characterized for the physical, chemical, mechanical and thermal properties such as density (1401 kg/cm<sup>3</sup>), cellulose content (72.76 wt. %), hemicelluloses content (13.6 wt. %), tensile strength of 173–658 MPa with a strain rate of 2.03–6.63% and thermal stability up to a temperature of 311 °C with kinetic activation energy of 99.82 kJ/mol, respectively (Santhanam et al., 2016). Nevertheless, there is no information on the use of morning glory stem fiber (MGSF) in the production of SPI cutlery. Therefore, this study aimed to develop an edible and biodegradable SPI-based cutlery reinforced with different levels of MGSF subjected to hydraulic hot press molding. Water resistance and mechanical properties of SPI incorporated MGSF cutlery were also investigated.

## 2. Material and methods

### 2.1. Materials

Soy protein isolate (SPI) was purchased from Guanxian Ruixiang Biotechnology Development Co., Ltd. China, and glycerol was supplied by Thai Glycerine Co., Ltd. Thailand was used as a plasticizer. Chemical analysis indicated moisture, protein, ash, and lipid content of SPI as 6.64, 90.80, 5.48, 0.70 % (wet weight basis), respectively.

### 2.2. Preparation of morning glory stem fiber

Morning glory (*Ipomoea aquatica*) stems (MGS) were collected as fresh vegetable waste from a local farmers market, Chiang Rai, Thailand in May 2021. MGS were washed using distilled water to remove the dust and soil particles. Washed MGS were cut into pieces 10 mm in length with a stainless steel scissor and dried at 80 °C for 15 h in a hot air tray dryer. Dried MGS were ground in a grinder and sieved using a stainless steel 230 mesh (63 µm pore size) to obtain crude morning glory stem fiber (MGSF) powder. The crude MGSF constituted of powdered particles and fibers was transferred into zip-lock bags and placed in a desiccator at 25 °C until used.

### 2.3. Bio-composite preparation from SPI without and with MGSF

SPI and crude MGSF were dehydrated in the oven at 60 °C and 80 °C for 6 h and 15 h before the preparation of bio-composite, respectively. SPI cutlery was prepared by mixing 70% of SPI and 30% glycerol added with different levels of MGSF (5, 10, 20%, w/w) to obtain a final weight of 8 g per cutlery sample (Table 1). All the cutlery sample abbreviations using SPI, glycerol, and MGSF are described as follows:

SPI-CON (70% SPI + 30% glycerol)

SPI-MGSF-5 (70% SPI + 30% glycerol + 5% MGSF)

SPI-MGSF-10 (70% SPI + 30% glycerol + 10% MGSF)

SPI-MGSF-20 (70% SPI + 30% glycerol + 20% MGSF)

Commercial polylactic acid cutlery (PLA-COM) sample was purchased from the market for comparison of mechanical properties with that of SPI-based cutlery. All the SPI cutlery samples without and with MGSF were subjected to compression molding process using a hydraulic hot-press machine (Labtech Engineering Co. Ltd., Thailand) at 160 °C, 100 bar for 5 min pressing time.

### 2.4. Impact on the physical and mechanical properties of SPI cutlery without and with the addition of MGSF

#### 2.4.1. Color values

The color of cutlery samples was evaluated using a CIE Lab-scale hand colorimeter (CR-10, Konica Minolta, Inc., Japan). Color parameters such as L\* (lightness), a\* (red-green), and b\* (yellow-blue) were analyzed following the method of Tongdeesontorn et al. (2020). The method of Guerrero et al. (2011), was employed for the calculation of Chrome and hue angle.

#### 2.4.2. Measurement of flexibility and mechanical properties of SPI cutlery without and with MGSF

The universal testing machine Model 5566 (Instron, USA) was used to measure the stiffness of SPI cutlery as per the method of (Demmer, 2011). Flexural modulus and impact strength (impact tester model, ceast 9050, Instron, Italy), were performed following the guidelines of ASTM D790 and ASTM D6110, respectively (Suharty et al., 2016). Before testing, SPI cutlery samples were pre-conditioned in an environmental chamber at 50% RH and 25 °C for 24 h. A vernier caliper was used to measure the widest part of the cutlery, marked with a first straight line and a second line was measured at 82.5 mm from the first line towards the handle on which the weight was placed during mechanical testing of cutlery

**Table 1.** Composition, Stiffness, deflection and color values of soy protein isolate (SPI) cutlery without and with different levels of morning glory stem fiber (MGSF).

Sample treatments	Composition/sample (g)			Stiffness (N/mm)	Deflection at 0.05 N (mm)	L*	a*	b*	Chroma	Hue
	SPI	Glycerol	MGSF							
SPI-CON	5.6	2.4	-	2.27 ± 0.7 <sup>b</sup>	5.5 ± 0.5 <sup>d</sup>	26.5 ± 1.6 <sup>b</sup>	7.5 ± 1.4 <sup>a</sup>	9.9 ± 1.0 <sup>a</sup>	12.4 ± 1.4 <sup>a</sup>	37.1 ± 4.1 <sup>e</sup>
SPI-MGSF-5	5.3	2.3	0.4	1.6 ± 0.2 <sup>c</sup>	8.6 ± 0.9 <sup>c</sup>	24.5 ± 0.3 <sup>c</sup>	3.6 ± 1.0 <sup>c</sup>	3.4 ± 0.3 <sup>c</sup>	5.0 ± 0.8 <sup>d</sup>	47.4 ± 7.4 <sup>d</sup>
SPI-MGSF-10	5.0	2.2	0.8	1.4 ± 0.4 <sup>c</sup>	10.9 ± 0.3 <sup>b</sup>	24.2 ± 0.7 <sup>c</sup>	3.6 ± 0.5 <sup>c</sup>	2.6 ± 0.9 <sup>cd</sup>	4.5 ± 1.0 <sup>cd</sup>	53.8 ± 6.8 <sup>c</sup>
SPI-MGSF-20	4.5	1.9	1.6	1.2 ± 0.4 <sup>c</sup>	12.8 ± 0.9 <sup>a</sup>	24.0 ± 0.2 <sup>c</sup>	3.0 ± 0.3 <sup>c</sup>	2.1 ± 0.4 <sup>cd</sup>	3.7 ± 0.3 <sup>c</sup>	55.0 ± 6.3 <sup>b</sup>
PLA-COM	-	-	-	123.7 ± 0.5 <sup>a</sup>	0.5 ± 0.3 <sup>e</sup>	69.5 ± 0.3 <sup>a</sup>	2.2 ± 0.4 <sup>b</sup>	6.4 ± 0.5 <sup>b</sup>	6.8 ± 0.4 <sup>b</sup>	71.3 ± 1.7 <sup>a</sup>

Values are presented as the mean ± standard deviation (n = 5). Different lowercase letters within the same column indicated significant differences (p < 0.05). SPI-CON, SPI-MGSF-5, SPI-MGSF-10 and SPI-MGSF-20 samples presented SPI without and with addition of MGSF at different levels of 5, 10 and 20% respectively. PLA-COM: Commercial polylactic acid cutlery.

samples (Figure 1A). The compression (50 mm/min) was done using a 6 mm probe, aligned at a midpoint of the widest part of cutlery samples. The deflection (mm) was recorded at 0.05 N compression force. All the tests were run in replicates (n = 5). Furthermore, dimensions of cutlery samples after compression molding were measured as total length (19 cm), the thickness of the widest part (1.568 mm), and thickness of the handle part (1.733 mm) (Figure 1B).

#### 2.4.3. Water absorption, degree of swelling, and solubility of SPI cutlery without and with MGSF

Water absorption of SPI cutlery samples was determined according to the ASTM D570 method. Samples were dried at 50 °C for 24 h and placed in a desiccator at ambient temperature. The initial dried weight of samples was recorded. Samples were immersed in distilled water (250 ml) for 24 h. The excess water drained and all the samples were squeezed using scratch and residue-free Kimberly-Clark™ Professional wipes (P.T. Science Lab Co., Ltd). The final weight of the samples was measured. The percentage of water absorption was calculated as follows using Eq. (1).

$$\text{Water absorption (\%)} = \{(M_1 - M_0) / M_0\} \times 100\% \quad (1)$$

Where  $M_0$  and  $M_1$  are referred to as initial dry weight and post water absorption weight of the samples (g).

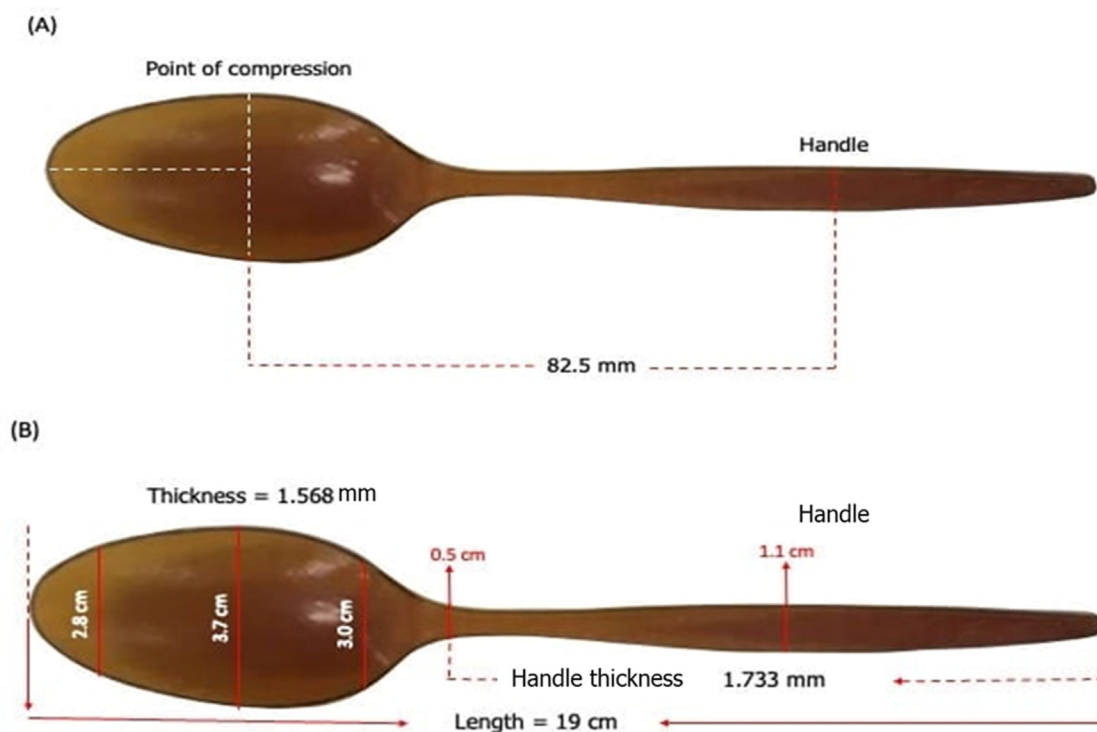
Water solubility was determined by the immersion of 3g of each sample in distilled water (30 ml) and placed on a rotary shaker (120 rpm) at 25 °C for 24 h. The insoluble was filtered using filter paper (Whatman® no. 1) allowed to dry in a hot air oven at 105 °C for 24 h. Solubility of SPI cutlery was calculated following the method of Tongdeesoontorn et al. (2020), presented as follows in Eq. (2).

$$\text{Solubility} = \{(\text{Initial dried weight} - \text{final weight}) / (\text{Initial dried weight})\} \times 100 \quad (2)$$

The degree of swelling was measured by the thickness of the SPI samples before and after pouring 5 ml on the surface of the samples for 1 h (Gamero et al., 2019). The thickness ( $t$ ) of all the samples was measured with a thickness gauge (Mitutoyo, Japan). The degree of swelling was calculated using Eq. (3).

$$\text{Degree of swelling (\%)} = (t - t_0) / t_0 \times 100 \quad (3)$$

Where,  $t_0$  is the initial thickness and  $t$  is the final thickness of SPI cutlery, respectively.



**Figure 1.** Photographs of SPI cutlery for mechanical testing (A) and dimensional measurements (B) after compressing molding.



**Figure 2.** Digital photographs of SPI cutlery supplemented with different levels of morning glory stem fiber (MGSF), (A) SPI-CON, (B) SPI-MGSF-5, (C) SPI-MGSF-10, (D) SPI-MGSF-20. SPI-CON (SPI without MGSF), SPI-MGSF-5, SPI-MGSF-10 and SPI-MGSF-20 samples presented SPI without and with the addition of MGSF at different levels of 5, 10, and 20%, respectively.

#### 2.4.4. Microstructure

Micrographs of the edible and biodegradable cutlery stored at 25 °C were observed by a scanning electron microscope (JEOL JSM-6700F, Tokyo, Japan) with gold sputtering following the method of [Tongdeesoontorn et al. \(2021\)](#).

#### 2.5. Statistical analysis

Analysis of variance (ANOVA) and Duncan's multiple ranges was performed using a statistical program, SPSS v. 10.0. Samples were tested at a level of significance ( $p < 0.05$ ) for all the parameters analyzed.

### 3. Results and discussion

#### 3.1. Effect of different levels of MGSF on physical properties of SPI cutlery

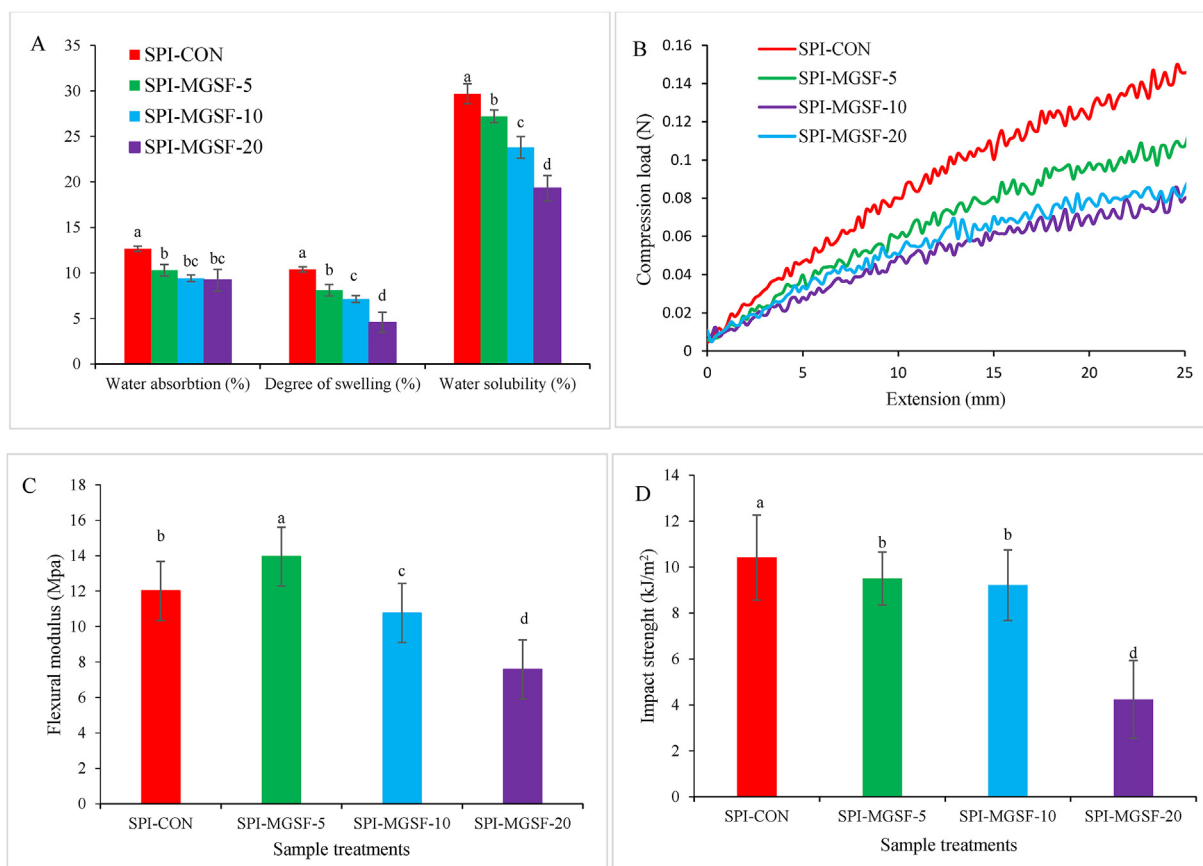
Color values of SPI cutlery samples with different levels of MGSF have been presented in [Table 1](#). Generally, the lightness of all the samples treated with 5–20% MGSF was decreased compared to the SPI-CON sample ( $p > 0.05$ ). However, the PLA-COM sample showed higher lightness values compared to SPI-CON, and SPI cutlery samples treated with 5–20% MGSF ( $p < 0.05$ ). Redness ( $a^*$ ) values of SPI-CON were higher ( $p < 0.05$ ), than the SPI with different levels of MGSF, and slight differences of  $a^*$  values were noticed in SPI treated 5–20% MGSF samples ( $p > 0.05$ ). PLA-COM sample showed the lowest  $a^*$  values compared to other samples. A similar trend was evidenced in  $b^*$  values, which tend to increase in SPI-CON and PLA-COM samples compared to the MGSF treated SPI cutlery samples ( $p < 0.05$ ). Additionally, the SPI-CON sample displayed higher Chroma values than the PLA-COM samples and the lowest Chroma values were attained in the SPI-MGSF-5 sample ( $p <$

0.05). Hue angle were obtained in descending order of samples such as PLA-COM  $<$  SPI-MGSF-20  $<$  SPI-MGSF-10  $<$  SPI-MGSF-5  $<$  SPI-CON ( $p < 0.05$ ). The photographs of different SPI-based cutlery samples produced without and with MGSF are presented in [Figure 2](#). The difference in the color attained in the SPI-MGSF-5 sample was correlated with the addition of MGSF that showed interference in the overall color values compared to the samples without MGSF. Additionally, SPI along with MGSF powder might have interacted with protein bases during hydraulic hot press molding to present different variations of colors in the resultant cutlery samples. The color variation has been associated with the Maillard reaction in SPI combined carboxymethyl cellulose blends to improve the sealing properties of biocomposite film ([Su et al., 2012](#)).

##### 3.1.1. Water absorption, degree of swelling, and water solubility

Water absorption of SPI cutlery with varying levels of MGSF is shown in [Figure 3A](#). SPI-CON sample showed higher water absorption than the SPI cutlery samples supplemented with a 10–20% level of MGSF ( $p < 0.05$ ). There was no difference observed in the water absorption of SPI samples with different levels of MGSF ( $p > 0.05$ ). This lower water absorption in SPI treated crude MGSF samples might cause interference among the hydrophilic functional groups of SPI. Hydrophilic groups ( $-\text{COOH}$ ,  $-\text{NH}_2$ , and  $-\text{OH}$  groups) in soy proteins have been reported to develop weaker interactions during protein chain crosslinking resulting in enhanced hydrophilic properties ([Zhao et al., 2019](#)). The water absorption in SPI-MGSF-5, SPI-MGSF-10, and SPI-MGSF-20 samples was decreased by 18.3%, 25.4%, and 26.9% compared to the SPI-CON (SPI only, without any treatment), respectively. Therefore, modifications of SPI have been reported with the addition of fibers to strengthen the biocomposite matrix thereby decreasing water absorption in the long-lasting packaging materials ([Gu et al., 2020](#)).





**Figure 3.** Water absorption, degree of swelling and water solubility (A); Compression load (B) Flexural modulus (C); and Impact strength (D) of SPI cutlery (SPI-CON (SPI without MGSF), SPI-MGSF-5, SPI-MGSF-10 and SPI-MGSF-20 samples) and PLA spoon. Different lowercase letters on the bars indicated significant differences ( $p < 0.05$ ).

The degree of swelling visualized in the SPI sample treated 10–20% of MGSF was lower than the SPI-CON sample ( $p < 0.05$ ) (Figure 3A). The results indicated that MGSF at 10–20% level corresponded to the decreased degree of swelling in SPI cutlery. This might be associated with the less water adhesion on the surface of SPI cutlery samples due to interference of reinforced MGSF shielding the hydrophilic groups of SPI. The degree of swelling decreased from SPI-MGSF-5, SPI-MGSF-10, and SPI-MGSF-20 that exhibit the lowest swelling on the surface ( $p < 0.05$ ). Similar findings were documented on the degree of swelling in plant-based proteins incorporated with plant fibers to enhance moisture resistance properties (Bruyninckx et al., 2016; Jerez et al., 2005; Li et al., 2017).

The water solubility of the SPI-CON sample was higher than the SPI samples treated with MGSF at different levels ( $p < 0.05$ ), as shown in Figure 3A. SPI-MGSF-5 showed lower solubility compared to SPI-CON, followed by the samples added with 10–20% MGSF ( $p < 0.05$ ). This MGSF at higher levels depicted lower solubility could be correlated with the lower values of degree of swelling owing to lower hydrophilicity. Earlier reports suggested that SPI powder contains many polar amino acids, resulting in the high moisture sensitivity of resin prepared from SPI (Lodha and Netravali, 2005).

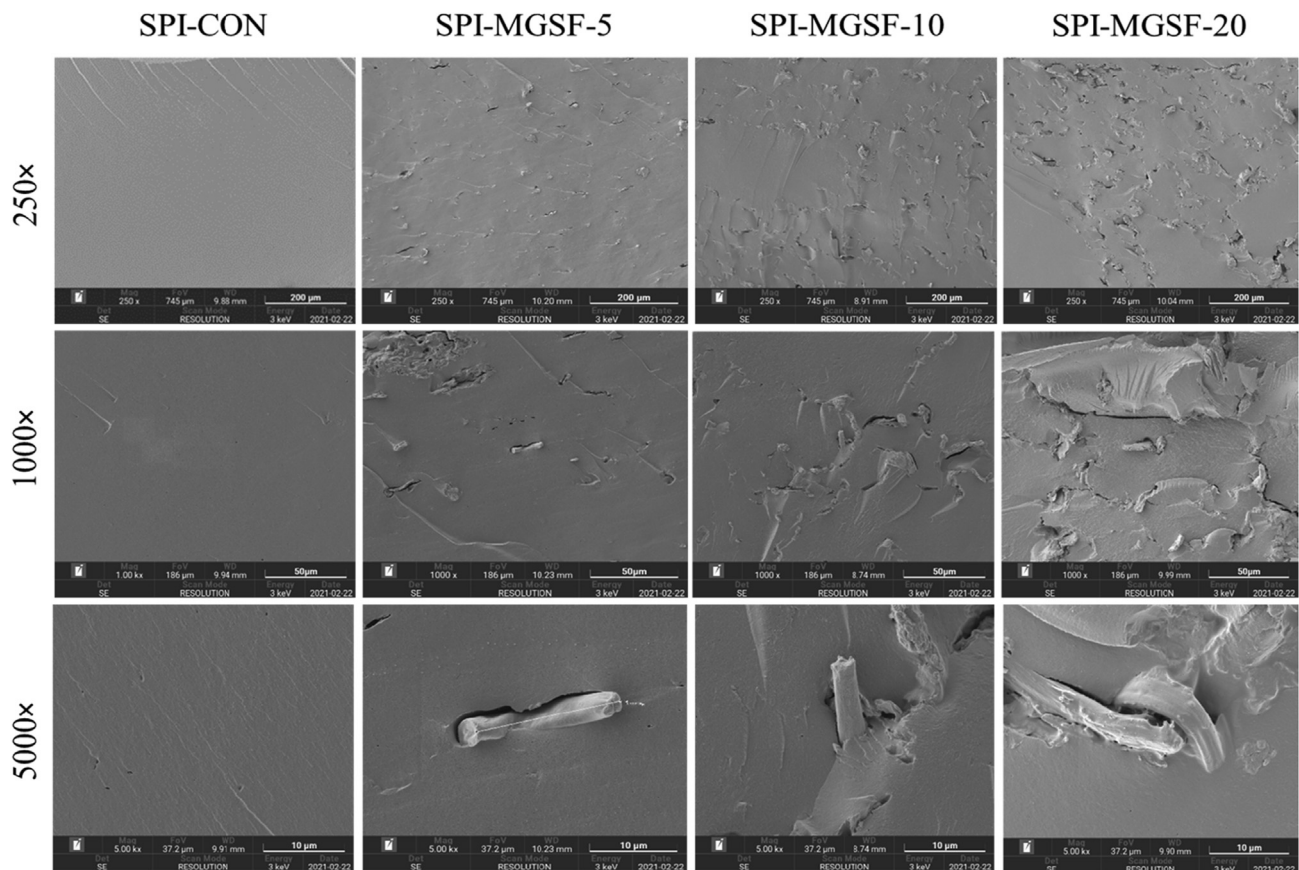
### 3.1.2. Measurement of compression load, flexural modulus, impact strength, stiffness, and deflection

The compression load of SPI cutlery samples with different levels of MGSF is presented in Figure 3B. SPI-CON sample exhibited the highest compression load in comparison with SPI samples treated with 5, 10, and 20% MGSF. The compression force required for the SPI-CON sample was higher than the samples treated with different levels of MGSF. SPI-MGSF-5 sample showed a lower compression load than the SPI-CON sample.

Additionally, with the increases in levels of MGSF levels in SPI cutlery, compression load decreased subsequently. The lowest compression load was attained in the SPI-MGSF-20 sample. This might be attributed to the larger size of fibers and the heterogeneous distribution of MGSF in the SPI matrix.

In addition to the compression load applied, the flexural modulus of SPI cutlery samples is depicted in Figure 3C. Flexural modulus was higher in SPI-MGSF-5 samples compared to SPI-CON and other treated samples ( $p < 0.05$ ). However, the addition of 10–20% MGSF showed a decreased trend in flexural modulus than the SPI-MGSF-5 ( $p < 0.05$ ). This could be related to the higher content of MGSF with heterogeneous distribution or agglomeration of fibers in SPI-MGSF-10 and SPI-MGSF-20 samples, respectively. The lowest values of flexural modulus were obtained in SPI-MGSF-20 compared to other samples ( $p < 0.05$ ). However, the flexural modulus of PLA material was reported to be  $1619.2 \pm 115.1$  MPa that showed a marked difference from the SPI samples without and with the addition of different levels of MGSF (Likittanaprasong et al., 2015).

The impact strength of SPI-CON was higher than the MGSF treated samples ( $p < 0.05$ ) (Figure 3D). Additionally, the result obtained in SPI-MGSF samples and those treated with 10% MGSF had no difference in impact strength ( $p > 0.05$ ) and thereafter showed decreased trend in the SPI-MGSF-20 sample ( $p < 0.05$ ). The reduction of impact strength was in line with the compression load and flexural modulus of SPI samples added with 10–20% of MGSF (Figures 3B and 3C). It has been postulated that the lower impact strength and flexural modulus could be due to immiscibility and heterogeneous distribution of high fiber content in the SPI matrix (Rey et al., 2002). The impact strength of the PLA-COM sample was highest ( $75.33 \pm 7.48$  kJ/m<sup>2</sup>) compared to SPI samples treated with different levels of MGSF.



**Figure 4.** Scanning electron micrographs of SPI-CON (SPI without MGSF), SPI-MGSF-5, SPI-MGSF-10 and SPI-MGSF-20 samples visualized at different magnifications (250 $\times$ , 1000 $\times$  and 5000 $\times$ ).

The stiffness and deflection values of SPI cutlery are presented in [Table 1](#). Stiffness values of the SPI-CON samples were higher than the SPI cutlery samples treated with 5–10% of MGSF ( $p < 0.05$ ). There was no marked difference visualized in SPI-MGSF-5, SPI-MGSF-10, and SPI-MGSF-20 samples ( $p > 0.05$ ). However, the PLA-COM sample showed the highest stiffness values compared to the SPI samples without and with different levels of MGSF ( $p < 0.05$ ). Conversely, the deflection value obtained in the SPI-CON sample was lower than the SPI samples treated with 5–20% of MGSF ( $p < 0.05$ ). Deflection values increased with the increased levels of MGSF from 5 to 20% in SPI samples following the order of SPI-MGSF-5 < SPI-MGSF-10 < SPI-MGSF-20, respectively ( $p < 0.05$ ). Furthermore, the PLA-COM sample showed the lowest deflection value compared to all the SPI samples with and without MGSF ( $p < 0.05$ ). Commercial PLA packaging materials have been reported to have good mechanical properties, high strength, and stiffness properties ([Boontima et al., 2015](#); [Farah et al., 2016](#)).

Several types of research have been conducted for improving the properties of soy protein-based biocomposites using biopolymers and plant fibers. [Saenghirunwattana et al. \(2014\)](#) prepared soy protein with PLA and cornhusk treated with silane 1.5% (w/v) showed potential adhesion to improve the strength of the resulting biocomposite. [Boontima et al. \(2015\)](#) SPI with sugarcane bagasse fiber at higher concentration showed improved tensile, flexural, and impact strengths as a result of reinforcement action of fibers in the biocomposite. [Wang et al. \(2017\)](#) compared the changing properties of six plant fibers including rice straw, wheat straw, peanut straw, rice husk, wheat husk, and peanut shell, in soy protein composite by the compression process. The peanut straw, peanut shell, and wheat fiber contained extra hydrophilic groups, induced hydrogen bonds, showed the lowest equilibrium moisture content followed by higher thermal stability during the initial pyrolysis temperature of 283.4  $^{\circ}\text{C}$ , in soybean protein composite, respectively.

There potential functional properties of the aforementioned fibers were documented to have effective binding interface compatibility resulting in higher mechanical properties. [Sun et al. \(2018\)](#) developed hydrolyzed SPI composite incorporated with straw fiber by injection molding for biodegradable flower pots to replace plastic wrapping with excellent mechanical and biodegradable properties. [Gamero et al. \(2019\)](#) developed soy protein-based bioplastics with 5% lignocellulose fibers by injection molding that improved the mechanical properties with reduced water absorption capacity.

### 3.2. Microstructure of SPI cutlery without and with MGSF

Micrographs of SPI cutlery samples incorporated with MGSF have been presented in [Figure 4](#). Microscopic structure at different magnifications (250 $\times$ , 1000 $\times$ , and 5000 $\times$ ) revealed that SPI-CON without any fiber showed the plain matrix compared to the MGSF treated samples. SPI-MGSF-5 sample showed a uniform distribution without any agglomeration and showed a smooth surface without any compression molding defect. However, the samples with high MGSF levels of 10–20% (w/w) displayed the heterogeneous distribution of crude fibers leading to the formation of voids that displayed roughness on the surface of SPI cutlery samples. Micrographs spotted the presence of crude fiber on the SPI matrix in the SPI-MGSF-5 sample, displayed that 5% MGSF was the optimal concentration distributed uniformly compared to other SPI samples with a higher concentration of MGSF. Microstructure of SPI-MGSF-10 and SPI-MGSF-20 samples depicted heterogeneous distribution of MGSF in SPI matrix and developed cracks upon compression molding process. Thus, MGSF levels from 10 to 20% were not feasible for the production of SPI-based cutlery. The micrograph results were in line with the SPI composite reinforced with coconut husk fibers 3–5% relatively well dispersed. However, 7–10 % of coconut husk fiber

agglomerated thereby affecting the biocomposite properties (Saenghirunwattana et al., 2014).

#### 4. Conclusion

Physical and mechanical properties were retained with the aid of MGSF in SPI cutlery. SPI-MGSF-5 sample showed a higher hue value, but lightness, chroma, stiffness, followed by flexural modulus and impact strength values were decreased compared to SPI-CON (without MGSF). SPI-MGSF-5 sample improved water resistance properties as evidenced by lower water absorption, degree of swelling, and water solubility than the other counterparts. Micrographs of the SPI-MGSF-5 sample showed uniform distribution of MGSF with any voids or cracks on the surface of resultant SPI cutlery. Thus, SPI reinforced MGSF composite can act as eco-friendly and could be commercially designed into edible and biodegradable cutlery for food applications. Above all, this research work explains some productive articles from natural fiber as alternant to nondegradable thermoplastic to save our globe from plastic pollution.

#### Declarations

##### Author contribution statement

Wissuta Choeybundit: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Khursheed Ahmad Shiekh: Analyzed and interpreted the data; Wrote the paper.

Pornchai Rachtanapun: Contributed reagents, materials, analysis tools or data; Wrote the paper.

Wirongrong Tongdeesontorn: Conceived and designed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

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##### Data availability statement

Data included in article/supplementary material/referenced in article.

##### Declaration of interests statement

The authors declare no conflict of interest.

##### Additional information

No additional information is available for this paper.

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#### References

- Agriculture, D.O., 2020. The Quantity and Value of Seed Exports. Retrieved from. <https://www.doa.go.th>.
- Austin, D., 2007. Water Spinach (*Ipomoea aquatica*, Convolvulaceae): a food gone wild. *Ethnobot. Res. Appl.* 5.
- Boontima, B., Noomhorm, A., Puttanlek, C., Uttapap, D., Rungsardthong, V., 2015. Mechanical properties of sugarcane bagasse fiber-reinforced soy based biocomposites. *J. Polym. Environ.* 23 (1), 97–106.
- Bruyninckx, K., Jansens, K.J., Delcour, J.A., Smet, M., 2016. The effect of cross-linking additives on the structure and properties of glassy wheat gluten material. *Ind. Crop. Prod.* 81, 38–48.
- Demmer, B.J., 2011. Comparison and Analysis of Biobased/biodegradable and Petrochemical Cutlery Flexibility.
- Echeverría, I., Eisenberg, P., Mauri, A.N., 2014. Nanocomposites films based on soy proteins and montmorillonite processed by casting. *J. Membr. Sci.* 449, 15–26.
- Farah, S., Anderson, D.G., Langer, R., 2016. Physical and mechanical properties of PLA, and their functions in widespread applications — a comprehensive review. *Adv. Drug Deliv. Rev.* 107, 367–392.
- Gamero, S., Jiménez-Rosado, M., Romero, A., Bengoechea, C., Guerrero, A., 2019. Reinforcement of soy protein-based bioplastics through addition of lignocellulose and injection molding processing conditions. *J. Polym. Environ.* 27 (6), 1285–1293.
- Gu, W., Liu, X., Ye, Q., Gao, Q., Gong, S., Li, J., Shi, S.Q., 2020. Bio-inspired co-deposition strategy of aramid fibers to improve performance of soy protein isolate-based adhesive. *Ind. Crop. Prod.* 150, 112424.
- Guerrero, P., Nur Hanani, Z.A., Kerry, J.P., de la Caba, K., 2011. Characterization of soy protein-based films prepared with acids and oils by compression. *J. Food Eng.* 107 (1), 41–49.
- Jerez, A., Partal, P., Martínez, I., Gallegos, C., Guerrero, A., 2005. Rheology and processing of gluten based bioplastics. *Biochem. Eng. J.* 26 (2-3), 131–138.
- Kaushalya, R.A.N.C., Dhanushka, M.K.D.T., Samarasekara, A.M.P.B., Weragoda, V.S.C., 2019. Development of biodegradable packaging materials using polylactic acid (PLA) and locally extracted starch. In: Paper Presented at the 2019 Moratuwa Engineering Research Conference (MERCon).
- Ketkrai, S., Dampin, N., Chunkao, K., 2018. Production and distribution of water spinach (*Ipomoea aquatic Forsk.*) in the Tha Chin river. *Thai Sci. Technol. J.* 1325–1335.
- Li, Z., Zhang, Y., Ge, H., 2017. The membrane may be an important factor in browning of fresh-cut pear. *Food Chem.* 230, 265–270.
- Likittanaprasong, N., Seadan, M., Suttiruengwong, S., 2015. Impact property enhancement of poly (lactic acid) with different flexible copolymers. *IOP Conf. Ser. Mater. Sci. Eng.* 87.
- Liu, C., Yu, B., Tao, H., Liu, P., Zhao, H., Tan, C., Cui, B., 2021. Effects of soy protein isolate on mechanical and hydrophobic properties of oxidized corn starch film. *LWT-Food Sci. Technol.* 147, 111529.
- Lodha, P., Netravali, A.N., 2005. Characterization of stearic acid modified soy protein isolate resin and ramie fiber reinforced 'green' composites. *Compos. Sci. Technol.* 65 (7-8), 1211–1225.
- Mohanty, A.K., Khan, M.A., Hinrichsen, G., 2000. Influence of chemical surface modification on the properties of biodegradable jute fabrics-polyester amide composites. *Compos. Appl. Sci. Manuf.* 31 (2), 143–150.
- Olatunde, O.O., Singh, A., Shiekh, K.A., Nuthong, P., Benjakul, S., 2021. Effect of high voltage cold plasma on oxidation, physicochemical, and gelling properties of myofibrillar protein isolate from asian sea bass. *lates calcarifer* 10 (2), 326.
- Putri, K.N.A., Chinpa, W., 2020. Physical properties and crystal violet adsorption of biosorbent prepared from lemon grass fiber coated with polylactic acid/cellulose acetate blend. In: Proceedings of the the Pure and Applied Chemistry International Conference 2020 (PACCON2020), 2020. IMPACT Forum: Nonthaburi, Thailand, pp. 31–36.
- Putri, K.N.A., Siswanta, D., Suherman, S., 2019. Synthesis of edta-crosslinked chitosancarboxymethyl cellulose film as cu (ii) adsorbent. In: Proceedings of the ASEAN/Asian Academic Society International Conference Proceeding Series, Songkhla, Thailand, 11–14 November 2019, pp. 75–85.
- Putri, K.N.A., Keereerak, A., Chinpa, W., 2020. Novel cellulose-based biosorbent from lemongrass leaf combined with cellulose acetate for adsorption of crystal violet. *Int. J. Biol. Macromol.* 156, 762–772.
- Qin, Z., Mo, L., Liao, M., He, H., Sun, J., 2019. Preparation and characterization of soy protein isolate-based nanocomposite films with cellulose nanofibers and nano-silica via silane grafting. *Polymers* 11 (11).
- Rajeshkumar, G., Arvindh Seshadri, S., Devnani, G.L., Sanjay, M.R., Siongchin, S., Prakash Maran, J., Ronaldo Anuf, A., 2021. Environment friendly, renewable and sustainable poly lactic acid (PLA) based natural fiber reinforced composites – a comprehensive review. *J. Clean. Prod.* 310, 127483.
- Rey, L., Duchet, J., Galy, J., Sautereau, H., Vouagner, D., Carrion, L., 2002. Structural heterogeneities and mechanical properties of vinyl/dimethacrylate networks synthesized by thermal free radical polymerisation. *Polymer* 43 (16), 4375–4384.
- Saenghirunwattana, P., Noomhorm, A., Rungsardthong, V., 2014. Mechanical properties of soy protein based "green" composites reinforced with surface modified cornhusk fiber. *Ind. Crop. Prod.* 60, 144–150.
- Santhanam, K., Kumaravel, A., Saravanakumar, S.S., Arthanarieswaran, V.P., 2016. Characterization of new natural cellulosic fiber from the *Ipomoea staphylina* plant. *Int. J. Polym. Anal. Char.* 21 (3), 267–274.
- Su, J.F., Yuan, X.Y., Huang, Z., Wang, X.Y., Lu, X.Z., Zhang, L.D., Wang, S.B., 2012. Physicochemical properties of soy protein isolate/carboxymethyl cellulose blend films crosslinked by Maillard reactions: color, transparency and heat-sealing ability. *Mater. Sci. Eng. C* 32 (1), 40–46.

- Suharty, N.S., Ismail, H., Diharjo, K., Handayani, D.S., Firdaus, M., 2016. Effect of Kenaf fiber as a reinforcement on the tensile, flexural strength and impact toughness properties of recycled polypropylene/halloysite composites. *Procedia Chem.* 19, 253–258.
- Sultana, R., Rahman, A.H.M., 2016. Convolvulaceae: a taxonomically and medicinally important morning glory family. *Int. J. Bot. Stud.* 1, 47–52.
- Sun, E., Liao, G., Zhang, Q., Qu, P., Wu, G., Xu, Y., Huang, H., 2018. Green preparation of straw fiber reinforced hydrolyzed soy protein isolate/urea/formaldehyde composites for biocomposite flower pots application. *Materials* 11 (9).
- Tongdeesoontorn, W., Mauer, L.J., Wongruong, S., Sriburi, P., Rachtanapun, P., 2020. Physical and antioxidant properties of cassava starch-carboxymethyl cellulose incorporated with quercetin and TBHQ as active food packaging. *Polymers* 12 (2), 366.
- Tongdeesoontorn, W., Mauer, L.J., Wongruong, S., Sriburi, P., Reungsang, A., Rachtanapun, P., 2021. Antioxidant films from cassava starch/gelatin biocomposite fortified with quercetin and TBHQ and their applications in food models. *Polymers* 13 (7).
- Wang, Y., Wang, M., Zhang, W., He, C., 2017. Performance comparison of different plant fiber/soybean protein adhesive composites. *Bioresources* 12 (4), 8813–8826.
- Zhao, S., Wang, Z., Li, Z., Li, L., Li, J., Zhang, S., 2019. Core-shell nanohybrid elastomer based on co-deposition strategy to improve performance of soy protein adhesive. *ACS Appl. Mater. Interfaces* 11 (35), 32414–32422.