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Eucheuma powder as a partial flour replacement and its effect on the properties of sponge cake

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ABSTRACT

In order to provide more healthy food choice, sponge cakes with high dietary fibre content need to be developed. In this study, *Eucheuma* powder which contains a high amount of dietary fibre (69.33%) was applied to replace 0, 5, 10, 15, and 20% of wheat flour to make sponge cakes, referred to as the control, EP5, EP10, EP15, and EP20, respectively. The results revealed that the specific gravity of the cake batters increased from 0.505 (control sample) to 0.559 (EP20 sample). Meanwhile, *Eucheuma* powder increased the viscosity and viscoelasticity of the batters. For the cakes, *Eucheuma* powder changed the crumb colour and the texture properties, however the flour can be replaced up to 10% without causing texture changes. After *Eucheuma* powder was applied, the total dietary fibre content of sponge cakes increased from 1.46% (cake with whole flour as control) to 8.07% (EP20). The sensory characteristic results indicated that up to 10% replacement of flour by *Eucheuma* in sponge cake was satisfactory in aspects e.g. quality, properties. Overall, up to 10% replacement of flour with *Eucheuma* powder was acceptable and beneficial for increasing dietary fibre intake.

1. Introduction

Sponge cakes are consumed worldwide with an increasing market demand. This is mainly due to its characteristics of fine texture, rich aroma and dense taste. But normally, this kind of dessert contains high amount of calories and lacks dietary fibre, which is not good as healthy diet.

Dietary fibre plays a vital role in human diet because it has important health beneficial effect. Eating food rich of dietary fibre regularly can decrease the incidence of several diseases, such as heart disease, constipation and cancer (Dhingra, Michael, Rajput, & Patil, 2012). In addition, dietary fibre contains both insoluble and soluble fractions, it could modify textures and enhance food stability during processing and storage (Thebaudin, Lefebvre, Harrington, & Bourgeois, 1997).

In order to develop healthy sponge cake, different sources of dietary fibre were used to partially or totally replace wheat flour in sponge cakes. Apple pomace incorporated into wheat flour led to higher acceptable quality of the cakes with 14.2% fibre content when 25% flour was replaced with apple pomace (Sudha, Baskaran, & Leelavathi, 2007). Green tea powder substituting some flour in sponge cakes produced a green tea cake with more effective antioxidant properties, as well as higher content of dietary fibre (Lu, Lee, Mau, & Lin, 2010).

Seaweeds have been utilised as food material for a long history (Kitade et al., 2018), which are also good sources of dietary fibre. Gómez-Ordóñez, Jiménez-Escrig, and Rupérez (2010) reported that the total dietary fibre content of five different edible Spanish seaweeds was ranged from 29.3 to 37.4% (dry weight). Sanz-Pintos et al. (2017) measured the total dietary fibre content of several Chilean seaweeds and found that the total dietary fibre content could be up to 59.8% based on dry weight.

Eucheuma (also known as *Eucheuma cottonii*) is a kind of red seaweed with high growth rate, good output per area, and great efficiency in CO_2 capture (Jumaidin, Sapuan, Jawaid, Ishak, & Sahari, 2017). It is one of the most antioxidative tropical edible species containing a high amount of dietary fibre, macro-minerals, trace minerals, and fatty acids (especially eicosapentaenoic acid), which all have health benefits (Chen, McClements, & Decker, 2013; Matanjun, Mohamed, Mustapha, & Muhammad, 2009). Thus using *Eucheuma* powder in food products could supply dietary fibre and mineral content. Because the Na/K ratio for *Eucheuma* powder was very low, consuming it may also decrease the incidence of hypertension (Matanjun et al., 2009). In addition, its high swelling and water holding capacities enable it to be applied as a functional ingredient to modify texture and reduce calories of formulated food. Moreover, it can be used to stabilise food emulsions due to its high oil absorption capacity (Senthil, Mamatha, &

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Mahadevaswamy, 2005). Senthil et al. (2005) added up to 10% *Eucheuma* powder into fish cutlets without affecting their appearance, texture, and acceptability. Kumoro, Johnny, and Alfilovita (2016) used *Eucheuma* powder in noodles and developed a consumer-acceptable noodle with the lowest fat content and the highest protein content. However, there has been little use or development of *Eucheuma* in food.

In the present study, *Eucheuma* powder was used to replace cake flour in sponge cake in order to develop a new sponge cake product containing high dietary fibre content. The rheological properties and specific gravity of the cake batters, and the volume, the crumb colour, the texture profile analysis and the image analysis of cakes were performed to explain the effect of *Eucheuma* powder on the cakes. The contents of ash and dietary fibre were measured as well to show the nutritional quality of the cakes and the sensory evaluation was performed to show the acceptability of consumers.

2. Materials and methods

2.1. Ingredients

Eucheuma was purchased from Indonesia via a local supplier (Tam Kah Shark's Fin, Singapore) and dried at 50 °C for 24 h using a cabinet dryer after thoroughly water-washing. The sample was then ground using a grinding mill and sieved through a 200-mesh sieve. Cake flour (12.22% moisture, 8.03% protein, and 0.44% ash) was purchased from PRIMA RND (Prima Group, Singapore); the cake emulsifier (Liang San, Singapore, Singapore) including emulsifier, sorbitol, proplylene glycol, potassium hydroxide, and permitted colouring was obtained from Liang San Food Industry Company (Pantech Industrial Complex, Singapore); the remaining ingredients (eggs, sugar, and canola oil) were purchased from a local supermarket (Fairprice, Singapore).

2.2. Chemical and physical characterization of Eucheuma powder

The components of *Eucheuma* powder, including moisture, protein, fat, and ash, were determined according to AOAC methods (AOAC, 1990). The total dietary fibre (TDF), insoluble dietary fibre (IDF) and soluble dietary fibre (SDF) were assayed using the gravimetric enzymatic method as reported by Ben Jeddou et al. (2017) and Kim et al. (2012).

The water holding capacity and oil absorption capacity of the *Eucheuma* powder were measured according to the methods of Senthil et al. (2005) and Mao, Miao, and Roos (2014) with some modifications. Dry *Eucheuma* powder (0.50 g) was added to a 50 mL centrifuge tube and 30 mL distilled water was added. The sample was stirred and left for 1 h at room temperature. After centrifugation at 3000 × *g* for 20 min, the supernatant was discarded and the residue was weighed. Water holding capacity was recorded as g of water/g of dry sample. For the oil absorption capacity, the same method as above was applied, but using canola oil instead of water. The oil absorption capacity was recorded as g of oil/g of dry sample and three repetitions have been performed.

2.3. Preparation of sponge cake batter and baking

The sponge cake recipe of Atsushi Ishii and Kunio Ishida (2009) was applied with some modifications. Table 1 shows the formula of the control cakes and the sponge cakes at four different *Eucheuma* powder levels. After sugar, whole eggs, and cake emulsifier were mixed thoroughly for 8 min at speed 6 in the mixer (KitchenAid, St Joseph, MI, USA), the shifted flour (or *Eucheuma* powder and flour) and canola oil were added separately and homogenised for 2 min at speed 1. Finally, 250 g of the batter was measured into a baking tin and baked in a convection oven (Fabricant Eurfours®, Gommegnies, France) which was pre-heated at 180 °C for 30 min. The cakes were taken out and kept at room temperature to cool for 120 min before conducting the analyses. For each sample, three batches were prepared for the analyses.

Table 1
Formulations of control sponge cake and cakes made with *Eucheuma* powder replacing some flour.

Sample	*Eucheuma* powder (g)	Flour (g)	Whole egg (g)	Sugar (g)	Cake emulsifier (g)	Canola oil (g)
Control	0	100	200	100	8	25
EP5	5	95	200	100	8	25
EP10	10	90	200	100	8	25
EP15	15	85	200	100	8	25
EP20	20	80	200	100	8	25

* Control, EP5, EP10, EP15, and EP20: cakes prepared with 0, 5, 10, 15, and 20% of flour replaced by *Eucheuma* powder, respectively.

2.4. Specific gravity and rheological properties of cake batters

The specific gravity of the batter was determined by the mass of the batter relative to that of water using a cylindrical cup. Then the specific gravity was obtained by using a formula (Lin, Tay, Yang, Yang, & Li, 2017a; 2017b):

Specific gravity = mass of batter/mass of water at 25 °C

The rheological characterisation was performed by a rotational Anton Paar MCR 102 rheometer (Anton Paar, Graz, Austria), with cone-plate geometry, a rotating cone of 60 mm in diameter, and a cone angle of 1° with a gap of 0.116 mm. The batter sample for rheological characterisation was put in the measuring system, and left for 5 min at 25 °C for structure recovery. The sample edges were coated with sunflower oil to reduce moisture evaporation during measurement (Sow, Tan, & Yang, 2019; Yang, Yang, & Yang, 2018a, 2018b). Flow curves were collected by changing the shear rate from 0.0001 to 1000 s^{-1}, amplitude sweeps from 0.1% to 100% at 1 rad s^{-1}. The storage modulus G′ and loss modulus G″ were recorded during the above dynamic rheological measurements.

2.5. Volume, weight, and crumb colour analysis of cakes

The volumes of the cakes were obtained using the displacement method as described by Salehi, Kashaninejad, Asadi, and Najafi (2016). The weight of each cake was measured by an electronic balance after thoroughly cooling. The colour of the cake crumb was determined using a CM-5 spectrophotometer (Konica Minolta Holdings, Inc., Tokyo, Japan). The colour parameters L^*, a^* and b^* represent lightness, redness/greenness, and yellowness/blueness, respectively. Plastic cling wrap was applied as a reference.

2.6. Texture profile analysis of cakes

The textural properties of the cakes were measured according to the method of Lin et al. (2017a) with some modifications. The properties were measured 2 h after baking via a TA-XT2i texture analyser (Stable Micro System Ltd., Surrey, UK). Cake samples were cut into cubes (20 × 20 × 20 mm^3). A double compression test was performed (Sow, Toh, Wong, & Yang, 2019) using a 36 mm cylinder probe. In the compression test, the parameters were set as: pre-test speed = 5 mm/s, test speed = 1 mm/s, and post-test speed = 1 mm/s. The compression distance was 10 mm. The textural properties measured were hardness, cohesiveness, springiness, resilience, and chewiness, and were calculated from the curves provided by the equipment.

2.7. Image analysis of cakes

A method similar to that of Lin et al. (2017a) was used. A cross section of the cakes, 1 cm in thickness, was applied. The sample pores were delineated after painted using black oil based ink. Images (pore area > 0.01 cm^2) were captured using a digital camera (Nikon DS5100, Nikon Corporation, Tokyo, Japan). An Olympus SZ61 (Olympus, Melville, NY) stereomicroscope with a camera attachment was used to reveal the details with pore area < 0.01 cm^2. Thresholding was conducted to get a black and white image of the pore skeleton applying ImageJ2 software (National Institutes of Health, USA). A histogram of the pore area was constructed using Microsoft Excel from the data collected. The pore area was equivalent to the sum of the calibrated pixel units.

2.8. Dietary fibre and ash content analysis of cakes

The amount of total dietary fibre (TDF), insoluble dietary fibre (IDF) and soluble dietary fibre (SDF) was assayed according to the gravimetric enzymatic method as mentioned previously. The ash contents of different cake samples were measured according to (AOAC, 1990).

2.9. Sensory evaluation

Sensory test was conducted by 60 volunteer students as untrained panellists (21–38 years of age) at room temperature. The cakes were cut into 2×2×2 cm^3 cubes and put in covered sensory cups to prevent moisture loss and flavour interance. All cups were coded with random three-digit numbers. Water was provided to clean the palate during evaluation. The acceptability of cake samples was evaluated based on their appearance, colour, odour, flavour, and overall quality using a 7-point hedonic scale (7 = like extremely, 4 = neither like nor dislike, 1 = dislike extremely) (Kim et al., 2012). The control cake was presented simultaneously with the rest of the samples.

2.10. Statistical analysis

Each data was presented as the mean and standard deviation of triplicate measurements. Differences between treatments were analysed using the Student-Newman-Keuls (SNK) procedure via software from SPSS Inc., USA. Differences with $P < 0.05$ were considered statistically significant.

3. Results and discussion

3.1. Physical and chemical characterisation of Eucheuma powder

The compositions of *Eucheuma* powder were assayed and the results are summarised in Table 2. The protein content and crude fat content were 4.68% and 2.46%, respectively, which are within the ranges of red seaweeds and vary due to species and seasons (Dawczynski, Schubert, & Jahreis, 2007; Matanjun et al., 2009). Notably, *Eucheuma* powder had high ash content (13.09%) and total dietary fibre content (69.33%). The high amount of ash in seaweeds consist of different kinds of beneficial minerals and is higher than that of land plants. The soluble dietary fibre accounted for 59.00% of total dietary fibre content while the insoluble dietary fibre was 11.05%. These values are a bit higher than those of the reported edible seaweeds (Dawczynski et al., 2007; Gómez-Ordóñez et al., 2010), which may be caused by species and growing areas. According to other research, carrageenan was considered to account for the majority of dietary fibre in *Eucheuma* (Jumaidin et al., 2017; Senthil et al., 2005). Food rich with dietary fibre has health benefits, for example, it can decrease the incidence of heart disease, certain types of cancer and constipation. Due to the high content of dietary fibre, *Eucheuma* has the potential to be used as a healthy food source.

Table 2
The composition analysis of *Eucheuma* powder.

Items	*Eucheuma* powder
Moisture content (%)	10.02 ± 0.25
Protein (%)	4.68 ± 0.09
Crude fat (%)	2.46 ± 0.48
Ash (%)	13.09 ± 0.09
Total dietary fibre (TDF) (%)	69.33 ± 3.35
Insoluble dietary fibre (IDF) (%)	11.05 ± 2.56
Soluble dietary fibre (SDF) (%)	59.00 ± 2.36
Water holding capacity (g of water/g of powder)	14.54 ± 0.11
Oil absorption capacity (g of oil/g of powder)	2.15 ± 0.14

Values are expressed as means ± standard deviations of triplicates.

Water holding capacity (WHC) means the ability to associate with water. In the current study, *Eucheuma* powder had a very high WHC, which is consistent with previous results (Senthil et al., 2005). *Eucheuma* has a great number of hydroxyl groups in its structure due to its high carrageenan content, which holds water molecules. Oil absorption capacity (OAC) is another important property of food ingredients, related to the porosity of fibre structure (Ben Jeddou et al., 2017). The OAC of *Eucheuma* powder was 2.15 g of oil/g of powder, suggesting it has the ability to stabilize food emulsions.

3.2. Physical properties of batters with different formulations

3.2.1. Specific gravity of the batters

Replacing flour with *Eucheuma* powder caused an increase of the specific gravity when added to the batter (Table 3). This clearly revealed that *Eucheuma* powder had greater capacity to prevent the foaming capabilities of eggs than wheat flour. *Eucheuma* had higher WHC (Table 2) than cake flour (0.64 g of water/g of powder). This property may change the influence of water with proteins, starch, and sugar, which might cause the decrease in foaming capabilities of eggs. Meanwhile, the oil absorption capacity of *Eucheuma* powder was also very high (Table 2, the OAC of cake flour was 0.61 g of oil/g of powder), suggesting it is helpful for the stability of the batter system. Therefore, the batters with *Eucheuma* powder were not damaged totally.

3.2.2. Apparent viscosity of cake batters

Fig. 1 shows the dependence of the apparent viscosity with the shear rate of different batter formulations at 25 °C. All samples showed shear-thinning behaviour because the apparent viscosity decreased with the shear rate. Similar behaviour was reported by several researchers for different kinds of cakes (Guadarrama-Lezama, Carrillo-Navas, Pérez-Alonso, Vernon-Carter, & Alvarez-Ramirez, 2016; Meza et al., 2011). All the batter samples containing *Eucheuma* powder showed higher viscosity than the control sample at the same shear rate, which was expected owing to the high amount of carrageenan in the *Eucheuma* powder (Sow, Chong, Liao, & Yang, 2018).

The experimental data in Fig. 1 could be described by the power-law equation $\eta_{app} = K \cdot \dot{\gamma}^{n-1}$, where η_{app} is the apparent viscosity (Pa•s), K is consistency coefficient (Pa s^n), $\dot{\gamma}$ is shear rate (s^{-1}), and n is flow behaviour index. The related power law parameters are shown in Table 3. Consistency coefficient K informs about the consistency of the system. Flow behaviour index n reflects the degree of change in viscosity as the shear rate changes. These values of the control batter were a little lower than the data range ($K \sim 29.06$–31.10, ñ0.50–0.70) reported by Hao et al. (2014) for sponge cake batters containing different sugar alcohols. This may be caused by the different amounts and properties of the ingredients used in the recipes. When *Eucheuma* powder was added to the batter system, K values increased. The more *Eucheuma* powder present, the higher the viscosity of the system (Table 3). The n values of all batter samples containing *Eucheuma* powder were lower than that of the control sample, meaning that *Eucheuma* powder in the batter system caused relatively faster decay of the apparent viscosity with the shear rate.

3.2.3. Viscoelasticity of batters with different formulations

Fig. 2a presents the strain sweep of the batter formulations and

Table 3
Batters, cakes, crumb colour, TPA parameters, and nutritional quality of the sponge cakes with different formulations.

Sample	Control	EP5	EP10	EP15	EP20
Batters					
Specific gravity	0.505 ± 0.006^{a}	0.516 ± 0.002^{b}	0.527 ± 0.004^{c}	0.546 ± 0.002^{d}	0.559 ± 0.003^{e}
Consistency coefficient *K* (Pa s^{n})	15.65 ± 0.38^{a}	25.10 ± 0.55^{b}	36.30 ± 0.74^{c}	159.34 ± 0.99^{d}	424.35 ± 1.13^{e}
Flow behaviour index *n*	0.40 ± 0.01^{d}	0.36 ± 0.02^{c}	0.37 ± 0.01^{c}	0.17 ± 0.01^{b}	0.13 ± 0.01^{a}
Cakes					
Weight (g)	217.40 ± 0.39^{a}	217.90 ± 0.16^{ab}	218.11 ± 0.19^{b}	220.87 ± 0.35^{c}	221.10 ± 0.29^{c}
Volume (cm^{3})	931.27 ± 1.16^{e}	922.17 ± 1.47^{d}	899.01 ± 0.87^{c}	876.47 ± 1.87^{b}	864.47 ± 1.15^{a}
Crumb colour^					
*L**	81.16 ± 0.34^{d}	80.13 ± 0.48^{c}	77.62 ± 0.49^{b}	77.22 ± 0.16^{b}	73.84 ± 0.43^{a}
*a**	0.29 ± 0.01^{a}	0.79 ± 0.01^{b}	1.24 ± 0.11^{c}	1.62 ± 0.17^{d}	1.99 ± 0.13^{e}
*b**	25.25 ± 0.32^{a}	26.07 ± 0.16^{b}	27.43 ± 0.47^{c}	27.13 ± 0.38^{c}	27.58 ± 0.21^{c}
TPA parameters					
Hardness (g)	300.42 ± 9.73^{a}	306.83 ± 12.08^{a}	321.94 ± 10.74^{a}	492.18 ± 21.79^{b}	689.46 ± 59.82^{c}
Springiness	0.96 ± 0.01^{a}	0.95 ± 0.01^{a}	0.96 ± 0.04^{a}	0.94 ± 0.02^{a}	0.95 ± 0.02^{a}
Cohesiveness	0.79 ± 0.01^{b}	0.80 ± 0.01^{b}	0.80 ± 0.01^{b}	0.75 ± 0.01^{a}	0.75 ± 0.01^{a}
Chewiness (g)	228.74 ± 6.25^{a}	232.84 ± 5.78^{a}	247.73 ± 18.25^{a}	346.23 ± 13.25^{b}	491.69 ± 44.19^{c}
Resilience	0.38 ± 0.01^{ab}	0.39 ± 0.01^{b}	0.39 ± 0.01^{b}	0.36 ± 0.01^{a}	0.36 ± 0.01^{a}
Nutritional quality					
Ash (%)	0.89 ± 0.01^{a}	1.09 ± 0.01^{b}	1.18 ± 0.03^{c}	1.46 ± 0.02^{d}	1.68 ± 0.04^{e}
Total dietary fibre (%)	1.46 ± 0.19^{a}	2.96 ± 0.02^{b}	5.36 ± 0.36^{c}	6.67 ± 0.70^{d}	8.07 ± 1.07^{e}
Soluble dietary fibre (%)	0.88 ± 0.05^{a}	1.96 ± 0.01^{b}	3.33 ± 0.21^{c}	4.68 ± 0.61^{d}	5.49 ± 1.12^{d}
Insoluble dietary fibre (%)	0.59 ± 0.19^{a}	1.09 ± 0.02^{b}	2.00 ± 0.20^{c}	2.30 ± 0.16^{c}	3.22 ± 0.34^{d}

* Control, EP5, EP10, EP15, and EP20: cakes prepared with 0, 5, 10, 15, and 20% of flour replaced by *Eucheuma* powder, respectively.
^ *L**, lightness; *a**, redness/greenness; *b**, yellowness/blueness.
Values are means ± standard deviations of triplicates. Superscripts with different letters in same column indicate significant differences ($P \le 0.05$).

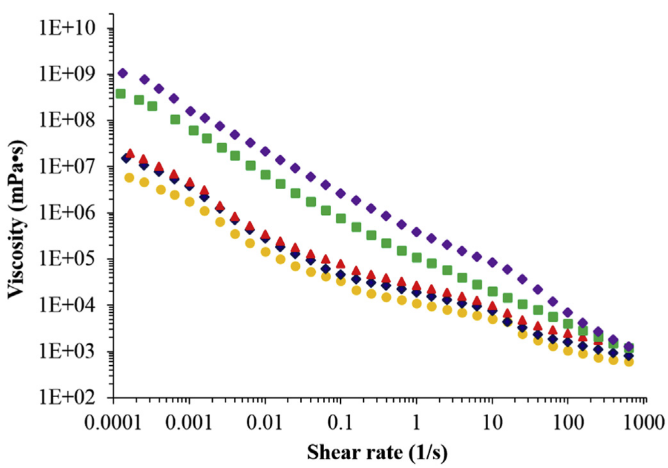

Fig. 1. The dependence of the apparent viscosity on the shear rate of the batter formulations. (●: Control; ♦: EP5; ▲: EP10; ■: EP15; ♦: EP20).

Fig. 2b presents the loss angle tan δ = *G″*/*G′* as function of the strain. The values of tan δ < 1 reflect a predominance of the elastic modulus (*G′*) versus the viscous modulus (*G″*) (solid-like behaviour), while tan δ > 1 denotes a predominance of *G″* versus *G*' (liquid-like behaviour). Both *G′* and *G″* of the batters containing *Eucheuma* powder were higher than the control sample at different strain values. However the crossover values of tan δ were very close except EP15 and EP20 samples. The crossover from solid-like behaviour to liquid-like behaviour was located at about 6.5% strain for the control sample, EP5 and EP10 samples. For the EP15 and EP20 batters, the crossover values were reduced to 4.5% and 2.7% strain, respectively. The addition of higher amounts of *Eucheuma* powder changed the gelling point of the batter system to lower strain, indicating the system had lower resistance to the applied strain and became more fragile. This might be caused by the loss of flour gluten content. In flour, gluten plays a critical role in forming 3D dough network. Previous research stated that the reduction of gluten content leads to fragile 3D networks because the links initiated by gluten are lost (Guadarrama-Lezama et al., 2016). Thus, replacing too much flour with *Eucheuma* powder could destroy the batter

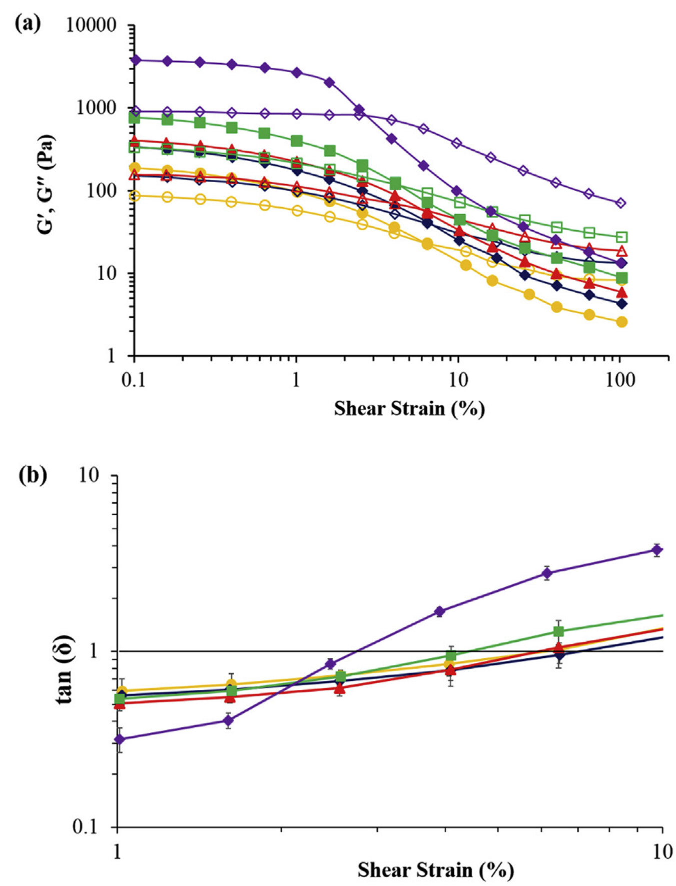

Fig. 2. Strain sweep of the different batter formulations. (a) Storage modulus (*G′*) (solid symbols) and loss modulus (*G″*) (open symbols) of different batter formulations. (b) tan δ values of different batter formulations. (● / ○: Control; ♦ / ◊: EP5; ▲ / △: EP10; ■ / □: EP15; ♦ / ◊: EP20).

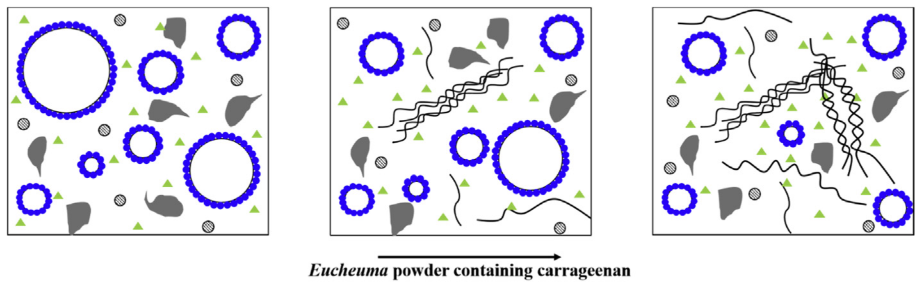

Fig. 3. A schematic diagram of cake batters with various amounts of *Eucheuma* powder.

system.

Based on the results for different batters, a pathway was proposed (Fig. 3) to elucidate the effect of *Eucheuma* powder addition on the properties of cake batters based former studies (Kocer, Hicsasmaz, Bayindirli, & Katnas, 2007; Wilderjans, Luyts, Brijs, & Delcour, 2013). The mixing of all ingredients produces an aqueous phase aeration in cake batter. Air bubbles could be stabilised by egg proteins adsorbing (Brooker, 1993; Wilderjans et al., 2013). By using *Eucheuma* powder replacing cake flour, the components of *Eucheuma* powder can influence the batter system. Since *Eucheuma* was used for carrageenan extraction in worldwide industry (Jumaidin et al., 2017), here we supposed that the high amount of carrageenan in *Eucheuma* powder should have great effect on cake batter properties (Fig. 3). With more *Eucheuma* powder addition, the big bubbles in batters disappeared since the long chain and gelling of carrageenan. As a result, the specific gravity and viscosity of cake samples increased.

3.3. Physical properties of cakes with different formulations

3.3.1. Colour analysis of cakes

Table 3 shows the L^*, a^*, and b^* values of the control cake and the cakes made with *Eucheuma* powder. The lightness decreased as the amount of *Eucheuma* powder increased. The L* values decreased due to the addition of *Eucheuma* powder (Table 3). Redness (reflected by the values of a^*) showed a significant increase in the cakes containing *Eucheuma* powder. Similarly, the yellowness (reflected by the values of b^*) of the EP10 sample was significantly higher than that of the control cake. The results indicate that a darker, redder, and yellower crumb was obtained due to *Eucheuma* powder substitution. The colour change of the baked cakes might be due to the pigments of *Eucheuma* powder. The ingredients and the formulation of cakes could affect their crumb colour (Majzoobi, Ghiasi, Habibi, Hedayati, & Farahnaky, 2014; Sinthusamran, Benjakul, & Kishimura, 2014).

3.3.2. Texture profiles analysis of the cakes

In textural profile analysis, hardness measurements showed that the cakes became harder in the EP 15 and EP 20 samples; however, EP5 and EP10 showed no significant differences compared with the control cake (Table 3). The hardness of the cakes was related to their density (Kamel & Rasper, 1989). Compared with the control sample, the weight of the samples containing *Eucheuma* powder was slightly increased probably due to the high WHC of *Eucheuma* powder, but the volume of these samples decreased sharply (Table 3). Thus, the volume change had a greater influence on density in this study. This result is in agreement with the findings of previous study (Lu et al., 2010), which reported that the increase in hardness of sponge cakes was mainly related to their volume. The TPA results revealed an increase in chewiness when *Eucheuma* powder was used to replace 15% and 20% flour; however, the EP5 and EP10 samples showed no significant difference compared with the control cake. A previous study found that hardness and chewiness are negatively correlated with cake quality (Schirmer, Jekle, Arendt, & Becker, 2012). Therefore, the quality of cakes with a higher amount of *Eucheuma* powder (EP15 and EP20) decreased, but sponge cakes with a lower amount of *Eucheuma* powder (EP5 and EP10) showed no significant changes in quality.

The TPA results of *Eucheuma* cakes showed the springiness and resilience were not significantly different compared to the control. For the cohesiveness, the EP5 and EP10 samples showed no significant difference compared with the control cake. However, there was a significant decrease in cohesiveness when *Eucheuma* powder replaced 15% and 20% of the flour (Table 3). Overall, *Eucheuma* powder can replace up to 10% of the flour in sponge cake without causing texture changes.

In addition, an interesting relationship between the consistency coefficient K of batters and the hardness of cakes was observed (Fig. 4). The consistency coefficient K of the batters and the hardness of cakes (Table 3) are positively correlated. The physicochemical properties of the batters play a critical role in determining the quality of the final products. The cake batter should be viscous enough to trap gas bubbles during mixing and further the bubbles will be retained during baking; however, if the batter viscosity is too high, the cake will have a low volume and quality.

3.4. Pore size and their distribution in the cakes

In cake baking, another important consideration is the pore quality of the cake crumb (Lin, Tay, Yang, Yang, & Li, 2017b). Fig. 5 shows the influence of *Eucheuma* powder on the pores in the cakes with different formulations under the optical microscope. The crumb of the control cake contained circular pores; however, these pore structures became fewer and smaller when adding more *Eucheuma* powder to the cake mix. Fig. 5k presents the average pore sizes of the cakes with different formulations. Compared with the control sample, the EP15 and EP20 samples revealed smaller average pore sizes, whereas the EP5 and EP10 samples had no significant differences with the control sample. A previous study claimed that the buoyancy of air bubbles in a batter is inversely proportional to the viscosity of the batter (Baixauli, Sanz,

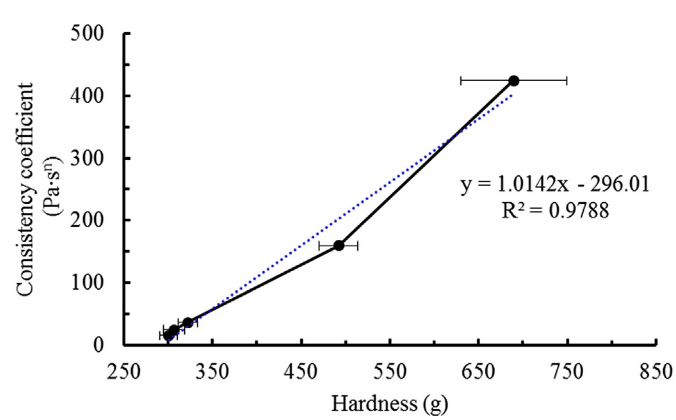

Fig. 4. The relationship between consistency coefficient of the batters and the hardness of the cakes.

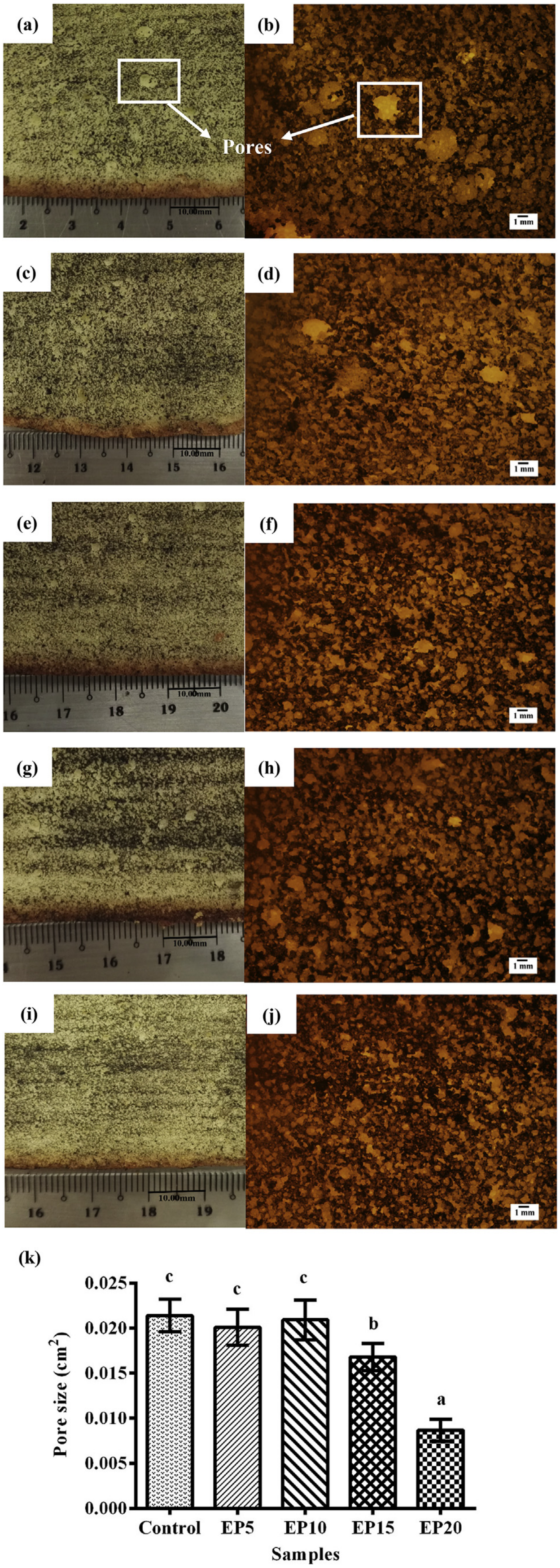

Fig. 5. Crumb structure of cakes with different formulations. Images of a crumb of the control cake (a), EP5 (c), EP10 (e), EP15 (g), and EP20 (i) under the camera. Images of the crumb of the control cake (b), EP5 (d), EP10 (f), EP15 (h), and EP20 (j) under the optical microscope. Average pore sizes of different cake samples (k).

Salvador, & Fiszman, 2008); therefore, the crumbs of cakes made with *Eucheuma* powder lacked these pore structures because of their high viscosity (Fig. 1), which was consistent with the results of other studies (Baixauli et al., 2008; Lin et al., 2017b).

3.5. Dietary fibre and ash content analysis of cakes

In terms of health benefits of the cakes, effects of *Eucheuma* powder substitution on dietary fibre and ash content of cakes were measured and summarised in Table 3. The ash measurement showed that all cakes containing *Eucheuma* powder had higher ash contents than the control sample, for example, the ash content of EP10 sample increased 32.6% comparing with the control one. As a kind of seaweeds, *Eucheuma* has the advantage of high potassium content and low sodium content, which could help balance the high Na/K ratio diets (Matanjun et al., 2009). As for dietary fibre, the TDF, SDF, and IDF content of cakes had all increased due to the addition of *Eucheuma* powder. In fact, the SDF content of EP10 increased by almost 2.8 times when compared with the control sample. Additionally, the IDF content of EP10 was nearly 3.4 times that of the control sample. The increased dietary fibre content in sponge cakes is beneficial for health due to the physiological effects of dietary fibre. Thus, the results showed that *Eucheuma* powder used in cake baking can increase the mineral and dietary fibre contents of cakes, thus improving the nutrition contents of cakes.

3.6. Sensory evaluation of cakes

The hedonic scale can provide reliable results to evaluate the product liking and preference (Kim et al., 2012). The sensory evaluation analysis (Fig. 6) showed that all cakes got similar scores in appearance and colour. Compared with the control sample, only the EP20 sample got lower scores (less than 4) in odour, flavour and overall acceptability. This indicated that high amount of *Eucheuma* powder in sponge cake had unpleasant smell and taste, but lower amount of *Eucheuma* powder showed no significant difference from the control sample in consumers' opinion, especially for the EP5 and EP10 samples. When the overall quality was assessed, the scores of the control, EP5, and EP10 samples were all equal or more than 5, indicating that the substitutions of 5% and 10% of flour were acceptable to the consumers. However, for

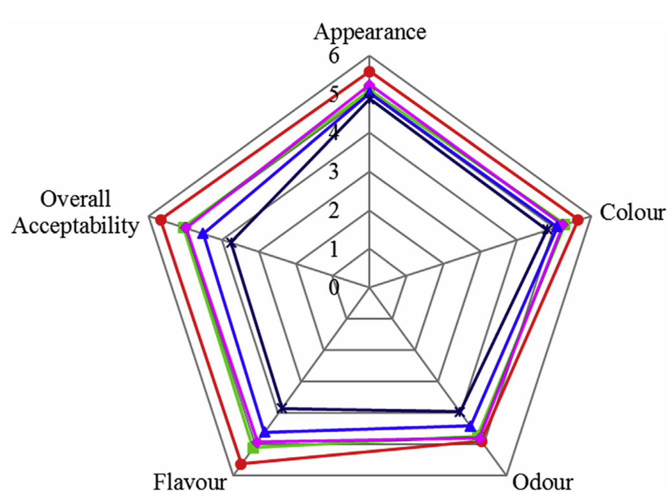

Fig. 6. Effect of *Eucheuma* replacement on the sensory evaluation of sponge cakes. (●:Control; ■: EP5; ♦: EP10; ▲: EP15; ⁎: EP20).

the EP15 and EP20 samples, lower overall scores were obtained due to their lower scores in all the other sensory parameters and due to their higher hardness and lower volumes (Moza & Gujral, 2017). The sensory characteristic results indicate that replacement of 5% and 10% cake flour with *Eucheuma* powder in sponge cake is satisfactory.

4. Conclusions

In the current study, *Eucheuma* powder showed high ash and dietary fibre content, high water holding capacity and oil absorption capacity. When *Eucheuma* powder was used as a flour replacer to make sponge cakes, the results showed that it increased the specific gravity, viscosity, and viscoelasticity of the cake batters. The inclusion of *Eucheuma* powder changed the crumb colour and the texture properties of the cakes. However, the cakes containing 5% and 10% of *Eucheuma* were not significantly different in texture parameters from control cakes. *Eucheuma* powder influenced the pore size and distribution in the cakes, and increased significantly the ash content and dietary fibre content. The sensory characteristic results indicate that up to 10% replacement of cake flour by *Eucheuma* in sponge cake was satisfactory. Overall, up to 10% replacement of flour with *Eucheuma* powder was acceptable and beneficial for increasing dietary fibre intake. The use of *Eucheuma* powder to replace flour in bakery products represents a new direction for the development and utilisation of *Eucheuma* in the food industry.

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