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SHORT COMMUNICATION

Cocoa bean shell waste as potential raw material for dietary fiber powder

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Abstract

Purpose The shell of cocoa beans is one of the cocoa industry byproducts that currently still become waste. Through this research, utilization of cocoa bean shell for producing alkalized fiber powder was observed. The aim of the study is producing fiber powder from the shell of cocoa beans.

Methods The shell of cocoa beans was obtained from the chocolate industry and directly used without any pretreatment. The shell of cocoa beans was alkalized to adjust the pH and remove the possible heavy metal. At the end of the alkalization process, the solid material was measured by atomic absorption spectroscopy (AAS). Later, the solid material was crushed into 30–200 mesh. The possibility for this powder to substitute other fiber powders (oat and whole wheat) was tested by texture profile analysis (TPA) and panelists test for cookies produced of those powders.

Results The experiment shows that an increase in temperature will cause the product's color to be more red and yellow, lowering the powder yield, and also increase the coarse fiber content of the alkalized-product.

Conclusions Powder size analysis, TPA, and acceptance test show that the produced cocoa powder can be utilized for a substitution or mixing flour as there is no significant difference observed among them. It contains rich fiber that is important for dietary food.

Keywords Cocoa bean shell · Fiber powder · Alkalization · Organoleptic · Texture

Introduction

Cocoa (*Theobroma cacao* L.) bean shell, a by product of the chocolate industry, is usually removed away from the bean using winnowing machine and sold to fertilizer companies or own use as fertilizer. Although the shell contains nutrients that benefit the body, for examples, polyphenols (ca. 1–2%), alkaloids such as theobromine (ca. 1–2%), vitamins such as Vitamin D, minerals such as calcium and phosphorus, amino acids, as well as soluble and insoluble dietary fibers (ca. 25–30%), etc., the utilization to upgrade its value is still low. In fact, the shell covers almost seventeen percent of total cocoa bean weight. In 2017, the world production of cocoa reached 4.7 million tons, increased from 4.0 million tons in 2016 (International Cocoa Organization (ICO) 2017). Cote d'Ivoire, Ghana, and Indonesia showed to be the three largest country producers of cocoa with a percentage of 42, 17, and 7%, respectively. For every single tree, the production could reach 20–50 of cocoa pulp/fruit and harvesting time could be done through the year. Considering the world production of cocoa beans, the world generation of this waste can be calculated at approximately 700,000 tons/year, which is a substantial amount (International Cocoa Organization (ICO) 2017). Therefore, it is necessary to find applications so that the shell of brown seeds that originally are waste can have added value.

Some initiatives have been done to obtain significant breakthrough of cocoa beans shell waste utilization, such as bio-recyclable paper packaging and supplement to feed the animal. In the field of engineering sciences, several publications described the use of cocoa bean shells as biofiltration support and material for removing metals from contaminated soil and industrial effluents (Meunier et al. 2003) and liquid

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smoke (Handojo et al. 2019). There are only a few of literature mentioning the utilization for food purposes.

The initiation work to utilize cocoa bean shell for food application was done by Bernaert and Ruysscher (2016a). They incorporated the addition of alkalized cocoa bean shells to the cocoa beverage and cheese up to 30%. It was claimed that the taste/flavor was very unique with another nutritional advantage on it due to the high-fiber content of cocoa bean shell. More comprehensive research to apply cocoa bean shell for food additive and cocoa powder was done by Bernaert and Ruysscher (2016b). It was shown that following the compositional analytic measurement, the produced cocoa bean shell powder could act as a replacer for cocoa powder, coloration imparter of the food product, and fat bloom inhibitor in cocoa-based products.

Based on the composition of cellulose, polysaccharides, and lignin, cocoa bean shell could be used as a source of dietary fiber (Dhingra et al. 2012). This cocoa fiber has antioxidant properties and physicochemical properties, which make it a suitable product for use in the preparation for low-calorie, high-fiber foods such as chocolate cookies and chocolate cakes where the color and flavor of this cocoa fiber might be advantageous for these food products (Anal 2017). One of the possibilities is by examining the potential and possibility of cocoa bean shell conversion for the production of fiber powder. Collar et al. (2009) mentioned that cocoa-derived fiber could also increase the shelf life and increase the fiber composition to the conventional wheat bread. As far author knows, the influence of cocoa shell fiber powder is cookies production has not been taught and published elsewhere in any scientific literature. Moreover, this study aims to determine the effect of alkalization treatment processing on color, coarse fiber content, the production yield of the cocoa bean shell powder. Texture profile and organoleptic test were conducted by analyzing the cookies made from flour-based products with additional wheat, oat, and cocoa shell.

Methods

Alkalization process

The raw material of cocoa bean shell was obtained directly from Papandayan Cocoa Industries, a chocolate producer located in West Java, Indonesia. The cellulose, hemicelluloses, and lignin contents of the fiber samples were determined by chemical analysis according to the literature reported (Reddy et al. 2013). Before being fed to the reactor, the alkalization process was conducted to neutralize the cocoa acidity (raise the pH between 7 and 8) and remove all possible heavy metals. Cocoa bean shell was first washed using water and then dried in an oven at a temperature of 110 °C. The dried cocoa bean shell was charged to the agitating chamber containing a sodium phosphate buffer (NaH_2PO_4) solution. This step is necessary to be conducted to remove all possible metals that were contained in the cocoa bean shell following the complexation reaction:

$$M^{2+} + 2\,NaH_2PO_4 \rightarrow M\left(NaH_2PO_4\right)_2^{2+}, \tag{1}$$

where M refers for metal species. The sodium phosphate solution also acts as alkalization agent which will alter the color and flavor of the processed powder. Following Minifie (1989), the alkalization could strengthen the original flavor of cocoa in the flour. Moreover, sodium phosphate was selected as chelating and alkalization agent because the cost price was considered cheap and abundant. Following the experiment result of Lee and Low (1985), it required to employ NaH_2PO_4 with a concentration of 0.225 M to completely remove all Pb and Cd. In this experiment, the concentration of sodium phosphate was varied from 0.1 to 0.6 M while maintaining a temperature of 80 °C. These values were selected in the concentration range recommended by Lee and Low (1985). To increase the complexation reaction rate, the chamber temperature was adjusted in four different points, i.e., 30, 55, 80, and 90 °C with sodium phosphate concentration of 0.25 M. The heating process was maintained stably for 1 h then followed by drying process at 110 °C for 5 h. The procedure was adopted from Bernaert and Ruysscher (2016b). Later, the dried alkalized cocoa bean shell was crushed to reduce the size into powder form.

Analysis of alkalized cocoa bean shell powder

The performance of the complexation reaction of heavy metals was evaluated by analyzing the concentration of metal using atomic absorption spectroscopy (SavantAA AAS, GBC, Australia). The analysis was carried out by dissolving 0.25 g of sample in 10 mL of perchlorate and nitric acid mixture with a volume ratio of 1–3. The mixture was then put into a digester for at least 2 h. The solution was diluted further in a 50 mL measuring flask using distilled water and put in a sample chamber of AAS. The powder product was analyzed for color, coarse fiber content, powder size range, and yield. Measurement of alkalized powder color employed Minolta CM-3500d spectrophotometer (Minolta, Japan). Color determinations were run in triplicate and results were converted to corresponding CIELAB values and expressed as brightness (L^*), red (a^*), and yellow (b^*). The analysis of fiber was conducted by destructing non-fibrous materials using strong acid and base chemicals, i.e., sulfuric acid, NaOH, and K_2SO_4. Gravimetry analysis was conducted after the drying process to measure the yield of powder produced in the research. Meanwhile, powder size was measured using sieve analysis and the size was compared to the analysis result of commercial oat and whole wheat powder. Four different sieves sizes were used those of (1) 30 mesh (equal to the particle diameter of 600 μm), 50 mesh (300 μm), 100 mesh (150 μm), and 200 mesh (75 μm).

Organoleptic analysis for cookies from cocoa bean shell powder

The possibility of alkalized cocoa powder for other fiber powders substitute was evaluated by producing cookies from wheat flour with 10, 20, and 30% substitution of cocoa bean shell powder. As a comparison, cookies with 10, 20, and 30% substitution of oat and whole wheat powder were also made. These cookies were analyzed by texture profile analyzer TA.XT*plus* (Stable Micro Systems, UK) with 3 point bend rig probe. The analysis will give the value of fracturability, hardness, and total work of the product. Moreover, we also conducted descriptive test panelist analysis to the produced cookies to 20 random panelists to obtain 9 parameters, i.e., color, texture, aroma, flavor, crunchiness, hardness, aftertaste, adhesiveness, and chewiness. This panelist test was done to test whether the substitution with cocoa bean shell powder affects those parameters of produced cookies or not.

Results and discussion

The feed analysis of the cocoa bean shell resulted in more than 50% of water-insoluble fiber. This value is comparable to the previous result of Cabrejas et al. (1994) gave a value of 50% for total dietary fiber. More recent Bonvehi and Beneria (1998) determined that total dietary fiber was 57%. The presence of hemicellulose in the feed was estimated to be 16.8%-w which is closed to the measurement of Redgwella et al. (2003) that accounted for ~ 20%. After alkalization process, the composition did not significantly change. It was an interesting result since some references applied the alkalization process to break or decompose the fiber structure such as lignin (Ariawan et al. 2015; Oushabi et al. 2017). However, compared to those references, the concentration of alkali solution in the current experiment was 10 times lower. This reduced the influence of alkalinity to break the lignin structure. Moreover, the most important of alkalization reaction was used to reduce the presence of heavy metals in the cocoa shell that currently became the major drawback of the utilization for food application. Based on the atomic absorption spectroscopy (AAS) analysis result of the raw cocoa bean shell, the feed was already contained of a trace amount of toxic metals, such as: Pb, Cd, As, Sn, and those metals were not detected in the product after alkalization process at any temperatures used in this experiment. It should be noted here that the reaction between metal species and sodium phosphate relies on the dissociation of metal species in the solution. It means that this technique could be applied when the concentration of metal is too high, or the reaction takes a longer period. The use of organic fertilizer (not chemical fertilizer) has shown to be an effective way to suppress the presence of toxic metals.

The fiber content of this agricultural waste sample was much higher than that of well-known wheat bran (40%), rice bran (26%), and oat bran (17%). Although it contents rich fiber, cocoa bean shell powder should be mixed or used as additional substrate only. This is necessary to balance the presence of high water-insoluble fibers in cocoa bean shell with soluble ones to meet the requirement of dietary fiber food. In many references, water-soluble fibers consistently lower the cholesterol levels and blood pressure while water-insoluble fibers have no effect on it (Swain et al. 1990).

Powder color and product yield

During the alkalization process, the presence of sodium phosphate solution could significantly change the color of the product. The measurement of color changes due to sodium phosphate concentration and reaction temperature are tabulated in Table 1.

Increasing alkalization temperature and concentration of sodium phosphate solution cause the color of the shell powder becomes darker (see Fig. 1), reflected by

Table 1 Effect of alkalization reaction to the produced powder color

Sample no.	[NaH_2PO_4] (M)	Temp. (°C)	CIELAB value				Yield (%)	Fiber (%)
			*L**	*a**	*b**	Δ*E*		
Base			20.4	16.4	15.3			51
1	0.1	80	15.7	13.1	13.6	6.0	86	49
2	0.25	80	12.5	13.9	14.8	8.3	74	47
3	0.4	80	10.6	16.6	10.1	11.1	79	43
4	0.6	80	10.2	14.9	13.7	10.4	81	37.5
5	0.25	30	19.7	12.7	11.8	5.1	86	36.5
6	0.25	55	13.9	13.5	13.2	7.4	82	40.5
7	0.25	95	7.7	17.2	7.3	15.0	74	41

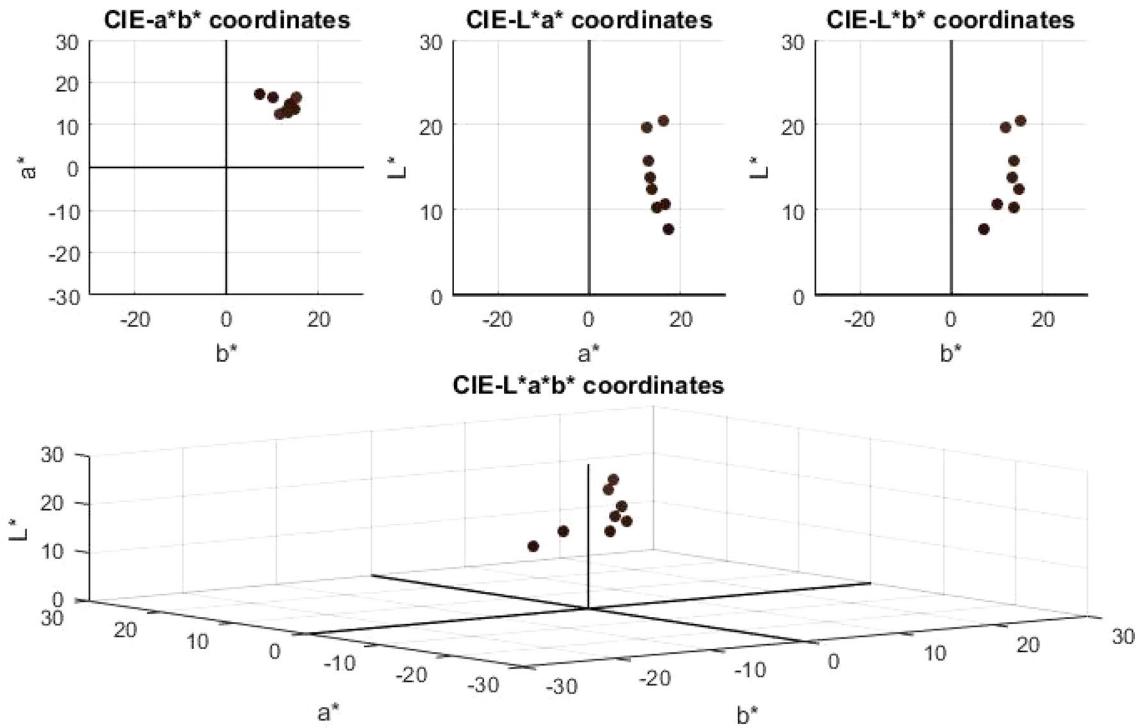

Fig. 1 CIELAB coordinate graph of the alkalized-product

the decrease in the brightness (L^* value). This is because higher temperature and concentration will cause more reactants in the cocoa bean skin were reacting in the alkalization process. On the other hand, the increase in alkalization temperature also tends to raise the values of a^* and b^* which indicates that the color becomes more red and yellow. The above result has a similarity when cocoa bean was roasted using supercritical steam (Zzaman and Yang 2013). By increasing temperature, darker color products were obtained. The entire samples yield a value of $\Delta E > 1$ means that each treatment has a significant effect and in higher concentrations and temperatures, the ΔE value is increasing.

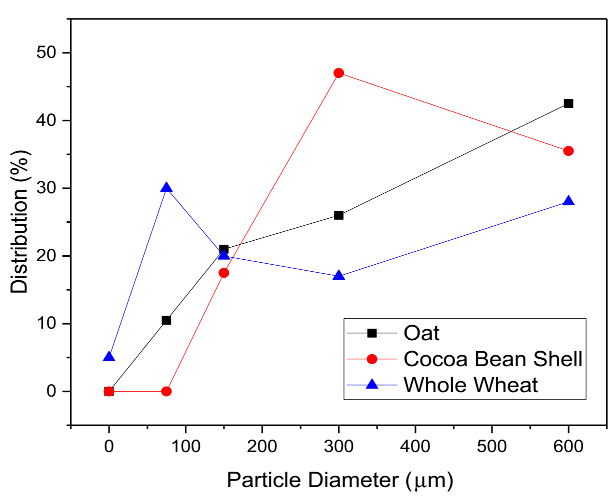

Fig. 2 Particle diameter distribution of the powder

Although the composition of water-insoluble fiber was not changing drastically, the reaction temperature could influence the yield of the powder product. As the temperature rise, shown in Table 1, the alkalization process decreases the production of solid powder. This is clearly due to the solubility increment of non-fiber compounds to the solvent, such as cocoa solid that may present in the skin of the seeds. The fragmentation of long-chain fiber into small fragment then dissolve in the alkali solution could be neglected due to low concentration of sodium phosphate. This point could be concluded as there is no certain trend regarding the variation of sodium phosphate concentration from 0.1 to 0.6 M (Table 1).

Table 2 Average particle diameter of three types of powder

No.	Powder name	Average particle diameter (µm)
1.	Oat	391.8
2.	Whole wheat	323.7
3.	Cocoa bean shell	377.5

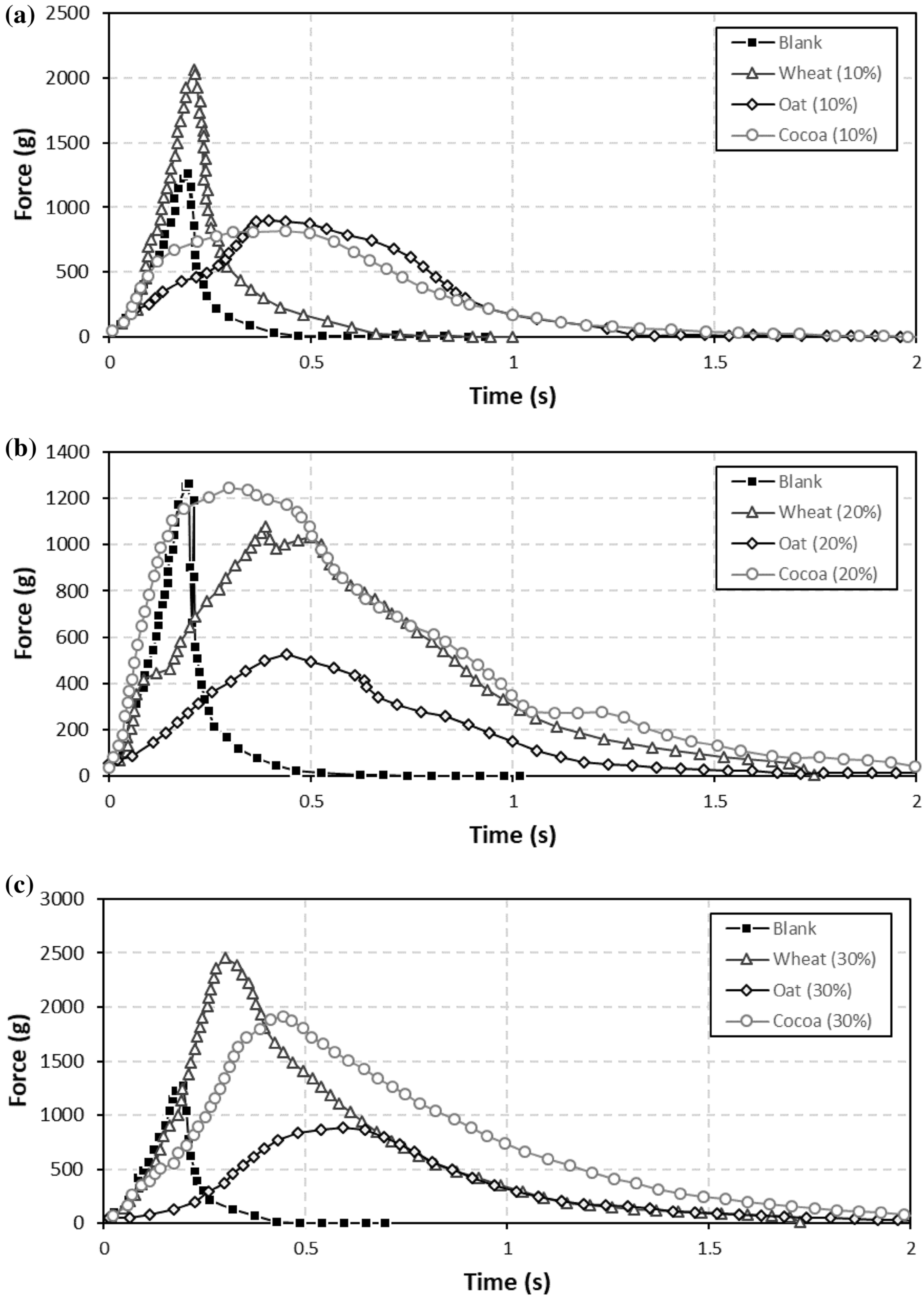

Fig. 3 Texture profile analysis of cookies with substitution ratio of **a** 10%, **b** 20%, and **c** 30%

Table 3 Results of texture profile analysis

No.	Powder name	Substitute ratio (%)	Fracturability (g)	Hardness (g)	Work (g s)	Rate of resistance change (g/s)
1.	Blank	–	486	1267	165	6324
2.	Oat	10	–	909	596	2204
3.	Cocoa	10	–	825	620	1792
4.	Whole wheat	10	786	2066	349	9592
5.	Oat	20	–	535	358	1098
6.	Cocoa	20	1142	1259	995	4008
7.	Whole wheat	20	421	1089	769	2626
8.	Oat	30	–	895	629	1429
9.	Cocoa	30	364	1912	1431	4252
10.	Whole wheat	30	–	2479	1146	8215

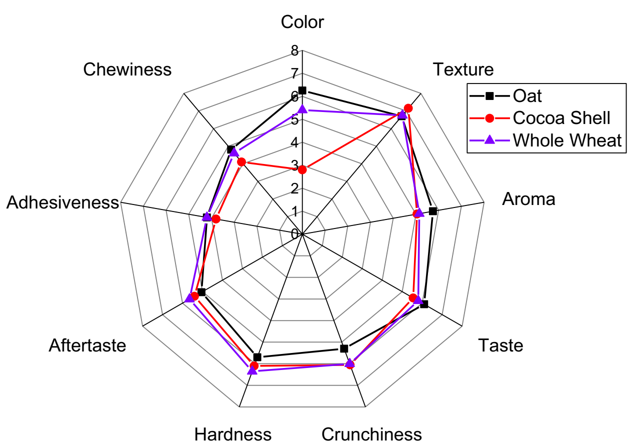

Fig. 4 Sensory analysis result of cocoa bean shell (20%), oat, and whole wheat cookies

Powder size analysis

In order to compare the produced cocoa bean shell powder with commercial oat and wheat bran, the particle size analysis was conducted. The results of the average particle distribution for these three fiber powders are presented in Fig. 2 while the mean particle diameter of each type of powder is tabulated in Table 2. The average diameter is calculated by the particle distribution area with a cumulative range of 50%. Different characteristics of each type of powder cause different particle distribution. However, the average particle diameter of each type of powder has a relatively close value. It was physically difficult to distinguish the difference in term of particle size except for the color of the solid powder.

Texture profile analysis (TPA)

Texture parameters of cookies made of wheat flour with the substitution of fiber powders were measured quantitatively using texture profile analysis. The cocoa bean shell powder used was the starch alkalized by 0.25 M NaH_2PO_4 at a temperature of 80 °C. The profile of the TPA curves of the cookies is shown in Fig. 3. Derived from Fig. 3, some physicochemical parameter analysis of the cookies product, such as fracturability (first peak), hardness (maximum peak), and total work (area) data, are presented in Table 3.

Cocoa bean shell powder cookies have the largest curve area compared to other cookies with the same amount of starch substitution. This is because high-fiber content on the cocoa bean shell provides great resistance to pressure from the probe. The increasing value of cocoa bean shell powder substitution gives more endurance to the cookies which is indicated by the increasing value of curve slope. Meanwhile, cookies made of wheat flour have relatively highest fracturability and hardness on the same substitution ratio (except for 20%). This indicates that it takes a bigger force to break and fracture the cookies. The absence of fracturability values in oat cookies are due to the soft texture of the cookies which made the first fracture occurred at the same time with the broken of the cookie.

Acceptance test (organoleptic)

When a new product is developed, one of the main points in the evaluation is its acceptability, in order to predict its behavior in the consumer market. Sensory analysis was conducted to the cookies with 20% of substitution (mixture with cocoa bean shell powder). The results of qualitative parameters assessed by the panelists are presented in Fig. 4. Two-tailed type *t* statistical tests were performed to test whether a significant difference exists among cocoa bean shell cookies with other substitution types for each parameter. Based on the statistical test, there is no significant difference in the parameters between the three fiber cookies, except in the color parameters. In conclusion, cocoa bean shell fiber powder can be used as a substitution for oat or whole wheat powder without producing a significant organoleptic difference when it was consumed.

Conclusion

The production of bran powder from cocoa bean shell has been conducted. The results showed that cocoa bean shell flour has high possibility although some modification or further study should be conducted. The concentration of sodium phosphate and temperature during the alkalization process played an important role to influence the color of the products. Higher sodium phosphate and temperature resulted in darker powder bran. The result of texture profile analysis showed that the alkalized cocoa bean shell powder in cookie resulted in a greater resistance than cookies from wheat or oatmeal at the same mixing ratio. Moreover, no significant differences between cocoa bean shell powder and other fiber powders were identified during organoleptic test.

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Compliance with ethical standards

Conflict of interest All contributing authors certify that they have NO affiliations with or involvement in any organization or entity with any financial or non-financial interest in the subject matter contained in this manuscript.

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