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Physicochemical, Thermal, and Polymorphic Properties of Binary Blends from Bambangan Stearin and Palm Stearin

NORAZLINA MOHAMMAD RIDHWAN[1], HASMADI MAMAT*[1], MD JAHURUL HAQUE AKANDA[2], MACDALYNA ESTER RONIE[1], AHMAD HAZIM ABDUL AZIZ[1]

[1] Food Security Research Laboratory, Faculty of Food Science and Nutrition, Universiti Malaysia Sabah, 88400 Kota Kinabalu, Sabah, Malaysia [2]Department of Agriculture, School of Agriculture, University of Arkansas, 1200 North University Dr., M/S 4913, Pine Bluff, AR 71601.
*Corresponding author: idamsah@ums.edu.my
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ABSTRACT

Increasing demand for sustainable and functional fat alternatives in the food industry has prompted research into fat modification resulting in specialty fats production that can imitate cocoa butter. This study investigates the binary blends of bambangan and palm stearin, focusing on their physicochemical, thermal, and morphological properties. The blends were blended in five different ratios, with the addition of palm stearin not exceeding 30%. The results show that the iodine value (33.78 to 34.24 g iodine+/g), slip melting point (33.25 to 38.35 °C), and acid value (1.31 to 1.59 mgKOH/g) of the blends were influenced by the palm stearin content. The melting behaviour and crystallisation properties of the blends analysed using differential scanning calorimetry revealed an improved melting profile compared to the palm stearin. The binary blends exhibited desirable polymorphic transitions to the stable β(v) form, preferred for chocolate applications. Notably, the blend with 70% bambangan stearin and 30% palm stearin (BS5) demonstrated an improved triglyceride profile with a reduction of tripalmitin content and melting properties similar to cocoa butter, reducing the waxy texture typically associated with palm stearin. The findings suggest that BS5 produced from bambangan seed waste is a functional, cost-effective alternative confectionery product, offering stability and desirable thermal properties.

Keywords: Palm stearin**,** bambangan stearin, blending, cocoa butter alternatives

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INTRODUCTION

Global demand for cocoa butter (CB) has risen steadily, but current production levels are not sufficient to meet this growing demand. The demand for sustainable and functional fat alternatives in the food industry has driven research into innovative fat blends that mimic the properties of CB. The global demand for CB keep on increasing and the production cannot meet on the global demand. It is used extensively in the food, cosmetics, and pharmaceutical industries. Its special fatty acid composition and triglyceride structure result in an exceptionally low melting point, which is only between 32 °C and 35 °C (Ying & Youk, 2022). CB is a valuable by-product used for chocolate processing, facilitating the dispersion, liquefaction, and diffusion of cocoa powder, paste, sugar, and other additives, helping to create a smooth, homogeneous, continuous phase. It consists mainly of 24.50 to 33.70 % palmitic acid, 3.30 to 40.20 % stearic acid, and 26.30 to 36.50 % oleic acid (Norazura, Sivaruby, & Noor Lida, 2020; Kadivar *et al*., 2016), which contribute to its desirable melting properties. Despite that, CB has limited supply and increased demand, which causes the price to fluctuate (Biswas *et al.,* 2018). Therefore, an alternative from other vegetable sources, such as bambangan seed fat, is plausible.

Bambangan stearin (BS) was produced from the fractionation of bambangan seed fat. It is an underutilized resource distributed around the Borneo region including Malaysia (Jahurul *et al.*, 2019) but has promising potential due to its unique triglyceride composition (TAG) and physicochemical properties. The stearin fraction consists of three dominant fatty acids: palmitic acid (7.26 to 6.76%), stearic acid (44.72 to 48.50%), and oleic acid (33.76 to 36.02%), which are comparable to those of CB (Norazlina *et al.*, 2020). However, the palmitic content in BS is lower than in the commercial CB. It also exhibited more than 50% of 1,3-distearoyl-2-

oleoyl-glycerol, which contributes to the high melting properties. Hence, the direct application of BS is limited by its melting behaviour and thermal stability. Blending of BS with a high palmitic fat content, such as palm stearin (PS), could influence the composition of BS and thus improve its properties.

PS is the most important product from the fractionation of palm oil. Palm oil is obtained from the mesocarp of palm fruit, which is naturally semi-solid at room temperature and then fractionated into different fractions with different physical and chemical properties through fractionation processes (Ahmad Bustamam *et al.,* 2022). In 2024, Malaysia produced 2.367 million tonnes of PS (MPOB, 2024) which is characterised by a higher saturated fatty acid content and a TAG profile with a melting point between 48 °C and 50 °C. Thus, Malaysia plays a crucial role in meeting the increasing global demand for fats sustainably (Roslan, Gerusu, & Mustafa Kamal, 2018). PS obtained by crystallisation at controlled temperatures, is widely used in edible and non-edible products. It serves as a natural source of fat without the need for hydrogenation and increases the plasticity of products. It is a valuable source of solid fats and is used in a range of foods such as margarine, shortenings, and vanaspati, as well as in the production of trans-free fats. However, it exhibits waxy characteristics at higher concentrations.

Blending BS and PS offers an opportunity to create binary fat blends with optimised physicochemical, thermal, and structural properties applicable to confectionery and food applications. The blending also offers the utilization of bambangan seed from agricultural waste into a functional application. Therefore, blending PS with BS could further extend the application of PS in confectionery products as an alternative to cocoa butter, offering functional and economic benefits. In this study, the blending ratio was carefully selected to ensure that the PS content in the mixture did not exceed 30%. This is because a higher PS content could lead to a hard fat with waxy properties due to its high saturation, which is undesirable for confectionery applications. A controlled addition of PS helps to increase the palmitic acid content while maintaining the desired melting and textural properties of the final fat blend.

MATERIALS AND METHODS

Samples and Materials

Matured bambangan fruits were collected from an orchid (kampung Pandasan) in Kota Belud (Sabah), Malaysia, and the palm stearin (Iodine value: 37 g iodine/g) was provided by Sime Darby Malaysia (Selangor, Malaysia). Acetone, cyclohexane, diethyl ether, ethanol, hexane, potassium iodide, phenolphthalein, potassium hydroxide, starch, sodium thiosulphate, and Wijs solution were supplied from Merck (Germany) and Fisher (United Kingdom). All chemicals and reagents used are of the highest purity available.

Sample Preparation

Bambangan fruits were collected, placed in a large basket, and stored at 5 °C before sample preparation. The seeds were carefully separated using a strong household knife, washed, and cut into uniform pieces (2 cm × 1 cm × 0.1 cm) to accelerate drying. The seeds were dried in a cabinet at 60 °C for 48 hours and ground into fine powder (<250 μm) using a mill grinder (MX-898M, Panasonic). The moisture content of the dried seed powder was determined following the official method Ca 2d-25 (AOCS, 2003) yielding a result of 5.08 ± 0.67%, indicating excellent quality. Crude bambangan fat was extracted from the powdered seeds using Soxhlet extraction, following the official method of AOAC (2005). For each extraction, 80.00 ± 0.03 g of bambangan seed powder was extracted with 400 ml of hexane (1:5, w/v) at 40 °C. The crude fat was then fractionated with acetone using the method described by Jin *et al.* (2016) to isolate high-melting-point symmetric triglycerides (stearin). 100.00 ± 0.02 g of extracted bambangan kernel fat was mixed with 500 ml of preheated acetone (40 °C, 1:5 w/v). Fractionation was performed at 18 °C for 180 minutes, after which the first stearin fraction was separated via vacuum filtration. The remaining solvent was evaporated at 45 °C using a rotary evaporator (4001, HEIDOLPH LABORTA, Germany). The second stearin (BS) was produced following the same procedure utilizing the fractionation of the first stearin.

Blending of BS and PS

The preparation for blended fat was performed following the method described by Sonwai *et al.* (2014) with slight modification. BS was blended with PS by gradually increasing PS content in 5% increments. The resulting blend ratios were designated as BS1 (90:10%, SS: PS), BS2 (85:15%, SS: PS), BS3 (80:20%, SS: PS), BS4 (75:25% SS: PS) and BS5 (70:30% SS: PS). The PS content was restricted to 30% to avoid elevated melting points or the development of waxy states due to the high PPP content in PS. Each mixture was melted at 80 °C while continuously stirred at 200 rpm for 10 minutes on a hot plate with a magnetic stirrer (SP131320-33-V, Thermo Scientific, China) to achieve uniform homogenization. The binary mixtures were then stored at 4 °C for further analysis.

Physicochemical Properties

Physicochemical properties such as iodine value (IV), slip melting point (SMP), and acid value (AV) were determined according to the AOCS (2023) established method of Cd 1b-87, Cc 3b-92 and Cd 3a-63, described by Norazlina *et al.* (2020).

TAG Content

The TAG content of the samples was determined following the official AOCS method Ce 5c-93 (AOCS, 2003) with minor modifications using high performance liquid chromatography (HPLC; 1200, Agilent, Canada) with a refractive index detector (RID). Approximately 0.20 ± 0.02 g of the fat sample was dissolved in 10 mL of acetonitrile and dichloromethane (3:2, v/v). The mixture was then filtered using a 0.45 µm PTFE syringe filter (WHATMAN, 47 mm diameter). The analysis was performed with an injection volume of 10 µL, a column temperature set at 30 °C, a detector temperature of 40 °C, a pressure range of 8–9 mPa and a mobile phase flow rate of 0.8 mL/min. The TAG compounds were identified by comparing their elution profiles with those of TAG standards, including a mixed TAG-lipid standard and known PS and BS control standards, and expressed %.

Thermal Behaviour

The melting and crystallisation properties of the samples were evaluated by differential scanning calorimetry (DSC, Diamond, Perkin Elmer, USA) according to recommended practice Cj 1-94 (AOCS, 2003). The binary blends were melted at 80 °C for 30 minutes and then 3–5 mg of the sample was placed in a volatile aluminium pan (0219-0062, Perkin Elmer, USA), which was then sealed. The samples were heated (80 °C for 30 minutes) and incubated at 25 °C for one week to stabilize and temper the fat. The samples were transferred to the sample cell for analysis using an empty dish as a reference. The melting profiles were determined by heating the samples at 10 °C per minute from -40 °C to 80 °C and then hold for 2 minutes. Whereas, the crystallisation profiles were analysed at 10 °C per minute from 80 °C to -40 °C. The initial, offset, and maximum melting and crystallisation temperatures as well as the enthalpy of the fat samples were recorded in °C and J/g.

Polymorphic Behaviour

The polymorphic form of the fat samples was examined using an X-ray diffractometer (XRD Rigaku Smartlab, Rigaku, USA) following the official method Cj 2-95 (AOCS, 2009). Fat blends melted at 80 ºC were placed in glass sample holders, maintained at 25 ºC for 24 hours, and subsequently analysed with the XRD. The analysis parameters included a wavelength (λ) of 1.54178 Å, voltage of 40 kV, and current of 40 mA. Fingerprint measurements were recorded over a range of 14 – 26° (2θ), and the polymorphic forms were identified based on the short spacings observed in the blends.

Statistical Analysis

All analyses were performed in triplicate. The obtained data were processed using SPSS software (version 29), using Analysis of Variance (ANOVA) followed by Tukey's test. Results are presented as mean ± standard deviation, with a significance difference of $p < 0.05$.

RESULTS AND DISCUSSION

The BS and PS mixtures were analysed with regard to their physicochemical properties as well as their thermal and polymorphic behaviour. The physicochemical properties of the binary blends (BS: PS), such as IV, SMP, and AV, are shown in Table 1. These results are complemented by the TAG profiles shown in

Figure 2 and the thermal behaviour described by DSC analysis in Table 2. The crystallisation properties of the blends are listed in Table 2, while the polymorphic forms observed are shown in Figure 3. The results show that the IV value of the blends decreases with the addition of PS, leading to values similar to CB. The SMP values were affected by the PS content and showed a proportional decrease with increasing PS concentration. AV values also showed slight variations, with BS1 having the highest AV content due to the higher stearic and oleic acid composition. Figure 2 shows significant changes in the TAG composition of the binary blends after mixing, with notable proportions of SOS, POS, and POP contributing to the melting and textural properties of the blends. The results of the thermal analysis (Table 2) show changes in the initial, offset, and peak melting temperatures, with the binary blends exhibiting a more consistent melting profile compared to PS alone. The crystallisation data (Table 3) show distinct crystallisation peaks, with the blends containing more than 20 % PS showing two separate peaks that correlate with the melting thermograms. The polymorphic behaviour of the blends, as shown in Figure 3, shows a transition to the stable β(v) polymorphic form, which is desirable for chocolate and confectionery applications.

Table 1. Physicochemical properties of bambangan stearin and palm stearin blends

	Iodine value (g iodine/g)	Slip melting point (˚C)	Acid value (mgKOH/g)
Bambangan stearin (BS)	38.89 ± 0.01^{e}	35.00 ± 0.04^{c}	2.89 ± 0.16^{f}
Palm stearin (PS)	35.79 ± 0.01^{d}	51.67 ± 0.28^{g}	1.03 ± 0.16^{a}
Cocoa butter (CB)	34.00 ± 0.11^{c}	$33.80 \pm 0.28^{a,b}$	2.81 ± 0.09^{f}
BS1 (90 % BS: 10 % PS)	33.78 ± 0.01^{a}	38.35 ± 0.40^{f}	1.59 ± 0.16^{e}
BS2 (85 % BS: 15 % PS)	33.78 ± 0.01^{a}	37.75 ± 0.25^{e}	1.31 ± 0.16^{b}
BS3 (80 % BS: 20 % PS)	$33.92 \pm 0.05^{a,b}$	36.75 ± 0.25^{d}	1.40 ± 0.01^{c}
BS4 (75 % BS: 25 % PS)	34.24 ± 0.02^{c}	35.00 ± 0.00^{c}	1.40 ± 0.07^{c}
BS5 (70 % BS: 30 % PS)	33.99 ± 0.02^{b}	33.25 ± 0.25^{a}	$1.49 \pm 0.16^{c,d}$

Values are the mean±standard deviation of triplicate; means a different letter within a column is significantly different ($p<0.05$) as measured by Tukey test.

Physicochemical Properties

The binary blends produced a solid white fat (Figure 1) at room temperature, indicating they have high saturated fatty acids because they solidify rapidly. This solidification contributes to the product's hardness, maintaining texture, and hardness during storage and transportation. PS is more saturated and harder makes it solidifies rapidly at room temperature and takes longer to liquefy during melting. It has low IV because PS has high saturated FA content (44.50 – 54.28% of palmitic and 4.47 – 4.78% of stearic acids) and ~ 30% of POP, with a significant presence of high melting TAG such as PPP. Thus, contributing to its waxy texture (Biswas *et al.* 2016; Oliveira *et al.*, 2017). The oleic content in PS is also relatively low. Table 2 shows that the IV of the blends is significantly ($p<0.05$) improved with the proportion of the PS in BS.

The IV for the binary mixtures decreased after adding PS, resulting in IVs ranging from 33.78 to 34.24, which are similar to CB. The decrease in the unsaturated fatty acid composition may reduce the unsaturation level of the binary blends. The low IV value in the CB and the binary blends obtained from this study are correlated with improved fat quality, long-term stability properties of oil that are essential for storage such as longer shelf life, and reduced susceptibility to oxidation (Ishaka, Aliyu, & Mohmmad Hassan, 2020; Kittiphoom & Sutasinee, 2013). High IV values are usually associated with unsaturated fatty acids with low melting points; thus, fat with high IV values also has a low melting point. PS in this study has an SMP of 51.67 °C, higher than BS: PS blends. The SMP in this study is consistent with the palmitic (64.0 °C) and PPP (66.4 °C) content of the blends, which required a higher melting temperature for a complete melting state. The

results can also be supported by Nusantoro (2009), who reported that the final non-isothermal melting point of PS is 49.8 °C.

However, the SMP of PS blends decreased after the blending process. PS was used only up to 30% in this study; thus, the physicochemical properties were mainly dominated by the BS fat. The blends have melting points between 33.25 °C and 38.35 °C, with values decreasing proportionally to the increase in PS ratios. The SMP for BS1 to BS3 (36.75 °C to 38.35 °C) is relatively higher than that of CB in this study, and CB (25.3 °C to 35.0 °C) reported by Sonwai, Kaphuekngam, & Flood (2014) and Jin *et al.* (2018), but BS2 to BS5 showed melting at body temperature (33.25 °C to 37.75 °C). BS5 (33.25 °C) also has comparable SMP values with the CB (33.80 °C). The changes were presumably correlated to the fatty acid content of the blends, which caused the SMP values to differ. Adding high saturated fatty acid PS into BS blends increases the saturated palmitic content, thus explaining the increase in SMP values. BS1 might contain more stearic than the other blends because 90 % of the composition is BS. An increase in the palmitic in BS1 increases the saturated fatty acid content; thus, it is prone to a higher temperature. In contrast, the stearic acid in the other blends decreased proportionally to the PS ratio; therefore, the blends have a lower SMP than BS1.

PS and the binary blends in this study showed low AV. More than 60 % of PS composition was dominated by saturated fatty acid (Biswas *et al.*, 2016; Oliveira *et al.*, 2017), owing to low unstable oleic (22.8%) and linoleic (4.6%) acids making it more stable. The stearic content is also less in PS. Therefore, it is less prone to rancidity and is thus considered higher quality. After blending BS and PS, the AV of the blends slightly increased than the values of individual PS, but they showed variation. Although PS has shallow AV content, BS contains relatively high stearic and oleic acids that cause the blends to have high AV; thus, BS1 showed higher AV (1.59%) than PS. BS5, on the other hand, had low AV values.

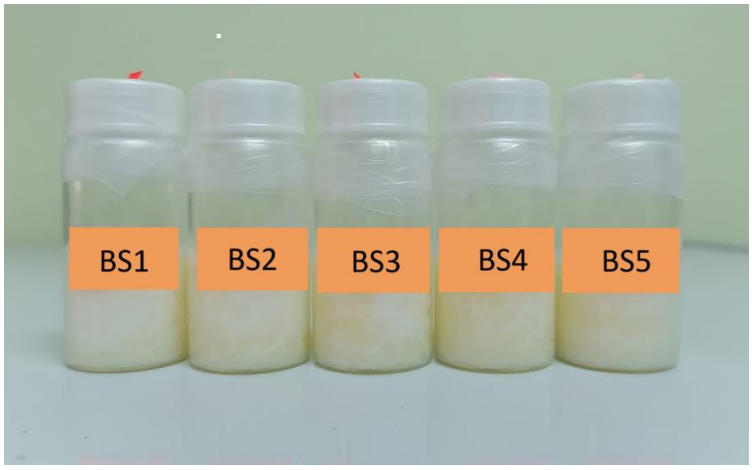

Figure 1. Binary blends produced from the blending of bambangan stearin and palm stearin

Triglycerides (TAG) Profiles

PS exhibited a significant ($P<0.05$) level of PPP, a high-melting TAG, resulting into incomplete melting state at 37 °C. The PPP (melting point: 66.4 °C) was attributed to the very high palmitic acid content (>50%), which impacts the fat's digestibility due to its elevated overall melting point (Biswas *et al.*, 2016; Berry & Sander, 2005; Oliveira *et al.*, 2017). Consequently, the direct use of PS as a specialty fat poses challenges due to its high melting properties, which may lead to a waxy texture. Blending PS with BS offers a way to modify its properties, making it a potential alternative to CB. Commercial CB typically contains symmetrically disaturated (SUS)-TAGs, such as POP, POS, and SOS (Bootello *et al.*, 2018). Similarly, the CB analysed in this study comprised POP (14.25%), POS (33.36%), and SOS (25.65%).

The binary blends were also dominated by these three TAGs but included a notable amount

of high-melting TAGs like SSS and PPP. Compared to CB, PS had a higher POP content (32.65%), followed by PPP (19.30%), POO (14.21%), PLL (7.71%), and POS (6.55%). Blending PS with BS resulted in significant ($p<0.05$) changes to the TAG profiles (Figure 2). SOS (30.22% to 37.73%) was the most abundant TAG in all mixtures, followed by POS (10.95% to 12.43%) and POP (5.66% to 10.35%). However, the binary blends showed reduced POP and POS levels compared to CB, presumably due to the dominance of BS in the mixtures. The SOS content in BS contributed significantly to this observation.

Furthermore, while the blends retained some PPP content from PS, it was significantly ($p<0.05$) lower than in pure PS, likely due to the influence of oleic and stearic acids in BS, which led to increased low-melting TAGs such as SOO and POO. Among the blends, BS1 had the highest SOS, POP, PPP, and SSS levels, indicating a higher melting point. The SSS content in BS1 was also 5% higher than in CB, potentially affecting CB's melting behaviour. Both PPP and SSS, with melting points above 60 °C, may contribute to a waxy texture in the fat. Previous studies (Norazura, Sivaruby, & Noor Lida, 2020; Yanty *et al.*, 2016) have shown that PPP levels above 4% can lead to waxiness, reducing the quality of the final product.

Notably, BS5, comprising 70% BS and 30% PS, demonstrated improved TAG profiles. Although its POS and POP contents were slightly lower than those in CB, BS5 had the lowest SOS range, indicating lower melting properties compared to other blends. The POP content of BS5 was also closer to that of CB. These findings align with previous reports on CB-Equivalent composition, including POP (10.70 – 30.33%), POS (4.60 – 49.53%), and SOS (3.26 – 27.53%) as noted by Bootello *et al*. (2018), Kadivar *et al*. (2016), and Sonwai *et al*. (2014).

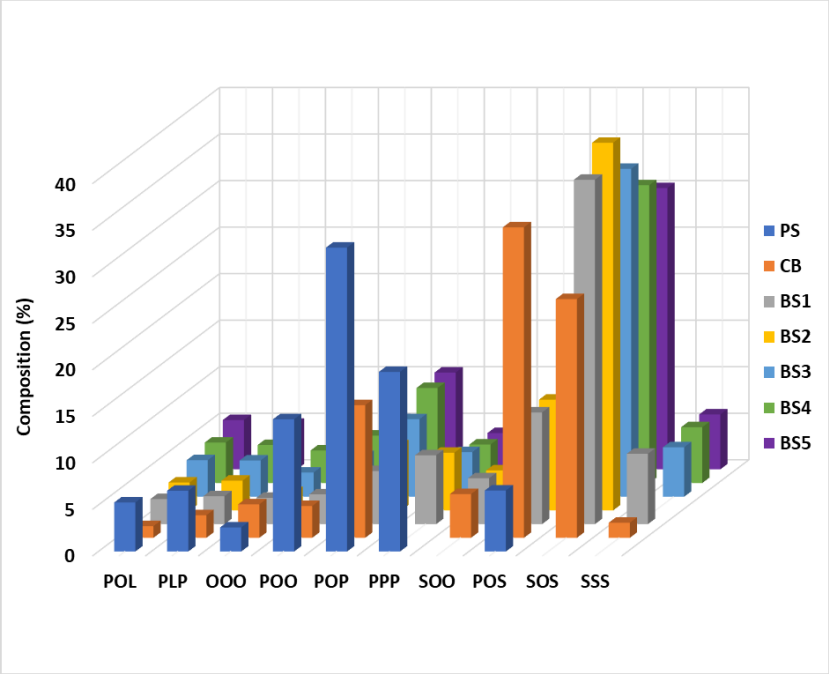

Figure 2. Diffraction pattern and short spacing of bambangan and palm stearin blends

Melting Properties

The individual and blended fat samples in this study were stabilized by incubating fat samples at room temperature for seven days. The stabilization of the fat is needed because the TAG can exist in a few crystalline forms such as (I) γ, (II) α, (III) β'_2, (IV) β'_1, (V) β_2, *and* (VI) β_1 while in a state of solid. Among these forms, (I) γ is the least stable, and (VI) β_1 is the most stable (Talhat *et al.*, 2015). According to Sagiri, Sharma, Basak, and Pal (2014), a peak at ~20 °C suggests the presence of the α-polymorph, which is followed by the β' and β states at increasing temperatures. The TAG is primarily crystallised in the (V) β_2 form, which is more stable and

contributes to a high melting peak temperature in a stabilized fat (Sullo, Arellano, & Norton, 2014). Additionally, the less stable forms may change into more stable ones after being stored for a long enough time. As a result, the melting characteristics of the fat blends have improved after stabilizing for seven days resulting in a melting curve that is sharp and narrow and less likely to cause a waxy mouthfeel (Kadivar *et al.*, 2016).

The melting properties of PS and its mixture are shown in Table 2. The interpretation of the thermal DSC curve is complex for BS, and PS blends due to the complexity of the TAG mixtures in the PS samples and the polymorphic transitions that may occur during melting (Bootello *et al.*, 2018). PS has a broad melting range at a higher temperature, starting at 31.26 °C and ending at 61.58 °C. It shows that this PS is harder, and the melting properties are because the POP and PPP are abundant in PS, which results in a high melting point and incomplete melting at body temperature Kang *et al.* (2013). Additionally, low-fat plasticity in PS results in challenges in generating edible fats like shortening and margarine. Due to its excessively high melting characteristics, which leave a waxy aftertaste, producing alternatives for cocoa butter is also affected (Sellami *et al.*, 2011; Edy & Rizki, 2020). Therefore PS is blended with BS to lower the melting properties. Significant ($p<0.05$) changes can be seen in the melting properties of PS after blending with BS.

The onset, offset, and maximum temperature of PS gradually declined with the blending of BKF-SS. The onset temperature showed an increasing trend proportional to the increment of the PS in the blends. In contrast, constant trends are observed in the offset and maximum temperature of the binary blends. The DSC melting curve for BS: PS blends obtained in this study showed two endothermic peaks but were less broad than the PS. The observation is consistent with the melting curve for PS blending reported by Jahurul *et al.* (2019). The TAG of PS contributed to the presence of the two peaks with a high melting temperature. The onset and offset values for the blends range from 23.05 °C to 26.06 °C and 39.66 °C to 39.71 °C, respectively.

Table 2. Melting properties of bambangan stearin and palm stearin blends

	Melting properties			
	Onset temperature (˚C)	Maximum temperature (˚C)	Offset temperature (˚C)	Enthalpy (J/g)
Bambangan stearin (BS)	22.19 ± 0.02^{b}	31.20 ± 0.01^{b}	37.82 ± 0.01^{b}	66.14 ± 0.56^{h}
Palm stearin (PS)	31.26 ± 0.36^{g}	60.25 ± 0.02^{g}	62.58 ± 0.67^{f}	40.97 ± 0.07^{c}
Cocoa butter (CB)	21.00 ± 0.60^{a}	28.20 ± 0.11^{a}	37.10 ± 0.08^{a}	56.30 ± 0.30^{g}
BS1 (90% BS: 10% PS)	23.05 ± 0.26^{c}	33.45 ± 0.02^{e}	39.66 ± 0.23^{c}	47.34 ± 0.11^{e}
BS2 (85% BS: 15% PS)	25.81 ± 0.19^{e}	35.27 ± 0.01^{f}	39.65 ± 0.34^{c}	45.40 ± 0.48^{d}
BS3 (80% BS: 20% PS)	25.95 ± 0.11^{e}	32.16 ± 0.03^{d}	39.80 ± 0.36^{e}	23.09 ± 0.16^{a}
BS4 (75% BS: 25% PS)	26.06 ± 0.12^{f}	32.13 ± 0.09^{d}	39.71 ± 0.34^{d}	28.43 ± 0.15^{b}
BS5 (70% BS: 30% PS)	25.07 ± 0.23^{d}	31.95 ± 0.02^{c}	39.71 ± 0.21^{d}	54.11± 0.49^{f}

Values are the mean±standard deviation of triplicate; means a different letter within a column is significantly different ($p<0.05$) as measured by Tukey test

The results are significantly ($p<0.05$) higher than the CB, indicating the blends (melting range: 13.65 °C to 16.61 °C) showed more rapid melting than the CB (melting range: 16.1 °C). According to Shetty, Reddy, & Khatoon (2014) and Rebecca *et al.* (2020), the melting temperature for SSS, PPP, POP, POS, and SOS are 73.1 °C, 66.4 °C, 35.2 °C, 37.5 °C to 58 °C and 41.6 °C, respectively. BS: PS blends in this study have higher SOS thus, the offset values for the blends are closer to 40 °C.

Crystallisation Profiles

Table 3 shows the changes in the crystallisation properties for BS: PS blends. PS showed a sharp crystallisation curve with the crystallisation starting at 26.36 ºC and ending at 23.57 ºC. The

crystallisation process occurs fast (crystallisation range: 2.79 ºC) because the high melting TAG dominated 50% of PS composition. Therefore, PS tends to crystallise faster below its melting temperature. Compared to CB, the PS crystallises at room temperature faster than CB and its blends. The onset and offset values for the blends were significantly higher than the CB observed in this study. The binary blends contain higher palmitic and POP content thus the blends have a rapid crystallisation range. The increase in the PS ratio induced the crystallisation peak of the binary blends to move toward lower temperatures.

The results correlate with the decrease of trisaturated TAG and the increase of disaturated TAG. The SSS and PPP content in the binary blends decreased proportionally to the increase in the PS ratio, lowering the melting and crystallisation properties of the blends. BS2 and BS3 showed a mixture of two crystallisation peaks, and blends with more than 20% of PS ratios showed two separate peaks. The thermogram is consistent with their melting thermogram, which indicates a mixture of two distinct TAGs. Among the blends, BS5 showed a comparable crystallisation value with CB (onset: 16.6 ºC and offset: 7.4 ºC) reported by Kang *et al.* (2013), indicating this blend resembled CB the most.

Table 3. Crystallization properties of bambangan stearin and palm stearin blends

	Crystallization properties			
	Onset Temperature (ºC)	Offset Temperature (ºC)	Max Temperature (ºC)	Enthalpy (J/g)
Cocoa butter (CB)	14.77 ± 0.23^{a}	3.42 ± 0.07^{a}	11.17 ± 0.56^{a}	-140.53 ± 1.46^{d}
Palm stearin (PS)	26.36 ± 0.18^{g}	23.57 ± 0.43^{h}	25.18 ± 0.11^{h}	-148.76 ± 0.81^{c}
Bambangan stearin (BS)	18.24 ± 0.01^{c}	7.92 ± 0.01^{b}	15.05 ± 0.13^{c}	-118.92 ± 0.04^{h}
BS1 (90% BS: 10% PS)	20.42 ± 0.18^{f}	11.58 ± 0.07^{g}	16.62 ± 0.23^{g}	-156.13 ± 1.85^{b}
BS2 (85% BS: 15% PS)	19.47 ± 0.14^{e}	8.28 ± 0.18^{c}	14.64 ± 0.05^{b}	-163.71 ± 2.81^{a}
BS3 (80% BS: 20% PS)	18.67 ± 0.04^{d}	11.37 ± 0.08^{f}	16.55 ± 0.07^{f}	-127.88 ± 2.13^{g}
BS4 (75% BS: 25% PS)	18.00 ± 0.03^{c}	10.48 ± 0.09^{e}	15.99 ± 0.32^{e}	-133.16 ± 2.01^{f}
BS5 (70% BS: 30% PS)	17.53 ± 0.01^{b}	9.18 ± 0.01^{d}	15.32 ± 0.32^{d}	-136.29 ± 2.01^{e}

Values are the mean±standard deviation of triplicate; means a different letter within a column is significantly different ($p<0.05$) as measured by Tukey test

Polymorphic Form

The effect of blending PS in the BS polymorphic behaviour is presented in Figure 3. Unlike BS, PS in this study has a different TAG composition with very high palmitic content that leads to the presence of PPP-TAG. Hence, the PS in this study exhibited *β'* (d-spacing of 4.13 Å) peak and a weak *β* peak at a d-spacing of 4.58 Å with *β'* peak being dominant. This finding is consistent with the fingerprint pattern of PS reported by Omar *et al.* (2018), who reported the *β'* form in PS. This is associated with grainy structure, and tripalmitin is the *β* form-tending. The polymorphic form for BS: PS blends changed significantly ($p<0.05$), resulting in a similar fingerprint pattern to the CB after integrating BS in the binary blends which showed a sharp *β* (v) form at 4.58 Å. This form is commonly associated with the desirable polymorphic form of chocolate. The stable *β* (v) form is preferred for chocolates and coatings because it melts at high temperatures and has a small to moderate crystal structure, providing a smooth mouthfeel effect.

Therefore, the blends might exhibit small to moderate crystal structures that result in the abovementioned properties. The binary blends exhibited a dominant *β* (v) form closer to the CB polymorphic form, with BS5 showing equal intensity and pattern. This behaviour was presumably due to the BS fingerprint pattern, which has a similar polymorphic pattern to the CB as well as the changes in the FA composition contributing to the presence of the three main TAGs (POP, POS, and SOS). The binary blends showed a mixture of *β'* and *β* polymorphic

forms, with the stable β form being dominant because a random TAG distribution in fat can independently present the β' form (Ribeiro *et al.*, 2009). BS1 showed an inseparable peak pattern at 22 to 24 Θ degrees, similar to the fingerprint pattern as BS. The intensity of the β peak is also the highest due to the high SOS content in this blend. The polymorphic form for these blends is also identical to the polymorphic behaviour CBE produced from high oleic high stearic sunflower-based CBE (Bootello *et al.*, 2018). These results indicate that the binary blend produced from the blending of 70% BS and 30% PS exhibited the desirable β (v) form of CB suggested for chocolate or confectionery production.

Overall, the BS: PS blends, especially at the PS content of 30% (BS5), exhibited physicochemical and thermal properties comparable to those of commercial CB. The IV (33.78 – 34.24 g iodine/g) and slip melting point (33.25 °C – 38.35 °C) of the blends were within the typical range for cocoa butter IV: 31.30 to 38.40 g iodine/g and SMP: 25.30 °C to 35.00 °C (Jin *et al*., 2018, 2017, 2016). In terms of TAG composition, the mixtures had a high content of SOS, a low content of POS, and POP. Although the POP and POS content was slightly lower than in cocoa butter, the melting and crystallisation profiles of BS5 were similar to those of cocoa butter, which exhibited a sharp melting range and stable β(V) polymorphism. This behaviour is essential for the desired mouthfeel and snapping properties in chocolate applications. These results suggest that the optimised BS: PS blends could be a potential alternative fat source to commercial cocoa butter.

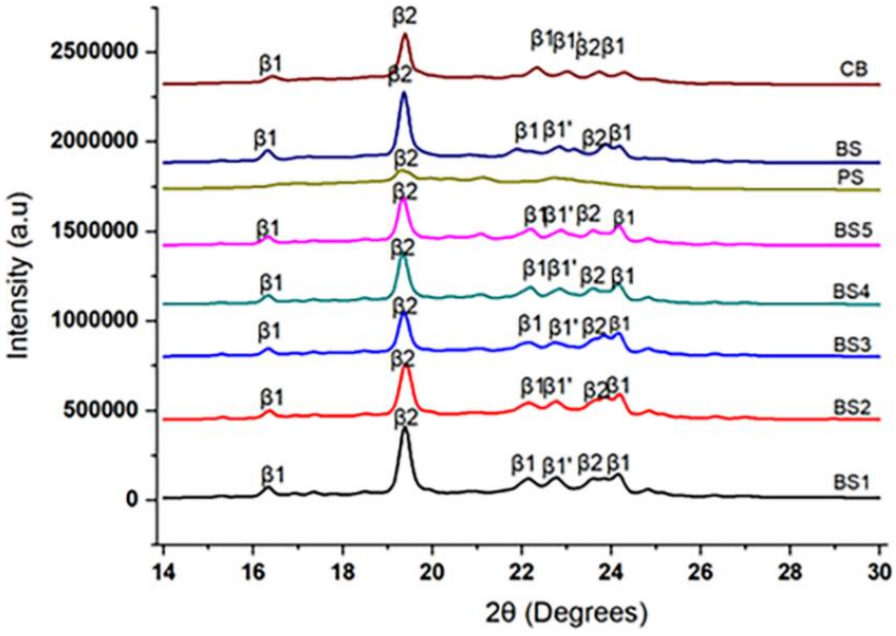

Figure 3. Diffraction pattern and short spacing of bambangan and palm stearin blends

CONCLUSION

This study successfully demonstrated that blending BS with PS can effectively modify the physicochemical and thermal properties of the resulting fat blends. The blends exhibited improved IV, SMP, and AV compared to individual PS, with BS5 (70% BS:30% PS) showing the most promising TAG profile and melting properties similar to commercial CB. The optimized blend reduces the waxy texture often associated with PS while maintaining desirable thermal stability and crystallisation behaviour. These findings suggest that BS: PS blends, specifically BS5, have significant potential as a functional alternative to CB in improving the thermal stability of products and confectionery applications. Further studies on sensory evaluation and product-specific performance are recommended to validate their commercial feasibility.

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