EVALUATING THE IMPACT OF COCOA BUTTER ALTERNATIVES ON THE MELTING BEHAVIOR AND SOLID FAT CONTENT OF COCOA BUTTER MIXTURE: PRELIMINARY STUDY

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Malaysian Cocoa J. 18: 32-37 (2026)

ABSTRACT – *The European legislation (2000/36/CE) permits the inclusion of vegetable fats, other than cocoa butter (CB), in chocolate, with a maximum limit of 5% in the final product. The vegetable fats utilized in chocolate couverture are referred to as cocoa butter alternatives (CBA) and are specifically known as cocoa butter equivalents (CBE) and cocoa butter substitutes (CBS). This study evaluates the melting profile and solid fat content of CB partially replaced with different levels (1–5%) of CBS from palm kernel oil and CBE from mango kernel fat to assess their suitability for use in chocolate couverture. Analytical results demonstrated that incorporating 1% to 5% of CBS and CBE into CB significantly affected the onset temperature (Tonset), peak temperature (Tpeak), end temperature (Tend), and enthalpy change (ΔH) during melting. The solid fat content (SFC) analysis showed that the inclusion of CBA impacts the melting behavior, flavor release, heat resistance, and overall product consistency. At final temperatures (35-40 ℃) of the CB+CBS and CB+CBE samples, the SFC exhibited moderate levels, indicating limited influence on the chocolate's structure but changes in melting characteristics. Results suggest mixtures of CB with CBS enhances heat resistance while CB with CBE mixture improves melt-in-mouth characteristics. These findings provide insights into the physicochemical compatibility of cocoa butter alternatives for enhancing the functional and sensory attributes to support better formulation strategies for chocolate couverture. These findings can serve as a basis for selecting suitable CBA percentage in combination with CB to develop chocolate couverture with a taste comparable to conventional cocoa butter-based chocolate.*

Keywords: Cocoa butter, cocoa butter alternatives, cocoa butter equivalent, cocoa butter substitute, cocoa butter mixture

INTRODUCTION

Cocoa butter (CB), a primary fat component in chocolate products, plays a vital role in defining the textural, sensory, and physical characteristics of chocolate, particularly its sharp melting point, snap, gloss, and mouthfeel (Mokbul *et al*., 2023). However, CB is one of the most expensive vegetable fats in the global food industry, with price volatility and limited supply posing significant challenges to manufacturers (Chira *et al*., 2016; Lipp & Anklam, 1998). In response, there has been a growing interest in the utilization of CBA in the formulation of milk chocolate couverture, which include CBE, CBR, and CBS. These alternatives, derived from a variety of tropical and temperate oil sources such as shea butter, palm kernel oil, sal fat, and illipe butter, offer potential cost benefits and improved thermal and oxidative stability of chocolate products (Jahurul *et al*., 2013). In particular, CBE structurally and functionally similar to CB are widely considered the most compatible for blending with CB without compromising critical quality attributes (Ramos Ramos *et al*., 2023; Timms, 2003). Despite their commercial and functional advantages, incorporating CBA into chocolate formulation presents complex physicochemical challenges, particularly in terms of melting behavior and SFC, both of which are critical determinants of chocolate's sensory profile and shelf (Afoakwa, 2010; Foubert *et al*., 2002)

Recent research has extensively explored the physical, thermal, and polymorphic properties of CBA and their interaction with cocoa butter in binary or multi-component fat systems. Studies have demonstrated that the blending ratio, fatty acid composition, and triacylglycerol (TAG) profile of CBA, including vegetable fat sources such as mango seed fat, bambangan kernel fat, shea butter, kokum butter, sunflower stearin, palm oil mid-fraction, and palm stearin, significantly influence the crystallization kinetics, melting range, and polymorphic transitions of cocoa butter-based formulations (Hondoh, 2023; Norazlina *et al*., 2021). Investigations using analytical techniques such as differential scanning calorimetry (DSC) and time-domian nuclear magnetic resonance (TD-NMR) have provided critical insights into the compatibility of various CBE with CB, especially those rich in symmetrical TAGs like POP (1,3-dipalmitoyl-2-oleoyl-glycerol), POS (1-palmitoyl-2-oleoyl-3-stearoyl-glycerol), and SOS (1,3-distearoyl-2-oleoyl-glycerol (Foubert *et al*., 2002; Lipp & Anklam, 1998). However, discrepancies persist across the literature

regarding optimal CBA blending concentrations and the mechanisms by which CBA modulate the fat crystal network and melting profile. For instance, some studies report that high levels of CBE mango kernel fat type of vegetable oil incorporation compromise tempering behavior and reduce snap quality of chocolate product, while others highlight successful applications of specific CBEs with minimal quality degradation (Akoh, 2017).

Therefore, this study aimed to provide a preliminary assessment of the effect of partially replacing CB with selected CBA, specifically CBE and CBS, at incorporation levels of 1–5%. The melting behaviour and SFC of the resulting CB–CBE and CB–CBS mixtures were evaluated and compared with those of pure CB. Previous studies have examined CB mixtures with CBE and CBS at relatively higher substitution levels and have shown that alternative fats can alter SFC, crystallization behaviour, and other physical properties (Quast *et al*., 2013). However, the effects of low-level CBE and CBS incorporation, particularly across a temperature range relevant to chocolate processing and consumption, remain less clearly defined. The novelty of the present study lies in directly comparing CBE and CBS at low incorporation levels of 1–5% using both DSC and TD-NMR to characterise their effects on melting behaviour and SFC. The findings provide practical information on the compatibility of these two types of CBA with CB and may help guide the selection of suitable CBA percentage for partial replacement of cocoa butter in chocolate couverture.

MATERIALS AND METHODS

Materials

The cocoa butter (CB) used in this study sourced from a local grinder, Guan Chong Cocoa Manufacturer Sdn. Bhd., located in Pasir Gudang, Johor. The cocoa butter substitute (CBS) was obtained from Southern Edible Oil Industries (M) Sdn. Bhd. in Klang, Selangor, while the cocoa butter equivalent (CBE) was supplied by Mewah Oils Sdn. Bhd., based in Pulau Indah, Selangor. Table 1 shows the solid fat content of CBE and CBS from above.

Table 1: Solid fat content of CBE and CBS from manufacturer

Solid Fat Content (%)	100% CBE	100% CBS
at 20 °C	72.2	95.12
at 25 °C	59.5	87.97
at 30 °C	44.1	48.33
at 35 °C	3.41	2.92

Sample preparation

Table 2 shows composition used to prepare cocoa butter mixture samples. When preparing of cocoa butter mixtures for experimental analysis, precise formulation is critical to ensure consistency and reliable evaluation of physicochemical properties. CB, along with CBE or CBS, was selected based on their specific triacylglycerol (TAG) profiles and incorporated into mixtures at predetermined ratios. Each fat component was accurately weighed according to the targeted composition, and the entire mixture was subjected to a controlled melting process in a convection oven set to approximately 40°C to ensure complete homogenization without inducing thermal degradation. This melting step allowed for uniform distribution of all lipid constituents, facilitating accurate assessment of melting behavior and SFC. Once fully melted and homogenized, the liquid mixture was poured into standardized containers and subjected to a rapid cooling step at 8°C to 12°C for one hour to induce crystallization and stabilize the fat network. This controlled cooling process helps to promote a consistent and stable fat crystal structure, ensuring that the samples are suitable for subsequent analysis of melting behaviour and SFC using DSC and TD-NMR.

Sampling Procedure

Each sample were stored at temperatures 20 ± 3 ℃ accompanied by a relative humidity below 60% and kept away from heat and light prior to analysis. All samples were prepared within one day and analysed within one month of preparation.

Table 2: The composition used in the creation of cocoa butter mixture samples

Sample/ Composition	CB	CBE	CBS
1%	-	CB +1% CBE	CB +1% CBS
2%	-	CB +2% CBE	CB +2% CBS
3%	-	CB +3% CBE	CB +3% CBS
4%	-	CB +4% CBE	CB +4% CBS
5%		CB +5% CBE	CB +5% CBS
100%	100% CB	-	-

Melting profiles

The melting profile of the cocoa butter mixture was determined using a DSC 8000 Perkin Elmer, which is a differential scanning calorimeter. The method followed the procedure described by (Md.Ali & Dimick, 1994). The sample were subjected to a temperature of 50 ℃ within an enclosed heating chamber. A quantity of cocoa butter mixture sample weighing between 3 and 5 milligrams was tightly packed in an aluminum pan. The samples underwent heating at a temperature of 60 ℃ for a duration of 30 minutes, followed by cooling at 0 ℃ for 90 minutes. Subsequently, it was transferred to a DSC chamber and maintained at a temperature of -25 ℃ for 5 minutes on the DSC head. The melting profile was recorded by heating the samples from −25 °C to 5 °C at a rate of 20 °C/min.

Solid fat content

The solid fat content (SFC) of cocoa butter mixture was determined according to the ISO 8292 using a time-domain nuclear magnetic resonance (TD-NMR) spectrometer called the Bruker, Minispec mq one series, manufactured by Bruker in Germany. Approximately 3- 4 g of the homogenous and melted samples (60 °C, 50 minutes, n=2) were inserted into NMR tubes up to accurate level. The NMR tube was then placed in metal blocks and let equilibrated at 0 °C for 90 min ± 5 min in a thermostatic bath and further incubated at 26 °C for 40 h ± 0.5 h. Afterwards, the tubes are stored again at temperature 0 °C for 90 min ± 5 min followed by 60 min immersion at the measuring temperature of 10, 15, 20, 25, 30, 35 and 40 °C respectively. The NMR tubes were taken one at a time from the blocks after the appropriate time, wipe off any condensation and place them immediately in the TD-NMR instrument. The solid fat content results for each tube were recorded in the system.

Statistical analyses

A one-way analysis of variance (ANOVA) and Tukey's multiple comparison test were performed in MINITAB version 21 at a significance level of 0.05.

RESULTS AND DISCUSSIONS

The study evaluated the impact of CBA on the melting behavior and SFC of CB mixtures, revealing significant variations in thermal properties and structural characteristics. Key findings demonstrated that incorporating 1%–5% CBE or CBS altered the onset temperature (Tonset), peak temperature (Tpeak), end temperature (Tend), and enthalpy change (ΔH) during melting as shown in Table 3. For instance, CB with 1% CBE exhibited a lower Tonset (28.44 °C) compared to pure CB (29.08 °C), while CB with 5% CBS showed a higher Tonset (31.63 °C), indicating divergent effects on melting initiation.

The SFC analysis further highlighted that CBS mixtures retained higher SFC at elevated temperatures (35–40 °C), enhancing heat resistance, whereas CBE mixture promoted lower SFC, improving melt-in-mouth properties as illustrates in Table 4. These results align with previous studies by (Foubert *et al*., 2002; Lipp & Anklam, 1998), who emphasized the role of triacylglycerol (TAG) composition in modulating fat crystallization and melting profiles. The observed trends suggest that CBE, with its structural similarity to CB, integrates more seamlessly into the fat matrix, while CBS, often derived from hydrogenated oils, introduces higher thermal stability but may compromise sensory attributes.

The 5% CBS mixture showed a noticeable decrease in SFC at 20 and 25 °C compared with the lower CBS percentage concentrations. This may be related to changes in the crystallization behaviour of the CB–CBS mixture as the proportion of CBS increased. The incorporation of CBS can affect the interaction and packing of fat molecules within the cocoa butter crystal network, resulting in a greater proportion of fat remaining in the liquid state at these temperatures (Balcázar-Zumaeta *et al*., 2026). In the present study, this effect was particularly evident at 25 °C, where the SFC of the 5% CBS mixture decreased to 58.3%, compared with approximately 66–67% for the 1–4% CBS mixtures. These results indicate that the effect of CBS on SFC was not linear and became more pronounced at the higher percentage level.

The physicochemical compatibility of CBA with CB is critical for optimizing chocolate formulations, as evidenced by the SFC and DSC results. At 20 °C, pure CB exhibited an SFC of 75.0%, which decreased to 69.5% and 73.6% for CB with 2% CBE and 1% CBS, respectively. This reduction in SFC with CBE incorporation correlates with improved melt-in-mouth characteristics, a desirable trait for premium chocolates (Afoakwa, 2010). Conversely, CBS blends maintained higher SFC values (e.g., 73.6% for CB +1% CBS at 20 °C), suggesting enhanced heat resistance, which is advantageous for tropical climates. The enthalpy changes (ΔH) further supported these observations, with CBE mixtures showing higher ΔH values (116.04 J/g for CB +1% CBE) compared to CBS (115.66 J/g for CB +1% CBS), indicating greater energy requirements for melting. These findings corroborate the work of (Jahurul *et al*., 2013), who noted that CBE's TAG profile (e.g., POP, POS, SOS)

mimics CB, facilitating polymorphic stability. However, the variability in Tpeak and Tend across blends underscores the need for precise formulation control to avoid undesirable textural outcomes, such as graininess or excessive softening (Timms, 2003).

The interpretation of these findings must be framed within the context of chocolate's functional and sensory requirements. The moderate SFC levels observed in all mixtures at 35-40°C confirm that low concentrations of CBA do not drastically alter the fundamental structure of chocolate at mouth temperature, which is essential for preventing a waxy or greasy mouthfeel. The higher SFC of CBS blends at 30°C (e.g., 47.0% for CB+3% CBS vs. 42.0% for pure CB) and their increased heat resistance (higher Tonset) support their potential application in chocolates destined for tropical climates, as they could help mitigate fat bloom and structural softening (Afoakwa, 2010). This enhanced thermal stability likely stems from the formation of a more tightly packed crystal network.

Table 3: Melting properties of CB with different levels of CBE and CBS

Samples	Tonset (°C)	Tpeak (°C)	Tend (°C)	Delta H (J/g)
100% CB	29.08 ± 0.01^{e}	36.13 ± 0.02^{c}	39.36 ± 0.01^{e}	106.44 ± 0.02^{f}
CB +1% CBE	28.44 ± 0.01^{h}	35.63 ± 0.01^{e}	38.41 ± 0.01^{g}	116.04 ± 0.04^{a}
CB +2% CBE	29.37 ± 0.03^{d}	36.64 ± 0.04^{c}	39.53 ± 0.01^{d}	95.62 ± 0.03^{j}
CB +3% CBE	28.86 ± 0.01^{f}	35.63 ± 0.02^{e}	39.63 ± 0.01^{cd}	110.28 ± 0.04^{d}
CB +4% CBE	28.62 ± 0.02^{g}	35.63 ± 0.02^{e}	39.28 ± 0.04^{ef}	99.38 ± 0.02^{h}
CB +5% CBE	29.32 ± 0.03^{d}	35.89 ± 0.01^{d}	39.15 ± 0.04^{ef}	97.10 ± 0.04^{i}
CB +1% CBS	29.86 ± 0.01^{c}	36.88 ± 0.01^{a}	40.60 ± 0.01^{a}	115.66 ± 0.01^{b}
CB +2% CBS	29.30 ± 0.01^{d}	35.88 ± 0.03^{d}	39.11 ± 0.07^{f}	113.49 ± 0.02^{c}
CB +3% CBS	34.47 ± 0.01^{a}	34.00 ± 0.01^{g}	39.91 ± 0.07^{b}	88.61 ± 0.03^{k}
CB +4% CBS	28.50 ± 0.01^{h}	35.13 ± 0.01^{f}	37.83 ± 0.02^{h}	108.87 ± 0.18^{e}
CB +5% CBS	31.63 ± 0.01^{b}	36.60 ± 0.02^{b}	39.82 ± 0.07^{bc}	105.59 ± 0.01^{g}

Table 4: Solid fat content of of CB with different levels of CBE and CBS

Samples	Solid Fat Content (% SFC)						
	at 10 °C	at 15 °C	at 20 °C	at 25 °C	at 30 °C	at 35 °C	at 40 °C
100% CB	85.8 ± 0.09^{ab}	80.3 ± 0.04^{a}	75.0 ± 0.01^{a}	66.4 ± 0.06^{b}	42.0 ± 0.17^{e}	1.3 ± 0.06^{d}	0.3 ± 0.03^{a}
CB +1% CBE	85.2 ± 0.70^{a}	78.0 ± 0.15^{cd}	70.2 ± 0.10^{f}	59.4 ± 0.10^{f}	34.1 ± 0.06^{g}	1.7 ± 0.10^{c}	0.2 ± 0.10^{ab}
CB +2% CBE	83.5 ± 0.65^{bcd}	77.3 ± 0.06^{e}	69.5 ± 0.00^{g}	58.9 ± 0.06^{g}	32.6 ± 0.30^{h}	1.4 ± 0.25^{cd}	0.2 ± 0.06^{ab}
CB +3% CBE	83.0 ± 0.65^{cd}	78.2 ± 0.00^{c}	72.0 ± 0.10^{e}	62.1 ± 0.15^{e}	36.7 ± 0.15^{f}	1.4 ± 0.00^{d}	0.1 ± 0.12^{ab}
CB +4% CBE	82.7 ± 0.55^{d}	77.7 ± 0.35^{de}	73.8 ± 0.45^{bc}	65.8 ± 0.25^{c}	43.6 ± 0.60^{d}	1.7 ± 0.06^{b}	0.3 ± 0.06^{a}
CB +5% CBE	85.2 ± 0.02^{a}	79.5 ± 0.08^{b}	74.0 ± 0.01^{b}	65.2 ± 0.02^{d}	42.3 ± 0.19^{e}	1.3 ± 0.06^{d}	0.2 ± 0.02^{ab}

CB +1% CBS	82.3 ± 0.10^{d}	80.3 ± 0.15^{a}	73.6 ± 0.20^{bcd}	67.1 ± 0.10^{a}	46.4 ± 0.10^{a}	2.2 ± 0.06^{b}	0.3 ± 0.06^{a}
CB +2% CBS	84.2 ± 0.30^{abc}	80.6 ± 0.10a	73.4 ± 0.30cd	67.0 ± 0.06a	45.4 ± 0.40b	2.1 ± 0.00b	0.0 ± 0.06b
CB +3% CBS	83.4 ± 0.30^{bcd}	80.2 ± 0.25^{a}	73.3 ± 0.20^{cd}	67.1 ± 0.10^{a}	47.0 ± 0.00^{a}	2.6 ± 0.06^{a}	0.2 ± 0.10^{ab}
CB +4% CBS	83.2 ± 0.40^{bcd}	80.3 ± 0.06^{a}	73.2 ± 0.06^{d}	66.4 ± 0.20^{b}	44.6 ± 0.06^{c}	2.1 ± 0.10^{b}	0.3 ± 0.10a
CB +5% CBS	85.3 ± 0.02^{a}	77.8 ± 0.04^{cd}	69.9 ± 0.07^{fg}	58.3 ± 0.03^{h}	32.6 ± 0.05^{h}	1.3 ± 0.11^{d}	0.3 ± 0.02^{a}

CONCLUSIONS

This study demonstrates that CBS and CBE distinctly modify CB's thermal properties, with CBS enhancing heat resistance and CBE improving meltability. The findings help formulators understand how the percentage amount of CBS and CBE influence the thermal properties of cocoa butter. Addressing the identified gaps through advanced analytical and sensory research will further refine chocolate design, ensuring quality, functionality, and consumer satisfaction in evolving markets.

ACKNOWLEDGMENTS

The author wishes to express the appreciation to Director General, Deputy Director General of R & D and the Director of Cocoa Downstream Technology Division of Malaysia Cocoa Board for providing laboratory facilities and financial support for this research study. The research was fully funded by the Temporary Research Fund (TRF: L15330) from the Malaysian Cocoa Board.

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