PARTIAL REPLACEMENT EFFECTS OF COCOA BUTTER ALTERNATIVES AND GRANULATED SUGAR ON THE MELTING PROPERTIES AND SOLID FAT CONTENT OF MILK CHOCOLATE COUVERTURE: PRELIMINARY STUDY

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Malaysian Cocoa J. 18: 42-48 (2026)

ABSTRACT – *The increasing cost and limited availability of cocoa butter have prompted the chocolate industry to explore cost-effective alternatives without compromising product quality. This preliminary study evaluated the influence of cocoa butter alternatives (CBA) and granulated sugar on the melting properties and solid fat content (SFC) of milk chocolate couverture. Five formulations were prepared comprising a control containing 100% cocoa butter with icing sugar, and four treatments containing granulated sugar with 5% cocoa butter equivalent (CBEm), cocoa butter replacer (CBRm) and different supplier of cocoa butter substitute of (CBSm), and (CBSs). Melting characteristics were determined using Differential Scanning Calorimetry (DSC), while SFC profiles were analysed using time-domain nuclear magnetic resonance (TD-NMR). The results showed that CBEm exhibited thermal properties most similar to the control, with onset temperature T(onset) values of 29.51°C and 29.82°C, respectively, and end of melting T(end) values of 38.75°C and 38.66°C. Furthermore, CBEm recorded the highest melting enthalpy (ΔH = 14.52 J/g) compared to the control (8.71 J/g), indicating improved crystal stability. In contrast, CBSm showed the highest T(onset) (33.19°C) and T(end) (40.66°C), suggesting delayed melting and a potential waxy mouthfeel. At 20°C, the control and CBEm maintained high SFC values of 71.27% and 70.66%, respectively, whereas CBRm and CBS formulations exhibited significantly lower values (64.87–66.30%). These findings indicate that partial replacement of cocoa butter with 5% CBEm combined with granulated sugar can produce a cost-effective milk chocolate couverture while maintaining thermal behaviour and fat crystallization characteristics comparable to conventional formulations that used 100% cocoa butter.*

Keywords: Cocoa butter alternatives, granulated sugar, cocoa butter

INTRODUCTION

Chocolate is one of the most widely consumed confectionery products worldwide, enjoyed by people of all ages due to its unique flavors (sweetness and bitterness) and functional properties (Muslim *et al*., 2025; Tuigunov *et al*., 2025). Chocolate also regarded primarily as a confectionery indulgence, has undergone a significant paradigm shift in nutritional science (Muslim *et al*., 2025). Among chocolate varieties, milk chocolate couverture is particularly valued because of its high cocoa butter content, which provides superior processing characteristics and desirable organoleptic properties (Bilal, 2023). Cocoa butter possesses a unique triacylglycerol composition that enables the formation of stable crystalline structures, resulting in the characteristic melt-in-the-mouth sensation preferred by consumers. However, the chocolate industry is currently facing substantial economic challenges due to the increasing and volatile prices of cocoa beans and cocoa butter, driven by supply shortages, climate related production constraints, and growing global demand (Jin *et al*., 2021). The significant increase in raw material costs, particularly for cocoa beans, which reached reached RM18,300 per metric ton in 2025 and about RM40,000 per metric ton in 2024, the cost of cocoa butter and cocoa liquor has also shown a dramatic increase (Affendi *et al*., 2026). Consequently, there is increasing interest in identifying cost-effective alternatives that can partially replace cocoa butter while maintaining product quality and consumer acceptance. Thus, the incorporation of cocoa butter alternative (CBA) that have an identical melting profile, but with different chemical composition compared to cocoa butter, is an alternative to reduce the raw material cost (Biswas *et al*., 2016). According to Biswas *et al* (2017), European Union Directive 2000/36/EC and Food Standards Agency 2003 limit the use of vegetable fats in chocolates to a 5 g/100 g blend. Therefore, a 5% CBA was selected as the substitution level in the present study to investigate its effect on the thermo-physical properties of milk chocolate while remaining within the specified limit for vegetable fat incorporation.

CBE are considered the most compatible with cocoa butter because they possess similar chemical and physical properties, allowing them to blend without

significantly affecting crystallization behaviour and melting characteristics (Castro-Alayo *et al*., 2023). In contrast, CBR and CBS, which are commonly derived from palm-based or lauric fats, offer greater economic benefits but may alter the thermal, rheological, and sensory properties of chocolate (Lillah *et al*., 2017). Previous studies have shown that while certain cocoa butter alternatives improve heat resistance and storage stability, they can also increase hardness, delay flavour release, and produce undesirable waxy mouthfeel due to incomplete melting at body temperature (Afoakwa *et al*., 2008;Rosales *et al*., 2017). Furthermore, thermal compatibility between cocoa butter and alternative fats remains a critical factor influencing the quality and acceptability of chocolate products.

In addition to fat composition, the selection of sweeteners plays an important role in determining production costs and product quality. Icing sugar is conventionally used in chocolate manufacturing because its fine particle size contributes to smooth texture and efficient refining. Traditionally, icing sugar is preferred for its fine particle size, which ensures a smooth texture; however, its higher processing cost makes granulated sugar a more attractive alternative if refining parameters can be optimized to prevent grittiness (Affendi *et al*., 2026). Granulated sugar represents a more economical alternative and has the potential to reduce production expenses if adequate refining conditions are applied to achieve the desired particle size distribution.

Moreover, current literature has largely emphasized rheological, sensory, and textural properties, with comparatively less attention given to melting behaviour and solid fat content (SFC), which are essential indicators of chocolate quality, thermal stability, and storage performance. Melting properties directly influence mouthfeel and flavour release, whereas SFC profiles provide valuable information regarding fat crystallization, hardness, and resistance to deformation under varying temperature conditions (Afoakwa *et al*., 2008a).

Therefore, this study aims to evaluate the influence of selected cocoa butter alternatives and granulated sugar on the melting properties and solid fat content of milk chocolate couverture to identify cost-effective formulations that maintain desirable quality attributes. The findings will contribute to the development of economically viable milk chocolate couverture products while providing valuable scientific insights into the optimization of alternative fat systems for sustainable chocolate manufacturing.

MATERIALS AND METHODS

Materials

Cocoa butter and cocoa liquor were bought from the local grinder, Guan Chong Cocoa Manufacturer Sdn. Bhd., Pasir Gudang, Johor. Cocoa butter equivalent, cocoa butter replacer and cocoa butter substitute from Mewah Oils Sdn. Bhd., Port Klang, Selangor. Another cocoa butter substitute from Southern Edible Oil Industries (M) Sdn. Bhd., Klang, Selangor. Milk powder from Fonterra Brands Malaysia Sdn. Bhd. Icing sugar and granulated sugar were purchased from Central Sugars Refinery Sdn. Bhd. (CSR). All chemicals used were food-grade and obtained from local chemical suppliers.

Sample Preparation

An experimental had been carried out to verify the melting profile and solid fat content in mixture of cocoa butter (CB), cocoa butter replacer (CBR), cocoa butter equivalent (CBE) and cocoa butter substitute (CBS). The pilot test of the chocolate sample had been done using melangeur (PG 506, Tamil Nadu, India) equipment to evaluate the performance of the new formulation of the chocolate sample before the actual chocolate sample will be produced using refiner conch (MJM50, China). Table 1 provides the components and quantities used in the creation of milk chocolate couverture chocolate samples. 1 kg of chocolate mass was used for each sample preparation. The melangeur utilised in the processing of the samples has a rotational speed of 120 rpm. The melangeur utilises 105 mm diameter roller stones made of high-quality granite. The mixing and refining times of the samples were determined as the moment when the entire mixture started to circulate in the melangeur drum. The cumulative duration of the processing was 12 h. Lecithin and vanillin were introduced to the refining process 2 h before it ended. In the subsequent phase, the chocolate undergoes a tempering procedure. The ideal ambient temperature for chocolate tempering was around 28°C, accompanied by a relative humidity below 50%. This procedure utilizes the hand tempering tabletop method. Once finished, the chocolate was placed into a mould for the moulding process and then chilled to a temperature of 8°C to 12°C for a duration of 1 hour to solidify. Thereafter, the chocolate samples were then carefully demoulded onto trays in preparation for the packaging process. It was crucial to ensure that the finished chocolates exhibit a high standard of visual appeal at this stage, as their aesthetic presentation significantly influences consumer perception and product value. The chocolate sample storage area maintains a temperature within the range of 20°C-23°C, accompanied by a relative humidity below 60%.

Sampling Procedure

Each sample was stored at temperatures 20 ± 2 °C and kept away from heat and light before analysis. All the analysis of each sample was accomplished within one month of the sample preparation.

Melting Profiles

The melting profile was determined using the differential scanning calorimeter (DSC) 8000. The methodology employed was selected in accordance with the approach proposed by Md.Ali & Dimick (1994). The specimens were subjected to a temperature of 50°C within an enclosed heating chamber. A quantity of sample weighing between 3 and 5 mg was tightly packed in an aluminium pan. The specimen underwent heating at a temperature of 60°Cfor a duration of 30 min, followed by cooling at 0°C for 90 min. Subsequently, it was transferred to a DSC chamber and maintained at a temperature of- 25 °C for 5 min on the DSC head. The fat's melting profile was determined by measuring its temperature change at a heating rate of 20°C/min, starting from -25°C and reaching a maximum of 5°C.

Solid Fat Content

The solid fat content (SFC) of chocolate was detemined 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 multiple comparison test were performed using MINITAB version 21 software, with a significance level of 0.05.

Table 1: The formulations used for the production of chocolate samples (g/100 g)

Ingredients	Icing sugar (control) 100% CB	Granulated sugar, +5% CBEm	Granulated sugar, +5% CBRm	Granulated sugar, +5% CBSm	Granulated sugar, +5% CBSs
Icing sugar	36.9	-			
Granulated Sugar	-	36.9			
CB	23	18			
CBA	-	5			
Cocoa liquor	17				
Milk powder	22.59				
Lecithin	0.5				
Vanillin	0.01				

RESULTS AND DISCUSSIONS

This pilot test successfully demonstrated that the strategic substitution of 5% cocoa butter (CB) with various cocoa butter alternatives (CBE, CBR, and CBS) and the replacement of icing sugar with granulated sugar can achieve significant cost savings while largely maintaining or closely approximating the desirable thermo-physical profile of control milk chocolate. Interpreting the physico-chemical data reveals crucial insights into the performance of the alternatives.

The DSC results presented in Table 2 show that the addition of 5% CBS (both CBSm and CBSs samples) resulted in significantly higher T(onset) and T(end) temperatures. The CBSm formulation exhibited the highest T(onset) (33.19 ± 0.01°C) and T(end) (40.66 ± 0.02°C) values compared with the control

sample (29.82 ± 0.01°C and 38.66 ± 0.01°C, respectively), alongside the lowest melting enthalpy value (ΔH = 2.87 ± 0.01 J/g). The elevated melting temperatures indicate that CBS formulations require greater thermal energy before melting begins and is completed. Such behaviour may delay melting during consumption at approximately body temperature (37°C) and potentially contribute to a waxy mouthfeel, which is generally considered undesirable in premium chocolate products. Previous studies have reported that incomplete melting near body temperature may negatively influence flavour release and overall sensory perception (Marriott, 1993).

Conversely, the CB + 5% CBEm sample exhibited the most similar thermal profile to the control, with a T(onset) value of 29.51 ± 0.01°C and a T(end) value of 38.75 ± 0.03°C. These values closely matched those of the control formulation which is 100% CB with icing sugar, indicating a high degree of compatibility between cocoa butter and the cocoa butter equivalent. Cocoa butter equivalents are generally formulated to possess a triacylglycerol composition similar to cocoa butter, allowing co-crystallization without substantial disruption of the crystal network (Ewens *et al*., 2021). Such compatibility enables the maintenance of thermal characteristics that closely resemble those of conventional chocolate formulations.

An interesting observation from Table 2 is the substantially higher melting enthalpy recorded for the CB + 5% CBEm formulation compared with the control sample. The ΔH value increased from 8.71 ± 0.01 J/g in the control to 14.52 ± 0.02 J/g in the CBEm treatment. Melting enthalpy represents the energy required to disrupt crystalline structures during melting (Najibi Hosseini & Ghanbarzadeh, 2025). The higher value observed in the CBEm sample may indicate the formation of a more ordered and stable crystal network. Such behaviour may contribute to desirable quality attributes including improved snap, enhanced structural integrity, and greater resistance to deformation during storage and transportation (Najibi Hosseini & Ghanbarzadeh, 2025). Although sensory evaluation was not conducted in the present study, the elevated enthalpy value suggests that the incorporation of CBEm may provide additional benefits in maintaining product quality during handling and distribution.

The solid fat content (SFC) data presented in Table 3 and Figure 1 further reinforce the DSC findings. All formulations generally maintained high SFC values at lower temperatures (10°C–20°C), which is important for product hardness, snap, and shape retention. At 20°C, the control and CB + 5% CBEm formulations recorded SFC values of 71.27 ± 0.07% and 70.66 ± 0.16%, respectively. The close similarity between these values further confirms the compatibility of CBEm with cocoa butter and indicates that the incorporation of 5% CBEm did not substantially alter fat crystallization behaviour.

In contrast, the CBRm and CBS formulations exhibited significantly lower SFC values at 20°C, ranging from 64.87% to 66.30%. These lower values suggest differences in crystal formation and fat network development. As shown in Figure 1, the CB + 5% CBRm and CB + 5% CBS formulations exhibited a more pronounced reduction in SFC as the temperature increased from 20°C to 30°C. Such behaviour indicates that these alternative fats may be less effective in maintaining a stable crystalline structure under moderate temperature conditions. Lower SFC values within this temperature range may contribute to reduced hardness and greater susceptibility to deformation during storage and distribution (Martini & Herrera, 2008).

At elevated temperatures between 35°C and 40°C, all formulations exhibited a further reduction in SFC, reflecting the progressive melting of the remaining crystalline fat fraction. As shown in Table 3 and Figure 1, the control sample retained SFC values of 51.96 ± 0.04% and 51.86 ± 0.14% at 35°C and 40°C, respectively, while the CB + 5% CBEm formulation recorded comparable values of 50.44 ± 0.09% and 50.35 ± 0.01%. Despite the difference in fat composition between CB and CBEm, the incorporation of CBEm did not cause a substantial change in the melting behaviour of the chocolate, particularly at temperatures close to body temperature. (Castro-Alayo *et al*., 2023).

The CBRm formulation recorded the lowest SFC values at 35°C and 40°C, namely 49.37 ± 0.01% and 49.17 ± 0.01%, respectively. This behaviour indicates that a greater proportion of the fat phase had transitioned into the liquid state. Meanwhile, CBSm and CBSs maintained intermediate SFC values despite exhibiting higher melting temperatures in the DSC analysis. This observation suggests that melting behaviour is influenced not only by the quantity of solid fat present but also by the nature, distribution, and stability of the crystalline structures formed within the chocolate matrix (Afoakwa *et al*., 2009). From a practical perspective, the retention of approximately 50% solid fat at 35°C and 40°C indicates that all formulations maintained a substantial crystalline fraction even at elevated temperatures. Such behaviour may be advantageous for preserving product shape during storage and transportation in tropical climates. However, excessive retention of solid fat near body temperature may also contribute to slower melting and a waxy mouthfeel (Marriott, 1993).

Table 2: Chocolate melting properties of 100% cocoa butter and added 5% of the cocoa butter alternatives

Samples	T_{onset} (°C)	T_{peak} (°C)	T_{end} (°C)	Delta H (J/g)
100% CB	29.82 ± 0.01^{c}	35.41 ± 0.01^{a}	38.66 ± 0.01^{d}	8.71 ± 0.01^{b}
CB + 5% CBEm	29.51 ± 0.01^{d}	35.40 ± 0.01^{a}	38.75 ± 0.03^{c}	14.52 ± 0.02^{a}
CB + 5% CBRm	29.91 ± 0.01^{b}	32.40 ± 2.14^{a}	37.59 ± 0.02^{e}	4.76 ± 0.01^{d}
CB + 5% CBSm	33.19 ± 0.01^{a}	37.41 ± 0.01^{a}	40.66 ± 0.02^{a}	2.87 ± 0.01^{e}
CB + 5% CBSs	29.47 ± 0.01^{d}	34.41 ± 0.01^{a}	39.51 ± 0.01^{b}	6.89 ± 0.01^{c}

Table 3: Chocolate solid fat content of 100% cocoa butter and added 5% of the cocoa butter alternatives

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	86.49 ± 0.33^{bc}	80.68 ± 0.35^{b}	71.27 ± 0.07^{a}	63.72 ± 0.05^{a}	59.11 ± 0.18^{a}	51.96 ± 0.04^{a}	51.86 ± 0.14^{a}
CB + 5% CBEm	86.73 ± 0.13^{b}	81.23 ± 0.04^{a}	70.66 ± 0.16^{b}	62.80 ± 0.63^{b}	57.98 ± 0.38^{b}	50.44 ± 0.09^{b}	50.35 ± 0.01^{b}
CB + 5% CBRm	86.05 ± 0.05^{c}	80.25 ± 0.10^{bc}	66.30 ± 0.08^{c}	54.92 ± 0.11^{e}	52.65 ± 0.01^{d}	49.37 ± 0.01^{c}	49.17 ± 0.01^{d}
CB + 5% CBSm	87.96 ± 0.24^{a}	80.00 ± 0.09^{c}	64.93 ± 0.10^{d}	59.07 ± 0.10^{c}	53.67 ± 0.25^{c}	49.46 ± 0.15^{c}	49.71 ± 0.09^{c}
CB + 5% CBSs	88.34 ± 0.04^{a}	80.28 ± 0.10^{bc}	64.87 ± 0.09^{d}	58.10 ± 0.38^{d}	53.78 ± 0.06^{c}	50.41 ± 0.25^{b}	50.39 ± 0.28^{b}

In addition to the influence of cocoa butter alternatives, the replacement of icing sugar with granulated sugar may also have contributed to the observed thermal and crystallization behaviour of the chocolate formulations (Wong *et al*., 2024). Icing sugar is conventionally used in chocolate manufacture because its finer particle size promotes a more uniform distribution of solid particles within the continuous fat phase (Afoakwa *et al*., 2008). In contrast, granulated sugar generally requires extensive refining to achieve a comparable particle size distribution. Differences in sugar particle characteristics can influence fat-particle interactions, packing density, and the distribution of cocoa butter within the chocolate matrix (Do *et al*., 2007).

Despite the complete replacement of icing sugar with granulated sugar in all alternative formulations, the CB + 5% CBEm sample exhibited melting temperatures and SFC values that remained remarkably close to those of the control formulation. The DSC results in Table 2 indicate that the use of granulated sugar did not substantially alter the melting profile when combined with a compatible cocoa butter equivalent. Similarly, the SFC profiles shown in Table 3 demonstrate that the control sample containing icing sugar and the CBEm formulation containing granulated sugar maintained comparable levels of solid fat throughout the evaluated temperature range. At 20°C, the difference between the two formulations was less than 1%, while similar trends were observed at 25°C, 30°C, 35°C, and 40°C. These findings suggest that the refining conditions employed in this study were sufficient to minimise any negative impact of granulated sugar on fat crystallization and melting behaviour.

From an industrial perspective, the findings indicate that partial replacement of cocoa butter with CBEm offers a promising strategy for reducing formulation costs while preserving desirable thermal and crystallization characteristics (Ramos *et al*., 2023). The increasing cost and fluctuating supply of cocoa butter have encouraged manufacturers to seek alternative fat systems capable of maintaining product quality without substantially increasing production expenses. Among the alternative fats evaluated, CBEm demonstrated the greatest compatibility with cocoa butter and the highest potential for commercial application (Smith, 2001). In contrast, CBS formulations may be more suitable for applications where enhanced heat resistance is prioritised over rapid

melting characteristics, such as chocolate coatings or products intended for warmer climates (Asiabar, A. H. *et al*., 2022).

It should be noted that the present investigation represents a preliminary assessment and focused primarily on melting characteristics and solid fat content. Other quality attributes including rheological behaviour, texture, bloom stability, particle size distribution, shelf-life performance, and sensory acceptance were not evaluated. Furthermore, the study focused on a 5% substitution level, which was selected to access the potential for meaningful cost reduction while aiming to retain a flavor profile comparable to that of conventional milk chocolate couverture. Future studies should examine a broader range of incorporation levels and include comprehensive physicochemical and sensory analyses to provide a more complete understanding of the suitability of cocoa butter alternatives in milk chocolate couverture formulations.

CONCLUSIONS

This preliminary study investigated the influence of selected cocoa butter alternatives and granulated sugar on the melting properties and solid fat content of milk chocolate couverture. The results demonstrated that the type of cocoa butter alternative significantly affected the thermal behaviour and crystallization characteristics of the chocolate. Among the tested formulations, the cocoa butter equivalent (CBEm) exhibited the closest performance to the control formulation containing 100% cocoa butter and icing sugar. The CBEm formulation showed melting temperatures and a solid fat content profile that were comparable to those of the cocoa butter control, suggesting good compatibility between CBEm and cocoa butter. Furthermore, the higher melting enthalpy observed in the CBEm formulation suggested the formation of a stable crystalline structure that may contribute to desirable product quality. In contrast, cocoa butter replacer and cocoa butter substitute formulations showed lower solid fat content and altered melting behaviour, which may affect mouthfeel and overall product performance.

The findings provide valuable insight into the development of cost-effective milk chocolate couverture formulations by partially replacing cocoa butter and substituting icing sugar with granulated sugar. The study demonstrates that a 5% incorporation of cocoa butter equivalent can maintain important thermal and crystallization properties while potentially reducing production costs. However, the research was limited to melting characteristics and solid fat content analyses. Future studies should include sensory evaluation, texture analysis, rheological measurements, and storage stability assessments to obtain a more comprehensive understanding of product quality. Overall, the results highlight the potential of cocoa butter equivalent as a practical alternative for sustainable and economically viable chocolate manufacturing.

ACKNOWLEDGMENTS

The author wishes to express the appreciation to Director General, Deputy Director General of Research & Development and the Director of Cocoa Downstream Technology Division of Malaysia Cocoa Board for providing laboratory facilities and financial support for this research study.

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