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Effects of Butterfly Pea (*Clitoria ternatea*) Powder and Cocoa Butter Replacer on the Physicochemical and Sensory Properties of White Chocolate

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ABSTRACT

This study investigated the effects of butterfly pea flower powder (BPP) and cocoa butter replacer (CBR) on the physicochemical and sensory properties of white chocolate, addressing the increasing demand for functional and sustainable food products. Six formulations were created, varying BPP (3% and 5%) and CBR (0%, 10%, and 36.8%). Comprehensive analyses included colour metrics, moisture content, pH, water activity, texture, melting behaviour, fatty acid composition, and sensory evaluations by semi-trained panellists. Results indicated that BPP significantly enhanced blue hues due to anthocyanins but also increased moisture content and water activity due to its hygroscopic properties. Conversely, higher CBR levels lightened the colour, reduced yellow tones by replacing carotenoid-rich cocoa butter, and reduced moisture and water activity, attributed to its hydrophobic nature. The pH ranged from 6.78 to 6.89, with slight increases at higher CBR levels. Texture analysis revealed that increased CBR levels softened the chocolate due to the absence of cocoa butter's crystalline structure. Melting profiles exhibited dual phases in CBR-containing samples, which were linked to triglyceride diversity. In contrast, higher BPP levels disrupted fat crystallization, thereby impacting thermal stability. Sensory evaluations showed that formulations without CBR were more acceptable due to their superior texture and flavour, whereas higher BPP levels, along with added functional benefits, negatively influenced sensory scores due to bitterness and insolubility. The study concluded that while BPP and CBR present innovative opportunities, careful balancing is essential to maintain quality. One improvement is to create dairy-free white chocolate with coconut milk powder as a substitute for milk powder. This offers a creamy texture, mild sweetness, and nutritional benefits while meeting demand for allergen-free, vegan, and sustainable products.

INTRODUCTION

White chocolate, though often less celebrated than its darker counterparts, occupies a distinctive niche in the world of confectionery. Known for its sweet, creamy flavour and smooth texture, it is composed of cocoa butter, sugar, and milk solids, but lacks the cocoa solids present in milk or dark chocolate. While its light colour and delicate flavour are favoured by many, white chocolate also poses formulation challenges, particularly in balancing taste, texture, and melting characteristics. Additionally, the growing cost and environmental concerns associated with cocoa butter production have driven interest in alternative fat sources for chocolate manufacturing [1-3]. Cocoa butter plays a crucial role in chocolate's sensory appeal and

physical structure. However, its limited global supply, susceptibility to temperature changes, and high production costs have prompted the food industry to explore cocoa butter replacers (CBRs). Among these, palm oil stearin, a solid fraction derived from the fractionation of palm oil, has emerged as a promising alternative. It offers several advantages, including availability, lower cost, desirable melting profile, and oxidative stability [4, 5]. Malaysia, being a leading palm oil producer, has an abundant supply of palm-based ingredients, making palm oil stearin a sustainable and economically beneficial choice for local chocolate production [6]. Nevertheless, the inclusion of palm oil stearin must be carefully studied as it may affect the chocolate's crystal structure, texture, and overall mouthfeel [7].

In parallel, increasing demand for health-conscious and functional foods has led to the inclusion of natural plant-based ingredients in confectionery products. One such ingredient is the butterfly pea flower (*Clitoria ternatea*), a vibrant blue flower native to Southeast Asia, traditionally used in herbal teas and as a natural food colouring. Butterfly pea flower is rich in bioactive compounds such as anthocyanins (specifically ternatins), flavonoids like quercetin and kaempferol, and phenolic acids, all of which contribute to its antioxidant, anti-inflammatory, and neuroprotective properties [8].

The incorporation of butterfly pea flower powder into food products is gaining attention due to its potential to enhance both visual appeal and nutritional profile. The vivid blue colour of the flower makes it an attractive natural colorant, especially for clean-label formulations that avoid synthetic additives. Furthermore, the stability of anthocyanins under various conditions and their functionality in fat-based systems, such as chocolate, is an area of growing research interest [9]. Although the flower has been widely used in beverages, jellies, and desserts, its integration into chocolate—particularly white chocolate—remains largely unexplored.

White chocolate provides a neutral base that can showcase the colour and functional benefits of butterfly pea flower while allowing for the evaluation of cocoa butter substitutes, such as palm oil stearin. The dual incorporation of these ingredients may offer a product that is both aesthetically pleasing and functionally enhanced. However, the formulation of such chocolate requires a thorough investigation of its physicochemical properties, including texture, colour stability, moisture content, and antioxidant activity, especially under various storage conditions [10]. Moreover, it is essential to determine how these ingredients affect consumer preferences and sensory perception, which ultimately influence marketability.

Given these gaps and opportunities, this study focuses on formulating functional white chocolate using palm oil stearin as a substitute for cocoa butter and butterfly pea flower powder as a natural antioxidant and colorant. The effects of these ingredients on the product's stability, sensory attributes, and overall acceptability will be systematically evaluated. The objectives of this study are twofold. First, to evaluate the effects of butterfly pea (*Clitoria ternatea*) powder and cocoa butter replacers on the physicochemical properties of white chocolate. This includes examining changes in texture, colour, moisture content, and antioxidant activity over storage. Second, to assess the sensory properties and consumer acceptability of white chocolate incorporating butterfly pea powder and cocoa butter replacers, with the goal of determining how these ingredients influence appearance, taste, mouthfeel, and overall consumer preference.

MATERIALS AND METHODS

The materials used in this work included cocoa butter and soy lecithin, which were provided by Lembaga Koko Malaysia Nilai (Negeri Sembilan, Malaysia). Non-Laric CBR was provided by SD Guthrie Research Sdn. Bhd. (Selangor, Malaysia). Butterfly pea powder was purchased from the local commerce. Sugar and vanilla extract were purchased from the local market at Taman Seri Serdang (Selangor, Malaysia), and milk powder was purchased from a bakery store (Selangor, Malaysia). White chocolate samples were prepared in different formulations with different percentages of cocoa butter, CBR, and butterfly pea powder based on **Table 1**.

The colour profile analysis was conducted using a colorimeter to test for brightness (L*), redness (a*), and blueness (b*). The instrument used for this analysis was a colorimeter from Konica Minolta, which is a well-known brand based in Tokyo, Japan. The moisture content was expressed as a percentage by mass. The oven-dried method was employed for the analysis, as specified in Malaysian Standard MS 1119:1988, "Method of Analysis of Malaysian Cocoa Butter and Cocoa Powder." The analysis was conducted using a metal or glass dish with a lid, a desiccator containing a desiccant, a Memmert ventilated oven (103 °C–105 °C), and an analytical balance with a precision of 1 mg. To determine the pH, a 20 ml sample was placed into a beaker. The pH was then measured using a digital pH meter [11].

Table 1. The formulation of white chocolate with different concentrations of cocoa butter replacer (0%, 10%, and 36.8% by weight) and butterfly pea powder (3%, and 5% by weight).

Samples	Composition (%)						
	Sugar	Cocoa Butter	Milk Powder	Cocoa Butter Replacer (CBR)	Butterfly Powder (BPP)	Pea Lecithin	Vanilla Extract
BPP3 + CBR0	40.00	36.80	20.00	0.00	3.00	0.40	0.20
BPP5 + CBR0	38.00	36.80	20.00	0.00	5.00	0.40	0.20
BPP3 + CBR10	40.00	26.80	25.00	10.00	3.00	0.40	0.20
BPP5 + CBR10	38.00	26.80	25.00	10.00	5.00	0.40	0.20
BPP3 + CBR36.8	40.00	0.00	20.00	36.80	3.00	0.40	0.20
BPP5 + CBR36.8	38.00	0.00	20.00	38.80	5.00	0.40	0.20

The hardness and snap texture of the chocolate samples were measured using a texture analyser equipped with an

HDP/BSK probe for hardness testing and a three-point bend rig probe for snap texture assessment. The chocolate samples were cut into uniform pieces, 80 × 20 mm with a depth of 8 mm, to ensure consistency in testing. Thermal analysis techniques were used to determine the Slip Melting Point, which measures the temperature at which fat transitions from a solid to a liquid under standardized conditions. The objective of the TAG (triglyceride) measurement is to analyse the triglyceride composition of chocolate samples. The analysis was conducted under specific gas chromatographic conditions. A capillary column measuring 15 m in length and 0.53 mm in internal diameter, with a film thickness of 0.15 µm, was utilized. The stationary phase for the analysis was HP-1/SIMDIST. The melting behaviour of white chocolate samples infused with butterfly pea flower powder and a cocoa butter replacer was analysed using Differential Scanning Calorimetry (DSC). The instrument was calibrated, and samples were prepared and loaded into the analyser. The temperature program was set, and the analysis was initiated. Heat flow curves were examined to determine the melting profile, and results were recorded.

To measure the FAC (Fatty Acid Composition), two millilitres of hexane were mixed with 20 µL of fat extracted from the fat-and-oil product samples. Following this, 100 mL of a sodium methylate solution, prepared by dissolving 2.7 g of metallic sodium in 25 mL of methanol (CH3OH), was added. The mixture was then shaken for 30 seconds using a vortex mixer (Ika, Vortex Genius 3, Germany) and left to rest at room temperature for 10 minutes. During this time, the transparent layer containing fatty acid methyl esters (FAME) separated from the opaque aqueous layer. The mixture was subsequently centrifuged at 3000 rpm for 5 minutes [12, 13].

The sensory evaluation involved 30 semi-trained panellists assessing the white chocolate samples using a 9-point hedonic scale (1 = Dislike extremely, 9 = Like extremely). Attributes evaluated included appearance, colour, hardness, smoothness, aroma, sweetness, bitterness, mouthfeel, and overall acceptability. The tests were conducted in the sensory laboratory at the Lembaga Koko Nilai (Negeri Sembilan, Malaysia), in individual cabinets illuminated with white light, designed in accordance with ISO 8589.

The experiment was conducted in the laboratory at LEMBAGA KOKO MALAYSIA NILAI to investigate the effects of varying concentrations of CBR and butterfly pea powder on white chocolate. The study examined three levels of CBR (0%, 10%, and 36.8% by weight) and two levels of butterfly pea powder (3% and 5% by weight). Each treatment was replicated three times to ensure accuracy, and every chocolate sample was prepared and analysed in triplicate following standard laboratory protocols. The results were expressed as mean ± standard deviation. One-way ANOVA and Tukey tests were used to analyse the data with a significance level of 5%.

RESULTS AND DISCUSSION

The results in **Table 2** revealed significant differences in the colour parameters (L*, a*, b*) of white chocolate formulations due to varying concentrations of butterfly pea powder (BPP) and Cocoa butter replacer (CBR). Higher CBR levels (e.g., 36.8%) resulted in greater lightness (L*), particularly in samples such as BPP3 + CBR36.8 (75.15), as CBR, which is often refined from hydrogenated vegetable fats, lacks the yellowish hue of cocoa butter due to the removal of carotenoids [14, 15]. In contrast, lower lightness values were observed in samples with no CBR and higher BPP content, such as BPP5 + CBR0 (62.48), due to anthocyanins in BPP absorbing more light and producing darker hues [16, 17].

The a* values shifted toward red with increasing BPP, as anthocyanins formed reddish flavylium cations in the slightly acidic pH of white chocolate, especially in samples like BPP5 + CBR0 (1.19) and BPP5 + CBR36.8 (1.18), while greener tones appeared in samples with lower BPP and higher CBR, such as BPP3 + CBR10 (-1.12) [18, 19]. The b* values became more negative with higher BPP and CBR, indicating enhanced blue tones due to anthocyanin pigmentation and the absence of carotenoids, as seen in BPP5 + CBR36.8 (-5.35), whereas positive b* values like in BPP3 + CBR0 (2.38) reflected the yellow tones of cocoa butter dominating in low-BPP, no-CBR formulations [18, 20]. Overall, the interaction between BPP and CBR, including pigment composition and concentration, critically influenced the final colour characteristics of the chocolate.

The moisture content as tabulated in **Table 3**, ranging from 0.93% to 1.53%, was highest in BPP5 + CBR0 (1.53%) and lowest in BPP3 + CBR10 (0.93%), with increased moisture retention in BPP-rich formulations attributed to the hygroscopic nature of butterfly pea powder (BPP), which facilitates water retention in the chocolate matrix [21]. Conversely, higher CBR levels, due to the hydrophobic nature of vegetable fats, reduced moisture content [22]. Water activity (aw) ranged from 0.3366 to 0.4494, with higher values in BPP5 + CBR36.8 (0.4494) due to the combined effects of BPP's hydrophilic components and CBR's structural changes [23], while lower values in BPP3 + CBR10 (0.3366) resulted from the hydrophobic nature of cocoa butter [24].

pH values, ranging from 6.78 to 6.89, were slightly higher in formulations with higher CBR levels, reflecting the neutral or slightly alkaline nature of vegetable fats, as opposed to the mild acidity of cocoa butter [25]. The impact of butterfly pea powder on pH was minimal at low concentrations (3%–5%) and buffered by the chocolate matrix [18, 26]. These findings highlight the interplay between hydrophilic and hydrophobic ingredients, with BPP increasing moisture retention and water activity, while CBR reduced moisture content and slightly increased pH.

Table 2: Average colour values for different formulations of white chocolate. Mean ± standard deviation within a column with different superscripts indicates a significant difference ($p<0.05$). L*: Lightness of a colour (ranging from 0 - black to 100 - white). a*: Red-green axis (positive values are red, negative values are green). b*: Blue-yellow axis (positive values are yellow, negative values are blue).

Samples	L*	a*	b*
BPP3 + CBR0	67.81 ± 0.959^{c}	-0.35 ± 0.103^{c}	2.38 ± 0.112^{a}
BPP5 + CBR0	62.48 ± 0.376^{e}	1.19 ± 0.128^{a}	-1.68 ± 0.067^{c}
BPP3 + CBR10	71.36 ± 0.938^{b}	-1.12 ± 0.152^{e}	1.18 ± 0.113^{b}
BPP5 + CBR10	65.56 ± 0.141^{d}	0.68 ± 0.029^{b}	-2.33 ± 0.043^{d}
BPP3 + CBR36.8	75.15 ± 0.716^{a}	-0.86 ± 0.038^{d}	-1.69 ± 0.185^{c}
BPP5 + CBR36.8	67.14 ± 0.240^{c}	1.18 ± 0.033^{a}	-5.35 ± 0.042^{e}

Table 3: Average moisture content, pH, and water activity for different formulations of white chocolate. Mean ± standard deviation within a

column with different superscripts indicates a significant difference ($p<0.05$).

Samples	Moisture Content (%)	pH	Water Activity (a_w)
BPP3 + CBR0	1.13 ± 0.76^{a}	6.78 ± 0.01^{b}	0.40 ± 0.004^{ab}
BPP5 + CBR0	1.53 ± 0.46^{a}	6.83 ± 0.01^{b}	0.38 ± 0.01^{ab}
BPP3 + CBR10	0.93 ± 0.46^{a}	6.82 ± 0.01^{b}	0.34 ± 0.002^{b}
BPP5 + CBR10	1.27 ± 0.30^{a}	6.82 ± 0.02^{b}	0.36 ± 0.01^{b}
BPP3 + CBR36.8	0.94 ± 0.31^{a}	6.89 ± 0.01^{a}	0.35 ± 0.01^{b}
BPP5 + CBR36.8	1.00 ± 0.34^{a}	6.83 ± 0.02^{b}	0.45 ± 0.07^{a}

Table 4 shows the hardness and snap texture of white chocolate formulations were significantly affected by the levels of cocoa butter replacer (CBR) and butterfly pea powder (BPP). Samples without CBR (CBR0) exhibited the highest hardness and snap values due to the crystallization properties of cocoa butter, which formed a stable, firm structure. As CBR concentration increased, both hardness and snap texture decreased, as CBR lacked the same crystallization properties and formed less stable structures, weakening the chocolate's texture [27, 28]. Intermediate CBR levels (10%) showed moderate reduction in hardness while maintaining some structural integrity. Higher BPP concentrations (5%) also reduced snap texture, likely due to the disruption of cocoa butter crystallization by BPP particles, increased viscosity, and possible moisture absorption, all of which compromised the chocolate's firmness and crispness [17, 29-32].

Table 4. The average hardness and snapping values of different formulations of white chocolate. Mean ± standard deviation within a column with different superscripts indicates a significant difference ($p<0.05$).

Samples	Hardness (kg)	Snap Texture (kg)
BPP3 + CBR0	21.77 ± 0.80^{a}	18.40 ± 0.33^{a}
BPP5 + CBR0	22.35 ± 0.53^{a}	12.04 ± 0.46^{d}
BPP3 + CBR10	20.70 ± 0.45^{a}	15.80 ± 0.46^{b}
BPP5 + CBR10	19.54 ± 1.81^{a}	13.70 ± 0.36^{c}
BPP3 + CBR36.8	9.72 ± 0.56^{b}	7.21 ± 9.93^{f}
BPP5 + CBR36.8	10.38 ± 1.24^{b}	9.93 ± 0.03^{e}

Table 5. The average composition of Triacylglycerides (TAG) in different formulations of white chocolate. Mean ± standard deviation within a column with different superscripts indicates a significant difference ($p<0.05$); TAG: Triacylglyceride.

TAG (%)	Samples					
	BPP3 + CBR0	BPP5 + CBR0	BPP3 + CBR10	BPP5 + CBR10	BPP3 + CBR36.8	BPP5 + CBR36.8
C46	0.00^{c}	0.00^{c}	0.12 ± 0.01^{b}	0.11 ± 0.01^{bc}	0.46 ± 0.00^{a}	0.56 ± 0.15^{a}
C48	0.79 ± 0.04^{c}	0.76 ± 0.05^{c}	1.26 ± 0.02^{b}	1.26 ± 0.00^{b}	2.68 ± 0.13^{a}	2.84 ± 0.18^{a}
C50	17.60 ± 0.01^{c}	17.72 ± 0.01^{c}	20.17 ± 0.11^{b}	20.64 ± 0.74^{b}	25.22 ± 1.56^{a}	25.10 ± 1.19^{a}
C52	42.43 ± 0.06^{c}	42.87 ± 0.00^{c}	44.43 ± 0.88^{b}	44.44 ± 0.45^{b}	47.31 ± 0.51^{a}	47.40 ± 0.25^{a}
C54	30.90 ± 0.06^{a}	31.21 ± 0.04^{a}	26.55 ± 0.24^{b}	26.53 ± 0.03^{b}	14.11 ± 0.57^{d}	14.66 ± 0.23^{c}
C56	2.24 ± 0.01^{a}	2.26 ± 0.01^{a}	1.78 ± 0.15^{b}	1.78 ± 0.12^{b}	0.68 ± 0.02^{c}	0.93 ± 0.35^{c}

Table 6. The average slip melting point (SMP) values of different formulations of white chocolate. Mean ± standard deviation within a column with different superscripts indicates a significant difference ($p<0.05$).

Samples	Slip Melting Point (°C)
BPP3 + CBR0	26.95 ± 0.21^{c}
BPP5 + CBR0	27.95 ± 0.07^{c}
BPP3 + CBR10	32.05 ± 0.07^{b}
BPP5 + CBR10	32.30 ± 0.57^{b}
BPP3 + CBR36.8	40.00 ± 0.42^{a}
BPP5 + CBR36.8	39.05 ± 1.48^{a}

Table 6 presented the SMP values of white chocolate formulations, which were influenced by the presence of cocoa butter replacement (CBR) and butterfly pea powder (BPP). Samples with no CBR (BPP3 + CBR0 and BPP5 + CBR0) had the lowest SMP (26.95 °C and 27.95 °C), as they contained only cocoa butter, which has a narrow melting range due to its unique TAG profile rich in symmetric triacylglycerides like C50, C52, and C54 [32]. Increasing CBR concentrations raised SMP, with the highest values observed in formulations containing 36.8% CBR (BPP3 + CBR36.8 and BPP5 + CBR36.8) at 40.00°C and 39.05°C, respectively. This was attributed to the inclusion of fats with higher-melting TAGs, such as long-chain saturated fatty acids, which enhanced the thermal stability of the chocolate matrix [33]. CBR lacked the polymorphic behaviour of cocoa butter, resulting in a broader melting range and higher SMP [34]. The concentration of BPP had a limited impact on SMP, though BPP particles may slightly interfere with fat crystallization.

TAG analysis in **Table 5** compares that as CBR replaced cocoa butter, lower-melting TAGs, such as C48, increased, while higher-melting TAGs, including C54 and C56, decreased [35]. High CBR formulations exhibited an increase in higher-melting TAGs, which contributed to a more stable crystalline structure and higher SMP [5, 36]. However, BPP particles likely disrupted crystallization, especially at higher concentrations, leading to slight variations in SMP [37]. **Table 7** pinpoints that the melting profiles of samples containing different amounts of butterfly pea powder (BPP) and cocoa butter replacer (CBR) were influenced by the types of triacylglycerides (TAGs) present in the fat matrix. In samples without CBR (BPP3 + CBR0 and BPP5 + CBR0), the melting range was narrow, with onset and peak temperatures of approximately 14.15 °C and 20.35 °C, respectively, reflecting the TAG composition of pure cocoa butter, which is dominated by symmetric TAGs such as C50, C52, and C54 [38]. The inclusion of 10% CBR (BPP3 + CBR10 and BPP5 + CBR10) introduced two melting phases, one corresponding to lower-melting TAGs like C48 and another to higher-melting TAGs like C54 or C56, with reduced crystallinity as indicated by lower enthalpy values (-79.41 to -82.75 J/g) [39].

At 36.8% CBR (BPP3 + CBR36.8 and BPP5 + CBR36.8), a broader melting range was observed, with negative onset temperatures for low-melting TAGs and higher temperatures for stable high-melting TAGs from structured fats in the CBR [28, 40, 41]. The addition of BPP (3% and 5%) caused minor disruptions in fat crystallization, particularly at the higher concentration (5%), affecting the overall melting behaviour. The results indicate that low CBR levels introduce lower-melting TAGs, while higher levels add complexity with high-melting TAGs, and BPP slightly modifies the crystallization without as significant an impact as CBR.

Table 7. Overview of the melting profile of different formulations of white chocolate. Mean ± standard deviation within a column with different superscripts indicates a significant difference ($p<0.05$).

Samples	Temperature °C			Enthalpy ΔH (J/g)
	T_{onset}	T_{peak}	T_{endset}	
BPP3 + CBR0	14.15 ± 0.11^{c}	20.37 ± 0.08^{c}	23.52 ± 0.13^{d}	-96.20 ± 3.75^{d}
BPP5 + CBR0	14.09 ± 0.02^{c}	20.32 ± 0.04^{c}	23.55 ± 0.11^{d}	-92.97 ± 3.41^{d}
BPP3 + CBR10 (1)	11.62 ± 0.25^{d}	18.61 ± 0.01^{d}	25.12 ± 0.15^{c}	-79.41 ± 2.26^{c}
BPP3 + CBR10 (2)	22.95 ± 1.35^{a}	26.68 ± 0.81^{b}	31.16 ± 0.87^{b}	-16.06 ± 3.45^{b}
BPP5 + CBR10 (1)	11.54 ± 0.18^{d}	18.73 ± 0.00^{d}	25.20 ± 0.12^{c}	-82.75 ± 3.97^{c}
BPP5 + CBR10 (2)	23.00 ± 1.29^{a}	26.61 ± 0.87^{b}	31.25 ± 0.83^{b}	-16.97 ± 3.13^{b}
BPP3 + CBR36.8 (1)	-11.38 ± 0.48^{e}	-2.79 ± 0.01^{e}	3.58 ± 0.32^{e}	-4.56 ± 0.42^{a}
BPP3 + CBR36.8 (2)	21.33 ± 0.58^{b}	33.83 ± 1.05^{a}	41.03 ± 1.12^{a}	-104.09 ± 2.65^{e}
BPP5 + CBR36.8 (1)	-11.66 ± 0.28^{e}	-2.99 ± 0.30^{e}	3.60 ± 0.59^{e}	-4.96 ± 0.56^{a}
BPP5 + CBR36.8 (2)	21.17 ± 0.76^{b}	33.75 ± 1.18^{a}	40.92 ± 1.38^{a}	-103.58 ± 0.53^{e}

Table 8. The average fatty acid composition of fats extracted from different formulations of white chocolate. Mean ± standard deviation within a column with different superscripts indicates a significant difference ($p<0.05$); C: Carbon; FA: Fatty acid.

Types of FA	Acid Common Nomenclature	% FA					
		BPP3 + CBR0	BPP5 + CBR0	BPP3 + CBR10	BPP5 + CBR10	BPP3 + CBR36.8	BPP5 + CBR36.8
C8:0	Caprylic acid	0.00^{c}	0.00^{c}	0.06 ± 0.01^{b}	0.02 ± 0.03^{bc}	0.29 ± 0.03^{a}	0.30 ± 0.03^{a}
C10:0	Capric acid	0.00^{c}	0.00^{c}	0.06 ± 0.01^{b}	0.07 ± 0.01^{b}	0.30 ± 0.02^{a}	0.31 ± 0.02^{a}
C12:0	Lauric acid	0.00^{c}	0.00^{c}	0.90 ± 0.08^{b}	0.91 ± 0.06^{b}	4.23 ± 0.24^{a}	4.28 ± 0.32^{a}
C14:0	Myristic acid	0.08 ± 0.0002^{c}	0.08 ± 0.001^{c}	0.64 ± 0.02^{b}	0.64 ± 0.01^{b}	2.74 ± 0.08^{a}	2.78 ± 0.11^{a}
C16:0	Palmitic acid	27.38 ± 0.08^{c}	27.34 ± 0.20^{c}	32.11 ± 0.36^{b}	32.42 ± 0.54^{b}	49.11 ± 1.46^{a}	49.64 ± 0.84^{a}
C16:1	Palmitoleic acid	0.35 ± 0.0001^{a}	0.35 ± 0.01^{a}	0.33 ± 0.0001^{a}	0.28 ± 0.06^{b}	0.16 ± 0.01^{c}	0.19 ± 0.002^{c}
C18:0	Stearic acid	36.34 ± 0.13^{a}	36.13 ± 0.05^{a}	29.19 ± 0.20^{b}	29.63 ± 0.73^{b}	7.98 ± 0.48^{c}	8.01 ± 0.32^{c}
C18:1	Oleic acid	31.51 ± 0.25^{d}	31.78 ± 0.31^{cd}	33.14 ± 0.08^{abc}	32.52 ± 0.71^{bcd}	34.07 ± 1.53^{a}	33.34 ± 0.62^{ab}
C18:2	Linoleic acid	2.88 ± 0.02^{a}	2.87 ± 0.04^{a}	2.38 ± 0.01^{b}	2.29 ± 0.24^{b}	0.58 ± 0.03^{c}	0.59 ± 0.05^{c}
C18:3	Linolenic acid	0.21 ± 0.001^{a}	0.21 ± 0.01^{a}	0.20 ± 0.04^{a}	0.20 ± 0.03^{a}	0.05 ± 0.01^{b}	0.05 ± 0.01^{b}
C20:0	Arachidic acid	1.25 ± 0.02^{a}	1.23 ± 0.01^{a}	1.03 ± 0.09^{b}	1.02 ± 0.12^{b}	0.49 ± 0.001^{c}	0.50 ± 0.002^{c}

Table 10. The average sensory evaluation scores (appearance, colour, hardness, smoothness, aroma, sweetness, bitterness, mouthfeel, and overall acceptability) of white chocolates with different formulations. Mean ± standard deviation within a column with different superscripts indicates a significant difference ($p<0.05$).

Samples	Appearance	Colour	Hardness	Smoothness	Aroma	Sweetness	Bitterness	Mouthfeel	Overall Acceptability
BPP3 + CBR0	7.70 ± 1.12^{a}	7.57 ± 1.28^{a}	7.37 ± 1.22^{a}	7.63 ± 0.81^{a}	7.43 ± 1.31^{a}	7.13 ± 1.43^{a}	6.23 ± 1.91^{a}	7.20 ± 0.93^{a}	7.73 ± 0.98^{a}
BPP5 + CBR0	7.60 ± 1.04^{a}	7.53 ± 1.17^{a}	7.40 ± 1.13^{a}	7.48 ± 0.78^{ab}	7.20 ± 1.13^{ab}	7.27 ± 1.34^{a}	6.30 ± 1.82^{a}	7.43 ± 0.97^{a}	7.67 ± 0.84a
BPP3 + CBR10	7.20 ± 1.37^{a}	6.97 ± 1.30^{a}	6.93 ± 1.41^{a}	7.07 ± 1.41^{ab}	6.70 ± 1.32^{ab}	6.37 ± 1.35^{a}	5.47 ± 1.87^{a}	6.50 ± 1.38^{a}	6.60 ± 1.16^{a}
BPP5 + CBR10	7.10 ± 1.21^{a}	7.10 ± 1.15^{a}	6.87 ± 1.43^{a}	7.23 ± 1.16^{ab}	6.50 ± 1.31^{ab}	6.33 ± 1.45^{a}	5.83 ± 1.97^{a}	6.73 ± 1.46^{a}	6.67 ± 1.21^{a}
BPP3 + CBR36.8	7.00 ± 1.44^{a}	6.83 ± 1.42^{a}	6.20 ± 1.85^{a}	5.67 ± 1.83^{b}	5.63 ± 1.33^{ab}	4.83 ± 1.91^{a}	5.17 ± 1.62^{a}	4.67 ± 2.14^{a}	4.47 ± 2.10^{a}
BPP5 + CBR36.8	6.70 ± 1.47^{a}	6.77 ± 1.43^{a}	6.20 ± 1.73^{a}	5.80 ± 1.52^{b}	5.03 ± 1.40^{b}	4.37 ± 1.79^{a}	5.03 ± 1.54^{a}	4.23 ± 1.81^{a}	4.33 ± 1.94^{a}

Table 9. The average iodine value for different formulations of white chocolate. Mean ± standard deviation within a column with different superscripts indicates a significant difference ($p<0.05$).

Samples	Iodine value (gI/ 100g)
BPP3 + CBR0	32.970 ± 0.171^{a}
BPP5 + CBR0	33.194 ± 0.172^{a}
BPP3 + CBR10	33.454 ± 0.188^{a}
BPP5 + CBR10	32.729 ± 1.185^{a}
BPP3 + CBR36.8	30.590 ± 1.364^{b}
BPP5 + CBR36.8	30.004 ± 0.633^{b}

Table 8 details the incorporation of CBR into white chocolate formulations altered the fatty acid composition, reflecting the distinct lipid profile of CBR compared to conventional cocoa butter. High CBR samples (36.8%) introduced lauric acid (C12:0), which was absent in formulations without CBR, likely originating from palm kernel oil [42]. Saturated fats like myristic acid (C14:0) and palmitic acid (C16:0) were elevated in high-CBR formulations, while oleic acid (C18:1) and stearic acid (C18:0) decreased as CBR content increased, indicating the shift towards more saturated, shorter-chain fatty acids [43-46]. Polyunsaturated fatty acids, such as linoleic acid (C18:2) and linolenic acid (C18:3), increased slightly with higher CBR concentrations. **Table 9** demonstrates the iodine value (IV) of the formulations decreased with higher CBR content, indicating a higher proportion of saturated fats and a reduction in unsaturated fatty acids [43, 47, 48]. This lower IV in high-CBR formulations contributed to greater firmness and oxidative stability, enhancing shelf life and textural properties [49]. The butterfly pea powder (BPP) did not significantly alter the fatty acid composition but likely contributed to colour and phytochemicals. The sensory evaluation of white chocolate samples with varying concentrations of butterfly pea powder (BPP) and cocoa butter replacer (CBR) revealed that higher CBR levels and BPP concentrations negatively impacted appearance, colour, hardness, smoothness, aroma, sweetness, bitterness, mouthfeel, and overall acceptability.

Table 10 highlights that samples with no CBR (CBR0) and lower BPP concentrations (3%) had the highest sensory scores, with cocoa butter providing characteristic gloss, smooth texture, and aroma [1-3, 50]. CBR's lack of crystallization properties and cocoa butter's beneficial effects resulted in reduced scores for these attributes. In contrast, higher BPP concentrations introduced darker hues, uneven textures, and increased bitterness and viscosity, further lowering sensory scores [17, 51]. The combination of BPP and CBR led to decreased overall acceptability, with the highest scores observed in BPP3 + CBR0 samples (7.73 ± 0.98 and 7.67 ± 0.84 for BPP3 and BPP5,

respectively) and the lowest in BPP5 + CBR36.8 samples (4.47 ± 2.10 and 4.33 ± 1.94) [16, 52, 53].

CONCLUSION

This experiment explored the effects of incorporating butterfly pea powder (BPP) and cocoa butter replacers (CBR) into white chocolate. The study found that BPP, at concentrations of 3% and 5%, introduced unique colour changes, enhancing blue and red tones due to its anthocyanins, while CBR at 0%, 10%, and 36.8% improved lightness by counteracting the yellow hue of cocoa butter. The moisture content ranged from 0.93% to 1.53%, influenced by the hygroscopic properties of BPP, and the pH remained stable across all formulations. DSC analysis revealed that CBR increased the thermal stability of the chocolate, resulting in higher melting points. Overall, BPP and CBR significantly influenced the colour, stability, and sensory qualities of white chocolate, offering a natural pigment and antioxidant source in BPP and improved physical stability through CBR, presenting opportunities for creating innovative, health-conscious, and visually appealing chocolate products.

CONFLICT OF INTEREST

The authors have declared that no conflict of interest exists.

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