Physiochemical characteristics of fabricated chocolate: cocoa butter replacement by beeswax oleo gel.

Azad Ismael Abdalla1*, Rafiq Muhammed Salih Rashid2

1College of Agricultural Engineering Sciences, Food Science and Quality Control Department, University of Sulaimani, Sulaymaniyah, Iraq
2College of Agricultural Engineering Sciences, Food Science and Quality Control Department, University of Sulaimani, Sulaymaniyah, Iraq

*Corresponding author’s email: azad.abdalla@univsul.edu.iq
Email addresses of coauthor: rafiq.salih@univsul.edu.iq

Abstract
Five different types of beeswax oleo gel (BW/OG) were created with varying concentrations of beeswax (BW) to develop a healthier version of dark chocolate, where cocoa butter was completely replaced. The goal was to study these fabricated chocolates and compare them to a standard version, aiming to create a healthier alternative with similar physicochemical and sensory characteristics .
To evaluate the performance of the fabricated chocolate samples, we conducted tests on storage stability, Oil binding capacity (OBC), texture analysis, blooming resistance, microstructure observation, and sensory evaluation. The results demonstrated that the samples exhibited robust OBC and storage stability and were highly resistant to blooming. However, in terms of texture, the fabricated samples had a softer consistency at room temperature compared to the standard version .
Panelists rated the sensory attributes of the fabricated chocolates except for hardness as acceptable. These developed chocolate versions can be classified as compound coatings rather than signature chocolates due to their lack of desired hardness. The fabricated chocolates also had a lower total caloric content and included a healthier fat phase, which may help reduce long-term health complications associated with high-fat products.
Keywords: Beeswax, Oleo gel, Chocolate, Fabrication, Healthier alternative .

Introduction

High-fat foods with an unhealthy fatty acid profile have been confirmed as contributors to obesity and food-related chronic diseases [1]. Researchers in the fields of food science and nutrition have long sought to create healthier versions of these products to address global health issues. As an emerging technique compared to other structuring agents in colloidal systems, Oleo gel (OG) has recently gained significant interest and is viewed as one of the most promising alternatives for fabricating such products [2], including confectionery, baked goods, and spreads. OG is a semi-solid blend composed of varying proportions of oil and a structuring agent, such as BW. This combination can form a three-dimensional network that traps oil inside, utilizing the needle-like long-chain hydrocarbons that develop when cooled below the melting point of BW (65°C) [3.[
Chocolate is one of the most commonly targeted products for developing healthier alternatives. Chocolate's popularity and frequent consumption mean it can significantly contribute to daily energy intake due to its high-fat content and unhealthy fatty acid profile. This profile is influenced by the

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types of fat used, including cocoa butter, cocoa solids, and milk fat, which primarily contain unsaturated fatty acids. To address health concerns, food producers often utilize cocoa butter equivalents, substitutes, and replacers [4]. However, even with these alternatives, the fat phase can still be considered unhealthy because cheaper options, such as palm and hydrogenated oils, may replace some signature fats like cocoa butter [5]. This practice can have health disadvantages, as it may introduce trans fats into the fat system .

BW/OG can be used to enhance chocolates by improving the fatty acid profile, as vegetable oils can serve as substitutes for fats and hydrogenated oils. The fatty acid profile of both sunflower oil and BW is well-documented in the literature. Sunflower oil is known for its healthy fatty acid composition. In contrast, BW has a unique combination of fatty acids and hydrocarbons that makes it completely indigestible by the gastrointestinal tract [6]. A small amount of BW can significantly reduce the total energy content by contributing to the fat phase [7]. However, formulating with BW presents challenges due to its distinct physicochemical properties compared to cocoa butter, such as differences in melting point and crystallization [8]. If formulations are not executed carefully, this can result in markedly different characteristics, including storage stability, blooming, mouthfeel, palate stickiness, waxy taste, and other sensory attributes. A key challenge in formulation lies in achieving the desired hardness of the final product. Both partial and total replacement of cocoa butter with BW/OG may lead to difficulties in attaining standard hardness levels.

While BW serves as a versatile structuring agent and an effective gelator, it can lead to the formation of a distinct polymorphic structure. In contrast, cocoa butter crystallizes into a well-organized block-piled structure that imparts the desired hardness and mouthfeel to the final product, remaining completely solid at room temperature [4]. On the other hand, BW creates a needle-like three-dimensional network that traps oil within, resulting in a softer texture in the final product [9]. Furthermore, chocolate-based BW/OG is considered a promising alternative for compound coatings rather than standard chocolate [4]. These coatings can be used in confections, fillings, and various bakery products, such as cakes and croissants.

Previous studies have focused on using various texturing agents to develop OGs for fabrication [10-14]. However, research focusing on BW/OG has been limited, particularly in chocolate production. While existing studies indicate promising findings related to sensory and physicochemical properties, the concentration of BW used has not surpassed 5% when partially replacing the fat phase [8], especially in chocolate formulation as a substitute for cocoa butter [10, 12, 15]. With the exception of one study, 20% of BW was used to create OG to develop healthier chocolate alternatives [9]. Consequently, healthier alternatives are restricted in terms of total energy content and reduced saturated and trans fats in the fat phase.

In this study, we aimed to extend these limitations by using an OG containing up to 25% BW and implementing a full replacement of cocoa butter instead of a partial replacement. To achieve this, both the OGs and the formulated chocolate were analyzed for storage stability, bloom test, rancidity, texture analysis, OBC, melting properties, and a sensory evaluation by skilled individuals to assess the acceptability of the final product by comparing it to the standard version of a certain type of dark chocolate .

Material and methods

BW was donated by a university honey production project and is considered 100% natural. Sunflower oil (Basso, FEDELE & FIGLI Co., LTD, Italy) was used. Soya lethicine powder was purchased from Lecilite

Ingredients Pvt. Ltd. Company with a phosphatidate concentration of 97% (USP-NF grade). Organic, unrefined Bio cocoa butter brand from Kamelur, Germany, was used. The unsweetened cocoa powder produced by Nestle was used. Glucose corn syrup was obtained from the local market .

Beeswax Purification:

BW was supplied by the University of Sulaimani's College of Agricultural Engineering Sciences through its natural beekeeping project, ensuring its quality is beyond question. Any compromise in quality could adversely affect both the OG and the chocolate-based BW/OG. To achieve the highest quality, the BW was purified to obtain the purest form. A water bath (lab tech water bath: LBW, digital) was utilized to melt small pieces of BW at 70°C, using indirect heat treatment to preserve its quality. Once melted, the it filtered through a two-layer, highly fine-pored specialized cloth and then poured into silicone molds. It was stored at room temperature until fully solidified and finally placed in a refrigerator at 4°C until ready for use.

Oleo gel preparation:

Five versions of OG were prepared. Each has a different BW concentration (10%, 17%, 20%, and 25%). OGs were prepared by combining the sunflower oil with BW (V/W%). The following OGs resulted in BW/OG 10%, BW/OG 17%, BW/OG 20%, and BW/OG 25%. They were prepared by melting the BW in a double jacket water bath at 70^0 C in a 250ml beaker. When completely molten, the specific volume of sunflower oil was gradually added while the mixture was stirred at 1100 rpm using a high-speed laboratory blender. At this stage, maintaining the melting temperature of BW is crucial to avoid partial wax crystalization and complete mixing. The mixture was continually stirred for another 30 min to obtain a finely homogeneous mixture (OG). This method was taken from the previous author (Gómez-Estaca et al., 2019). The OGs were then preserved at room temperature in a dark place and completely covered to prevent rancidity and deterioration. At this stage, the OGs initiate the crystalization as the temperature gradually decreases from the melting point of BW (65^0 C). Crystallization is usually initiated from the bottom to the top and then toward the centre. After completely hardening, the OGs were placed in the refrigerator to make the chocolate later .

Oxidative stability:

Chocolate contains a significant amount of fat, which makes it important to evaluate its stability against rancidity, especially when fabricated using vegetable oils. Tests including peroxide value, acid value, and free fatty acid levels were conducted on OG samples, which reflect the primary oil composition of the product. These assessments were carried out at the moment of production (zero time) and again after four weeks of storage to determine any rancidity development.

Peroxide value (PV:(

The measurement was conducted using the AOAC method No. 965.33 (AOAC, 1995) [16]. The interaction between saturated potassium iodide and oil in BW/OG samples was the mechanism of this method. The iodine formed is then titrated against sodium thiosulfate with starch as an endpoint indicator. The results are expressed as the sample’s equivalent of peroxide oxygen per kilogram oil (mEqO2/kg:(

PV (mEqO2/kg OG) = [(S – B) * Normality] * 1000 / sample weight (g(

Where S=titration of test sample (mL(

B=titration of blank (mL(

Acid value (AV) and Free Fatty Acid (FFA:(

This measurement was reproduced based on AOAC method 940.28. ethanol and ether release the free fatty acid in the BW/OG. The released free fatty acid was then titrated against an ethanolic solution of sodium hydroxide [17]. The acid value and the percentage of fatty acid were calculated as follows:

%FFA = (mL NaOH*Normality)/(sample weight (g))*100

Acid value (mgKOH / g OG) = FFA * 1.99

Chocolate preparation:

Four versions of dark Chocolate-based BW/OG were prepared according to Table (1): Chocolate-based 10% BW/OG (CHOCO-10% BW/OG), Chocolate-based 17% BW/OG (CHOCO-17% BW/OG), Chocolate-based 20% BW/OG (CHOCO-20% BW/OG), Chocolate-based 25% BW/OG (CHOCO-25% BW/ OG). The cocoa butter was fully replaced in all samples. These versions of fabricated chocolates were then compared with the control (C.CHOCO). The formulation process and the quantity of ingredients were taken from the previous studies with a bit of modification [10 .[

Table 1. Ingredients of fabricated chocolates

Samples	Ingredients (%)				
	Cocoa butter	Oleo gel	Cocoa powder	Glucose syrup	Lecithin
C.CHOCO	47	-	20	32	1
CHOCO-25% BW/OG	-	47	20	32	1
CHOCO-20% BW/OG	-				
CHOCO-17% BW/OG	-				
CHOCO-10% BW/OG	-				

To prepare the Chocolate-based BW/OG, first, the OG was heated to the melting temperature (65^0 C) in a water bath. Lecithin was added, and steirer was added for 5 min at 100 rpm when it was completely molten. After that, the glucose corn syrup was added to the cocoa powder and stirred for another 5 min at a rate of 300 rpm while maintaining the mixture temperature at 65^0 C. This step is crucial to obtain the homogenous mixture since the BW starts solidifying below that temperature. The mixture is then poured into a silicon mould (10 mm * 20 mm) to get a chocolate bar-like shape and stored in the refrigerator at 4^0 C .

Storage stability and appearance:
Chocolate-based BW/OG samples were stored in clear plastic containers under two different temperatures (refrigerator temp, 4^0 C) and (room temperature, 20^0 C) for eight weeks. Visual observation was made to see any textural, appearance, and color changes on a daily basis. These changes, like surface roughness and glossiness, melting, and recrystallization, cause structure deformation, color change due to fat and sugar blooming .

Texture analysis (hardness:(
A texture analyzer (CT3 BROOKFIELD) equipped with a specific probe (polyoxymethylene P/10, 10 mm) was utilized to evaluate the hardness as a maximum force (N) to penetrate the samples. Following the methods established by other authors [18], the TPA two-cycle mode was chosen, applying a deformation of 4 mm at a rate of 1 mm/s with a zero trigger setting for the test. All results were recorded based on three replicates, and the testing was conducted at room temperature.

Oil binding capacity (OBC:(

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OBC was determined based on the amount of lost oil during a certain period. This test was reproduced, followed by the previous authors with a bit of modification [14]. A chocolate bar (3 mm thick, 10 mm length, 20 mm width) was placed on a filter paper (125 mm of diameter) and then stored at 4^0 C. after 24 h the OBC was calculated using the below formula:

OL (%)=((Wt-W0))/Fc

Where OL is oil loss during 24 h of storage in the refrigerator, Wo is the weight of the filter paper at zero time, and Wt is the weight of filter paper after 24 h. OBC was then calculated by subtracting the amount of lost oil (OBC = 100 - OL). All treatment was tested with three replicates .

Microstructure observation:

Digital polarized light microscopy (Motic DM0405 Digital Microscope) was used to observe the microstructure core of chocolate-based BW/OG samples. It can provide information about the homogeneity and uniformity of the wax content and the oleo gel concentration in various fabricated samples. This method was reproduced based on the previous study [19]. The sample was put on the microscope slide and heated to the melting point. When completely molten, it is covered with the cover slide to make the layer as thin as two millimeters. This way, the polarized light can penetrate the sample, and the wax's birefringence property can be seen. It can be noted that overheating the sample before covering can disrupt the microstructure. 40x lens was used to capture the microstructure .

Bloom test:

Bloom test. As stated in the literature, the cause of bloom can refer to three factors: composition (mixing of two or three incompatible fats and high oil centre content), processing (over-tempering or under-tempering), storage condition (temperature change)) [20-22]. Based on three parameters, the fat bloom test was designed. A temperature cycling-induced fat bloom test was adopted according to a previous study [18]. The temperature change was done by fluctuating the storage temperature cycling from low temperature (18 ^{0} C) for 16 hours to high temperature (30 ^{0} C) for 8 hours; this is considered one cycle in 24 hours. This routine was continued for 8 weeks. After every cycle, visual observation was performed to detect any blooming on the surface of the samples. The chocolate-based BW/OG samples were deliberately over-tempered not just for smoothness and glossiness but to promote the fat bloom phenomenon. Furthermore, cocoa butter was completely replaced by different versions of BW/OGs. These three factors can cause blooming if the oil part (BW/OG) cannot resist the oil migration. The fat bloom was observed at every interval (cycle) by visual observation to see any oil migration on the surface as a form of grey dul to white round spots .

Sensory evaluation:

To assess the sensory quality of commercial and chocolate-based BW/OG samples, a panel of 12 evaluators was formed. Although they are academic staff from the Food Sciences and Quality Control Department with considerable experience, they underwent a two-hour lecture to clarify the sensory evaluation parameters necessary for obtaining accurate results, as outlined in Table (2). The evaluators were instructed to conduct the test individually to ensure accuracy .

The sensory evaluation consisted of seven parameters: taste, odor, texture, mouthfeel, appearance, overall acceptability, and purchase intention. This evaluation was structured around five attributes using a 5-point hedonic scale, ranging from 1 (dislike a lot) to 5 (like a lot). This approach was adapted from previous studies with minor modifications [23, 24.[

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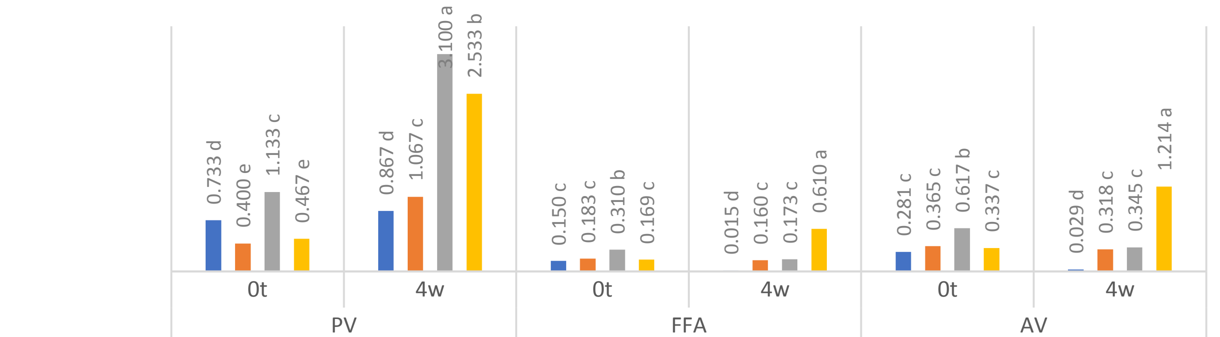
Purchase intention served as a metric to assess how likely the evaluators were to buy each sample, using a scale from “definitely purchase” to “definitely not purchase”.

Table 2. Sensory and non-sensory parameters of the 5-point hedonic test with their description.

Taste & Odor	The intensity of the bittersweet flavor & cocoa aroma
Texture	Consistency, homogeneity, mouthfeel
Mouthfeel	stickiness on the palate surface, amalgamation, and smoothness.
Appearance	Glossiness, broken surface, and roughness,
Overall acceptability	Acceptable or not acceptable
Purchase intention	The extent of the desire to purchase

Results and discussion

Oxidative stability.



	PV 0t	PV 4w	FFA 0t	FFA 4w	AV 0t	AV 4w
BW/OG 10%	0.733 d	0.867 d	0.150 c	0.015 d	0.281 c	0.029 d
BW/OG 17%	0.400 e	1.067 c	0.183 c	0.160 c	0.365 c	0.318 c
BW/OG 20%	1.133 c	3.100 a	0.310 b	0.173 c	0.617 b	0.345 c
BW/OG 25%	0.467 e	2.533 b	0.169 c	0.610 a	0.337 c	1.214 a

Figure (1): Storage stability of different BW/OG samples after 4 weeks of storage. Rancidity parameters: PV, peroxide value; FFA, free fatty acid; AV, acid value. BW/OG, beeswax oleo gel, 0t, zero time; 4w, after 4 weeks of storage. Values without the same letter are significant ($p<0.05$ (

The storage stability results for all BW/OG samples are presented in Figure (1). In this study, which involved a full-fat replacement, OGs serve as the primary fat phase and play a crucial role in preventing rancidity. To assess primary oxidation, we measured the peroxide value (PV), free fatty acid (FFA), and acid value (AV). The results are expressed as equivalents of peroxide oxygen per kilogram (mEqO2/kg.(

As shown in Figure 1, all BW/OG samples, except for the BW/OG 10%, experienced a significant increase in PV ($p > 0.05$) after four weeks of storage. The PV ranged from 0.4 to 1.1 mEqO2/kg at zero time, increasing to between 0.8 and 3.1 mEqO2/kg after four weeks. However, these values remain within an acceptable range, as levels up to 10 mEqO2/kg are permitted [25]. Previous works had nearly the same results (around 2-4 mEqO2/kg) for OGs contain 3-6% (w/w BW) when stored at 4^{0} C [26, 27]. It can be stated that the BW/OGs in this study contain a significantly higher concentration of BW (10-

25% w/w) and still achieve similar results. Researchers noted that as long as the oil portion remains stable, the PV does not increase over time [26]. Stability is linked to how effectively the organo gel (BW) can encapsulate the oil. The key factor is the concentration of BW in the OG and its OBC. As the wax concentration increases, a stronger three-dimensional network is formed [8] (see Figure 1), resulting in improved OBC [28]. Ogutuca et al. (2015) explained that the strong stability of OGs may be related to the saturation level of the fat phase in the products created. This is supported by the observation that oleo gel-based products typically have a higher PV compared to their commercial versions, as they contain less saturated fats [27 .[

Texture analysis (hardness (

Table 3. Textural property (hardness) of commercial and different formulated chocolates.

Treatments	Max force (N) after 24 hours (4^0 C)	Max force (N) after 24 hours (20^0 C)	Max force (N) after 2 weeks (4^0 C)	Max force (N) after 2 weeks (20^0 C)
C.CHOCO	43.000 a	43.000 a	44.000 a	43.000 a
CHOCO-25% BW/OG	13.533 b	8.933 b	11.833 b	7.533 b
CHOCO-20% BW/OG	11.667 b	6.700 b	11.367 b	6.800 b
CHOCO-17% BW/OG	6.700 c	6.733 b	6.233 c	3.700 bc
CHOCO-10% BW/OG	4.200 c	1.500 c	3.500 c	1.567 c

C.CHOCO (commercial chocolate), BW/OG (beeswax oleo gel) the effect of BW concentration in OG, and storage time on hardness. For each hardness and temperature parameter, values without the same letter are significant ($p<0.05$ (

The effect of storage time at different temperatures of both commercial and different formulated chocolate samples is represented in Table (3). Chocolate based on various versions of BW/OG was compared with the commercial sample (control). OGs made with a greater concentration of BW used to formulate chocolates induced a greater hardness in both storage times and temperatures. This difference can be seen between CHOCO-10% BW/OG and CHOCO-25% BW/OG. However, their hardness values are at least threefold smaller than those of the control .

It seems the two-week storage period does not significantly affect the textural property of all samples. However, regarding formulated samples, while statical analysis does not indicate a significant difference, hardness is dramatically reduced, at least twofold, when stored at higher temperatures (20^0 C .(

The softer textural property of chocolate-based BW/OG might be attributed to the fact that cocoa butter (in commercial chocolates) and BW are both structuring agents but function differently. BW primarily acts to hold the two phases together and can trap a large amount of oil, providing properties similar to those of cocoa butter. However, BW is less hard, more pliable, and less crystalline than cocoa butter, which creates a harder and more crystalline structure at room temperature, giving the final product a rigid texture [10.[

Additionally, most commercial chocolates are formulated with cocoa mass and milk fat, which also contribute to a more crystalline structure at room temperature [29, 30]. Cocoa butter can crystallize into various crystal forms depending on the specific process and the heat and cooling treatment applied. The most stable and desirable form is the beta form (V), also known as V crystals or cocoa butter crystals, which can be produced during the tempering process. This particular type of crystal results in a smooth, shiny, and more crystalline structure, contributing to a preferred mouthfeel [4]. On the other hand, BW can also crystallize but does not provide the same properties. Instead, it forms an amorphous three-dimensional gel-like network that yields a softer, less rigid structure at room temperature [31]. This is the main difference between the two.

When BW oleogel is used as a substitute for cocoa butter in chocolate making, the final product is softer and exhibits plasticity rather than rigidity, resulting in a malleable mouthfeel. Other authors also obtained this result [30, 32, 33]. As can be seen from Table (2), there is a significant difference between the control and formulated chocolates, as they exhibit a significant difference in hardness. Although an increase of BW concentration increased the hardness, especially in CHOCO-25% BW/OG, the hardness of commercial chocolate is significantly greater. BW in the pure state poses a great hardness and melting point. However, when utilized as an oleo gelator, it might exhibit the eutectic softening effect and explain the hardness discrepancy between the formulated and commercial chocolate samples [34 .[

Due to this lack of structural rigidity, chocolate formulated with BW is suitable for different types, such as coatings, fillings, and moulded chocolates. These variations typically do not require a brittle structure at room temperature.

Oil binding capacity (OBC(

Table 4. The OBC of commercial and different Chocolate-based BW/OG after two different storage periods.

	OBC (%)	
Treatments	after 24 h	after 2 weeks
C.CHOCO	100a	100a
CHOCO-25% BW/OG	100a	99.7a
CHOCO-20% BW/OG	100a	99.8a
CHOCO-17% BW/OG	98.9b	98.1a
CHOCO-10% BW/OG	97.2c	96.6a

OBC, oil binding capacity; BW/OG, beeswax oleo gel; C.CHOCO; commercial chocolate, each value with the same letter means not statically different (p<0.05 .(

The OBC is considered one of the crucial properties of high-oil-content products as it represents the physical stability of long-term storage. The test was performed for all fresh chocolate samples, and after two weeks of storage. This step evaluates the integrity of the physical structure during storage at room temperature (Table 4). Formulated samples show a strong physical structure and are compact enough to hold a certain amount of liquid oil. Compared to C.CHOCO, all other formulated chocolates show a similar result after two weeks of storage. CHOCO-10% BW/OG obtained a least value of around 97%, which can still be marked as significantly acceptable. A previous study showed an inverse relationship between increased oleo gelator and OBC; the more the concentration of oleo gelator, the less OBC resulted [10]. However, in the case of BW, the relationship is positive. This means OG with more BW concentration gives a more robust physical structure. This result agrees with the study by patel, et al. (2013) that chocolate-based BW/OG, even with as small as 1% oleo gelator can prevent oiling out for three months [28 .[

Solid fat content in commercial chocolates compared with vegetable oils (liquid) in chocolated-based BW/OG is more effective of preventing a phase separation, especially oiling out. However, BW as a structuring agent can rap even coarse oil droplets by creating three-dimensional networks to provide a stable colloidal system [35]. Other authors refer to great OBC as a large surface area of waxes that interact with the oil phase since both have similar physiochemical properties [36], double bond interaction between waxes and the oil phase due high degree of unsaturation [37] (see Figure1). Researchers determined that an OBC of as low as 94% is still acceptable [38 .[

Microstructure Observation

Samples were examined using polarized light microscopy to analyze the microstructure and crystal morphology of chocolate-based different BW/OGs in comparison to a commercial version. The microstructure images of all samples are presented in Figure (2). As part of the chocolate-based oleogels, the BW component is characterized by grainy crystals that exhibit a brown to red color when illuminated with polarized light[39]. Another study reported that BW crystals have a similar morphology to candelilla wax, which is a small, grainy-like crystal with a length of 3-5 micrometres [13 .[

The figure illustrates that commercial chocolate, which is cocoa butter-based, exhibits a very fine, uniform, and compact microstructure. In contrast, the chocolate-based BW/OG displays a less compact and homogeneous microstructure, with the exception of CHOCO-25% OLEO. The images reveal individual and clustered wax aggregates that form a network to stabilize the system. Additionally, it is evident that an increase in wax concentration results in a denser and thicker microstructure, as observed in CHOCO-25% BW/OG. This particular formulation of chocolate shows a microstructure similar to that of commercial chocolate

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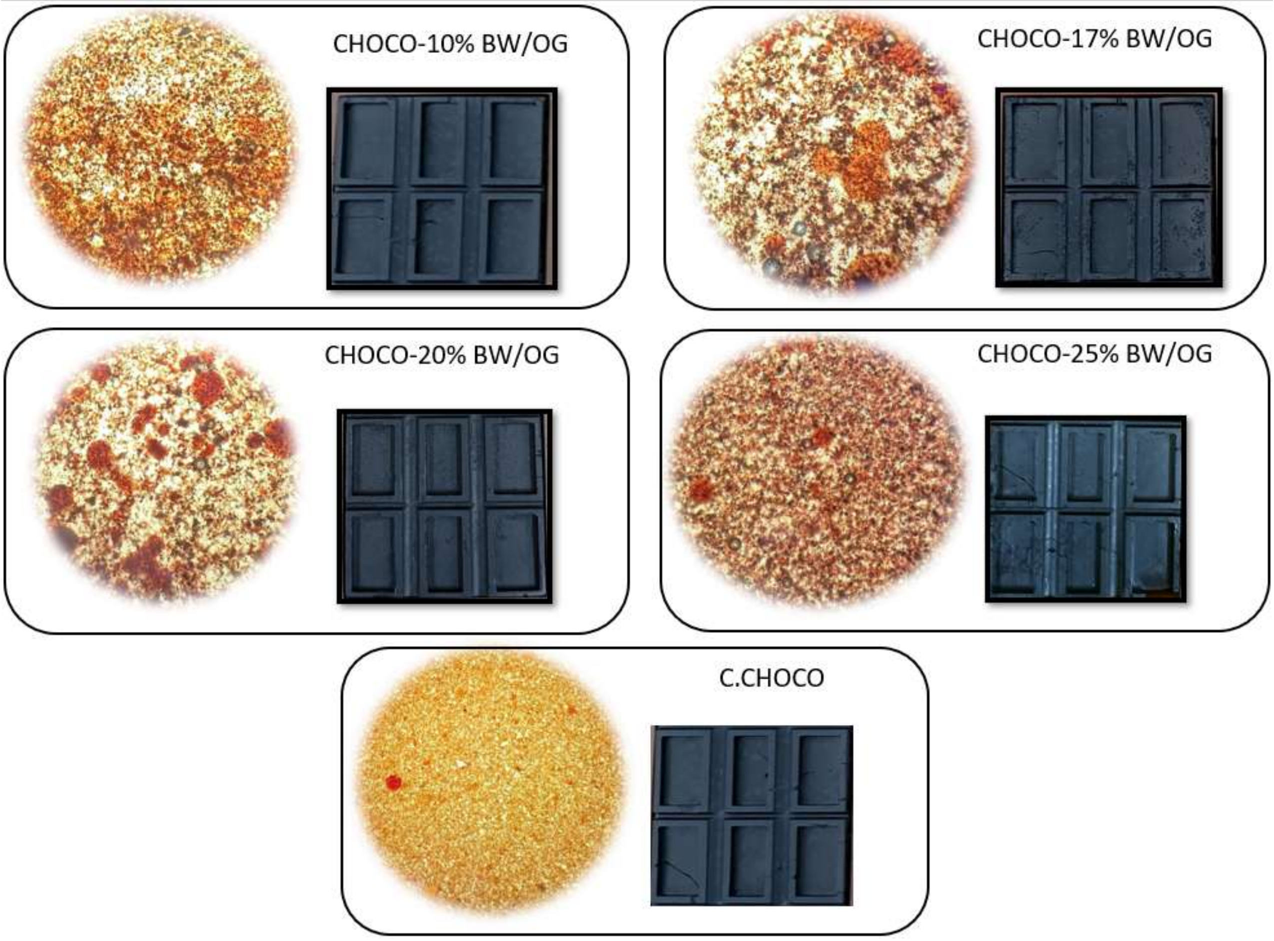

Figure (2): Microstructure of commercial and chocolate-based BW/OGs. The microstructure was captured under 40x magnification by polarized light microscopy .

Appearance and blooming

Table 5. Blooming observation, the results applied for each treatment (CHOCO-10% BW/OG, CHOCO-17% BW/OG, CHOCO-20% BW/OG, CHOCO-25% BW/OG.(

Weeks	Storage Temperature (^{0} C)			
	18^0 C		30^0 C	
	Fat Bloom	Cycles	Fat Bloom	Cycles
1	-	7	-	7
2	-	7	-	7
3	-	7	-	7
4	-	7	-	7
5	-	7	-	7
6	-	7	-	7
7	-	7	-	7
8	-	7	-	7

1week = 7cycles; 1cycle = 24h storage (16 hrs. at 18^0 C + 8 hrs. at 30^0 C); test duration = 8 weeks; texture change and appearance detected by visual observation; - means no blooming; + means slight blooming ++ means moderate blooming; +++ means extrem bloomimg .

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The results of the blooming occurrence are presented in Table (5). Blooming was determined through visual observation conducted at each cycle interval. The findings apply to each treatment, exhibiting the same result: negative blooming over the eight-week storage period (comprising seven cycles) of temperature fluctuations. All fabricated chocolate samples demonstrated resistance to blooming, particularly fat blooming .

The results indicate that BW/OG effectively prevents fat blooming, even in the sample with the lowest BW content (CHOCO-10% BW/OG). Although the concentration of BW is a contributing factor, it appears that a 10% concentration is sufficient to prevent blooming. Research shows that higher oil center content and lower cocoa butter concentration increase the likelihood of blooming. This claim was supported by the accelerated bloom formation test conducted on filled chocolates [40, 41]. However, in the case of the chocolate-based BW/OG, oil migration was inhibited by the crystalline structure barrier of BW. It is suggested that long-chain hydrocarbons, esters, alcohols, long-chain fatty acids, and long-chain alcohols may contribute to the prevention of fat blooming [4 .[

It has been reported that cocoa butter triglycerides migrate to a lesser extent from the centre to the surface compared to the triglycerides in other fat phases, such as cocoa butter replacers, equivalents, and substitutes used in manufacturing. This migration typically happens when temperatures fluctuate, especially near the melting point of the fat phase, which is around 35°C [4.[

BW/OG falls into the categories previously mentioned. Notably, even without the tempering process, which is essential for stable fat crystallization, the BW crystalline structure can directly form the stable (β’) crystal type [4, 42]. This property may explain why chocolate-based BW/OGs resist fat bloom, as the wax components tend to organize themselves into an ordered, compact structure that acts as an effective barrier [4]. A prior study confirmed this finding when BW/OG was used in chocolate formulation [9]. While this technique may not perform as well as cocoa butter in terms of sensory attributes, it has the potential to replace hydrogenated oils, particularly trans fats, which are associated with various health issues.

Sensory evaluation

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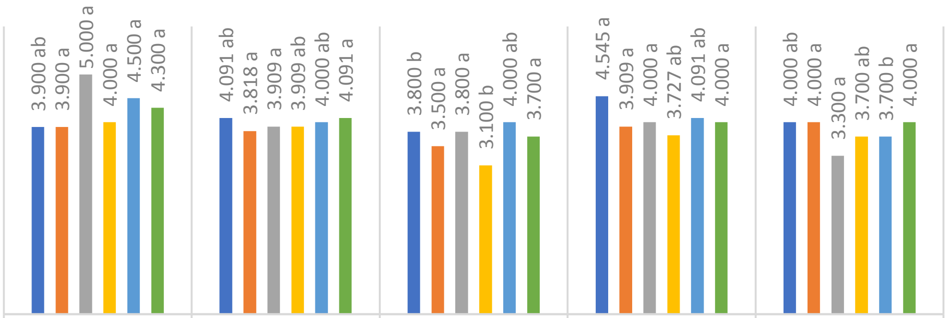

	C.CHOCO	CHOCO-25% BW/OG	CHOCO-20% BW/OG	CHOCO-17% BW/OG	CHOCO-10% BW/OG
Taste	3.900 ab	4.091 ab	3.800 b	4.545 a	4.000 ab
Odor	3.900 a	3.818 a	3.500 a	3.909 a	4.000 a
Texture	5.000 a	3.909 a	3.800 a	4.000 a	3.300 a
Mouthfeel	4.000 a	3.909 ab	3.100 b	3.727 ab	3.700 ab
Appearance	4.500 a	4.000 ab	4.000 ab	4.091 ab	3.700 b
Overall acceptability	4.300 a	4.091 a	3.700 a	4.000 a	4.000 a

Figure (3): 5-point hedonic sensory evaluation test is used to compare commercial and chocolate-based different types of BW/OGs. (mean value=12); C.CHOCO, commercial Chocolate; OLEO, oleo gel. Values that share the same letter are not statistically different (p<0.05 .(

The sensory evaluation test was carried out by 12 trained academics (Figure 3). All samples were tested for their five sensory attributes (taste, odor, texture, mouthfeel, appearance, and overall acceptability). Statistical analysis shows no significant difference between commercial chocolate and chocolate-based BW/OGs. However, It can be observed that commercial chocolate was preferred over formulated chocolates in a number of sensory attributes, such as texture, mouthfeel, and overall acceptability. The appearance of commercial chocolate was also one of the parameters that participants picked over the formulated versions, except for CHOCO-25% BW/OG, which obtained a similar score.

The texture is one property the formulated chocolates lack most, especially CHOCO-10% BW/OG. This result can be confirmed by the hardness in texture analysis results in Table (3). This result agrees with the previous study that complete replacment of cocoa butter by OG clearly affects the texture [43]. Instead, other authors preferred that complete replacement rather be made in other types of chocolates called compound coatings [4], such as filling and pastries [10 .[

All chocolate-based BW/OG received marginally higher taste scores compared to the commercial version, including the one with the highest BW content (25%). This suggests that a high concentration of BW in this particular formulated chocolate can be acceptable. In other words, the panellists were unable to detect any waxy taste, which supports the use of OG containing more than 25% BW. This formulation could lead to a significant reduction in total energy content while also improving the fatty acid profile. Additionally, CHOCO-17% BW/OG emerged as the most preferred version. A significant reason behind the favourable scores for high BW-content chocolate-based BW/OGs is that they impart a desirable chewiness that appeals to tasters.

Conclusion

Healthier versions of chocolates were developed using a specific formulation in which the OG completely replaced cocoa butter. The BW/OG, with concentrations of up to 25% BW, was utilized to fabricate these chocolates. This formulation successfully addressed concerns related to saturated fat reduction and its long-term health implications. The physiochemical and sensory properties of all fabricated chocolate samples were comparable to those of commercial chocolates, except in terms of physical texture (hardness). The samples exhibited a softer texture at room temperature. In fact, the hardness issue could potentially be remedied by incorporating certain types of fats, such as hydrogenated palm oil or milk fat, which contribute to a firmer structure. Nevertheless, the primary goal was to create a healthier alternative. This formulation presents promising potential for industrial applications in the production of compound coatings or chocolate-filled confectionery products.

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