Research Article

The effects of adding water and polyglycerol polyricinoleate on the texture, appearance, and sensory qualities of compound milk chocolate

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Water and polyglycerol polyricinoleate (PGPR) contents were varied to investigate the effects of these parameters on the textural properties, surface color, and sensory qualities of compound chocolates. The content levels of water and PGPR were manipulated between 3–10 and 0.3–3.3%, respectively (content expressed as % by weight of finished product). Simultaneous variations in water and PGPR levels, especially in high ratios, resulted in a drastic reduction in the hardness values ($p < 0.001$), darker color ($p < 0.01$), and an unusual taste ($p < 0.05$) but the effect of water addition was more pronounced than PGPR. It was observed that compound chocolates with 3% water content were not dissimilar from the control with respect to all properties. In the samples of the same water content, the effect of PGPR addition was nearly insignificant. For these confectionaries, the best proportion of ingredients for producing water-containing compound chocolate was considered the one which has the least negative effects on bloom surface area and the texture.

Practical applications: Manufacturing water-containing imitation chocolates represent a general approach for adding all water-base materials to chocolate such as cream, yogurt, milk, etc. or water-soluble substances like trace elements and vitamins. Conventional chocolates become soft at above 28°C, and lose shape retention at above 32°C. Water addition provides a heat-resistance compound chocolate with shape retention at a temperature above 40°C, being not sticky to the direct touch. However, there has been very limited information about water addition's effects on the chocolate structure. In order to be able to predict the structural variations, it is important to study how water affects the physical properties of the chocolates.

Keywords: Image analysis / Polyglycerol polyricinoleate / Sensory quality / Texture / Water

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1 Introduction

Compound chocolate is a cocoa product containing cheap hard vegetable fats in the place of cocoa butter. Thus one of the chief benefits of compound chocolate is that it can deliver cocoa flavor at a greatly reduced cost. Another advantage of compound chocolate is that it does not need to be tempered. Because of the texture of the vegetable fat, the melted compound chocolate will harden within a few minutes of removal from a heat source, creating a firm adherent coating on an item dipped in melted compound chocolate [1].

To obtain appropriate flow properties compatible with the production stages of chocolate, care should be taken to maintain the moisture level of the chocolate masses below 1% by weight [2]; consequently, conventional chocolate processing methods avoid contact with water as it causes abnormal rheological behavior in the product, usually accompanied by lumping or granulation, leading to an unacceptable rough texture [3]; furthermore, the probability of sugar bloom formation is enhanced, since it usually occurs when the moisture

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Abbreviations: CBE, cocoa butter equivalent; **HLB,** hydorophile–lipophile balance; **PGPR,** polyglycerol polyricinoleate; **WI,** whiteness index; **W/O emulsion,** water-in-oil emulsion dissolves the sugar in the chocolate and draws it to the surface [4]. Ziegleder stated that bloom forms (both fat and sugar) reduce the quality, causing a grainy texture as well as poor color and appearance [5]. Therefore, low humidity storage conditions, stable temperature, and suitable packaging are all important for producing high-quality chocolate with a perfect texture.

The addition of water in a way that does not contact with solid materials has several advantages. Replacing compound chocolate ingredients with water effectively reduces the total calories consumed, which carries implications for obesity and obesity-related diseases [6], making it cheaper to produce and sell. Function and nutritional value can still be achieved with the addition of all water-soluble and fat-soluble components to compound chocolates [3]. In addition, water can increase the thermal stability of chocolate products by creating a three-dimensional matrix or network of sugar crystals [7]. When the temperature is thereafter raised, this network acts as a sponge, holding the melted fat and preventing collapse of the structure [8].

Several ingenious approaches have been offered in preventing water-induced texture deterioration in chocolates; for example, using the water-in-oil type emulsion, which contains a lipophilic emulsifier with HLB (hydorophile–lipophile balance) value of 1–3. Baba et al. preferred to use the mixture of lecithin together with polyglycerol polyricinoleate (PGPR) as emulsifiers of water-containing chocolates. They also held that if the moisture content exceeds 10% by weight of finished product, an efficient mold separation will not be provided [9]. The size of dispersed water droplets in the oil continuous phase emulsion is also critical, and should not exceed 30 μm. Coincidentally, this water droplet size carries surprising advantages, such as reducing microbial development, improving the emulsion stability, and mimicking the sensory properties of regular chocolates [10]. The kind of fat is another important criterion. Padley and Talbot stated that suitable fats for use in the preparation of water-containing chocolates should preferably be rich in 2-oleyl triglycerides of palmitic or stearic acids. These fats have a narrow melting range, giving chocolate its desirable properties of snap and resistance against fingerprinting at ambient temperature conditions, while maintaining melt consistency at body temperature [11]. Furthermore, lauric base fats are not recommended in the emulsions as they might release in the presence of water, resulting in a soapy off-flavor [12].

Heretofore, there has been no information about the effects of water addition on the imitation chocolate structure. One of the common deterioration effects in emulsion-based confectionaries is surfacing sugar bloom, so this study will determine the effects of increasing the water content on texture, sugar bloom formation, and sensorial properties of compound milk chocolate, and also compare the effect of increase in the amount of PGPR in samples with the same water content.

2 Materials and methods

2.1 Materials

Low fat cocoa powder (with 10–12% fat content) was supplied by Guan Chong cocoa manufacture SDN. BHD. (Johor, Malaysia); milled sugar (with particle size of 100–400 μm) was purchased from Toos Arjan Company (Mashhad, Iran); CBE (Coberine^{TM} 608) was obtained from Loders Croklaan Asia Co. (Malaysia); refined sun flower oil (Ladan) was purchased from Behshahr Industrial Company (Behshahr, Iran); whole milk powder was obtained from Golshad Company (Mashhad, Iran); PGPR was obtained from Dr. Straetmans Chemische Produkte GmbH (Hamburg, Germany) and soy lecithin (GMO free) was obtained from Kimia Sazan Company (Tehran, Iran).

2.2 Chocolate samples and their preparation

The method employed for producing water-containing chocolates was similar to that of Traitler et al. [2]. In this respect, in order to produce chocolate mass, CBE was first melted in an oven (PAAT-ARIA Co., no. 2006, Tehran, Iran) at 70○C, weighed, and mixed thoroughly with the lecithin (0.7% by weight of chocolate mass). To reach the particle size of below 30 μm [13], all solid materials (sugar, milk powder, and cocoa powder) were divided into 2.5 kg batches and transferred to the laboratory ball mill (manufactured by Sepehr Machine Co., Tehran, Iran) together with the oil mixture. The settings on the ball mill used were 60 min at 100 rpm per 2.5 kg batch, which produced D_{90} particle sizes below 23 μm [14]. The finished chocolate masses were molded in the plastic containers, wrapped in aluminum foil and refrigerated prior to mixing with the emulsion base.

To create emulsion bases, a two-step homogenization procedure was employed: the first step consisted of stirring a pre-emulsion of water-in-oil at approximately 45○C in the presence of PGPR. The emulsifier was completely dissolved in the molten CBE at approximately 70○C and transferred to a kitchen blender (Odacio 3 Duo Press Food Processor, Moulinex, Ireland). After cooling the mixture down to 45○C, the water was added very slowly while the blender was set to the highest setting and switched on for 2 min. In the second step, samples (70 ± 0.01 g) were homogenized using a homogenizer (T25 digital ultra-turrax, IKA, Germany) for 3 min. To obtain w/o emulsions with the same droplet size range, homogenizing speeds were varied and eventually stable fine emulsions with an average diameter of 0.161 ± 0.059 μm were formed. The mean droplet diameter of the dispersed aqueous phase was determined by photon correlation spectroscopy (PCS) approximately 1 h after preparation (keeping storage at 50○C). Approximately 20 μL of the sample was dispersed into 750 μL of sunflower oil (with refractive index = 1.467 (at 40°C), dielectric constant = 4.2 and dynamic viscosity = 17.097cp).

Measurements were conducted at 40○C and at a scattering angle of 90○ and recorded. The PCS system consisted of a Zetasizer nano zs (Malvern Ltd., UK) with a helium-neon laser (wavelength = 632.8 nm) and a correlator connected to a computer running Malvern PCS-software version 1.35 for data collection [15].

Eventually, with the molten chocolate mass held at approximately 45°C, it was carefully incorporated in small quantities into the emulsion base. To prevent emulsion breakage, the rotational stirring movements were slightly carried out on the mixture by hand. This resulted in a smooth, creamy, homogenous composition. The ratio of the W/O emulsion mixture to the chocolate mass by weight was 15:85.

The finished product was promptly poured into molds and shaken for approximately 2–3 min. The molds were 30 × 10 × 7 mm^3 polycarbonate and held about 3.5 g of chocolate. The molded chocolate was immediately put into a freezer at −18°C for almost 30 min. To prevent fat bloom on the surface of chocolates, samples were wrapped in aluminum foils and stored at RT (18–25°C) prior to analysis [16]. The speed of homogenizing, the measurement results of droplet diameters, the composition of chocolates mass, emulsion base, and final product are presented in Table 1.

2.3 Physical tests

2.3.1 Texture measurement

After 30 days storage at ambient temperature, the hardness of the chocolate bars (the maximum peak force in Newton) was measured using the Universal Texture Analyser (CNS Farnell, UK) connected to a computer programmed with Texture ProTM texture analysis software and a cylindrical flat-ended stainless steel probe with a diameter of 2 mm. The maximum penetration force through the sample was measured at the speed of 1 mm/s, penetrating to the depth of 5 mm at RT [17], converting values of the penetration force exerted by the 50 kg load cell into hardness (g force). Sample orientation was kept constant in all texture analyzer tests. The results were expressed as the mean value of 5 repeated penetrations conducted on different samples.

2.3.2 Color measurements

After 30 days storing at ambient temperature, image processing techniques were applied to investigate the color changes in the water-containing milk chocolates and in the control batch. Images were acquired using a flatbed scanner

Table 1. Composition of emulsion base, the intensity od homogenizer, mean droplet size, chocolate mass, and final product

Emulsion base					Chocolate mass					Final chocolate						
Water (%)	PGPR (%)	CBE (%)	Rotational speed of homogenizer (rpm)	Droplet size (μm)	Lecithin (%)	CBE (%)	Sugar (%)	Milk powder (%)	Cocoa powder (%)	Water content (%)	PGPR content (%)	Lecithin (%)	CBE (%)	Sugar (%)	Milk powder (%)	Cocoa powder (%)
17.2	2	80.8	5000	0.2	0.8	24.7	54	15.2	5.3	3	0.3	0.7	33.1	45.6	12.8	4.5
17.2	4	78.8	5000	0.1	0.8	24.7	54	15.2	5.3	3	0.6	0.7	32.8	45.6	12.8	4.5
17.2	6	76.8	5000	0.2	0.8	24.7	54	15.2	5.3	3	0.9	0.7	32.5	45.6	12.8	4.5
17.2	8	74.8	5000	0.2	0.8	24.7	54	15.2	5.3	3	1.2	0.7	32.2	45.6	12.8	4.5
17.2	10	72.8	5000	0.15	0.8	24.7	54	15.2	5.3	3	1.5	0.7	31.9	45.6	12.8	4.5
30.5	6	63.5	8000	0.2	0.8	26.2	52.9	14.9	5.2	5	0.9	0.7	31.8	44.7	12.5	4.4
30.5	8	61.5	8000	0.15	0.8	26.2	52.9	14.9	5.2	5	1.2	0.7	31.5	44.7	12.5	4.4
30.5	10	59.5	8000	0.25	0.8	26.2	52.9	14.9	5.2	5	1.5	0.7	31.2	44.7	12.5	4.4
30.5	12	57.5	8000	0.25	0.8	26.2	52.9	14.9	5.2	5	1.8	0.7	30.9	44.7	12.5	4.4
30.5	14	55.5	8000	0.2	0.8	26.2	52.9	14.9	5.2	5	2.1	0.7	30.6	44.7	12.5	4.4
47.2	10	42.8	12 000	0.15	0.8	28.2	51.5	14.5	5	7.5	1.5	0.7	30.4	43.5	12.2	4.2
47.2	12	40.8	12 000	0.15	0.8	28.2	51.5	14.5	5	7.5	1.8	0.7	30.1	43.5	12.2	4.2
47.2	14	38.8	12 000	0.2	0.8	28.2	51.5	14.5	5	7.5	2.1	0.7	29.8	43.5	12.2	4.2
47.2	16	36.8	12 000	0.2	0.8	28.2	51.5	14.5	5	7.5	2.4	0.7	29.5	43.5	12.2	4.2
47.2	18	34.8	12 000	0.2	0.8	28.2	51.5	14.5	5	7.5	2.7	0.7	29.2	43.5	12.2	4.2
63.8	14	22.2	20 000	0.1	0.8	30.1	50.1	14.1	4.9	10	2.1	0.7	28.9	42.3	11.9	4.1
63.8	16	20.2	20 000	0.1	0.8	30.1	50.1	14.1	4.9	10	2.4	0.7	28.6	42.3	11.9	4.1
63.8	18	18.2	20 000	0.1	0.8	30.1	50.1	14.1	4.9	10	2.7	0.7	28.3	42.3	11.9	4.1
63.8	20	16.2	20 000	0.1	0.8	30.1	50.1	14.1	4.9	10	3	0.7	28.0	42.3	11.9	4.1
63.8	22	14.2	20 000	0.1	0.8	30.1	50.1	14.1	4.9	10	3.3	0.7	27.7	42.3	11.9	4.1
Control					0.7	34.5	47	13.2	4.6							

(HP scanjet G4010). Color images of chocolate surfaces were converted to CIELAB system: L^*, luminance ranging from 0 (black) to 100 (white); and a^* (green to red) and b^* (blue to yellow) with values from -120 to $+120$. Information was obtained using Image J software (1.42e) convertor tools. Then according to acquired data and Eq. (1–3), a total of six features per class (L^*, a^*, b^*, C^*, h°, and WI) were computed for all samples. Mean values from five replicate measurements and SDs were calculated [18].

$$\mathrm{WI} = 100 - [(100 - L*)^2 + (a*^2) + (b*^2)]^{0.5} \quad (1)$$

$$\text{hue angle}\ (h^\circ) = \arctan(b^*/a^*) \quad (2)$$

$$\text{chroma}(C^*) = [(a^*)^2 + (b^*)^2]^{0.5} \quad (3)$$

2.4 Sensory analysis

Sensory evaluation was carried out by ten trained panelists (aged 20–28 years) selected from graduate students at the Department of Food Sciences and Technology (Ferdowsi University of Mashhad, Iran). Selection criteria were availability of the assessors, interest to participate in the study, the absence of aversions, allergies, or intolerance against chocolate, normal perception abilities, and no chocolate craving.

After 30 days of storage at RT, the chocolate acceptance was evaluated based on the product appearance and texture using a 10-point hedonic scale (0 = extremely dislike, 5 = moderate, and 10 = extremely like) [19]. The sensory attributes included color, glossiness, sandiness, flavor, hardness, and overall acceptability. Chocolates were served randomly in odorless plastic containers along with mineral drinking water for mouth rinsing between tests. Panelists tasted five samples in every session and were asked to compare each one with the control. Sessions were carried out in individual booths between 9:00 and 12:00 a.m. under incandescent lamp and at ambient temperature. All samples were analyzed in triplicate.

2.5 Statistical analysis

The analysis was conducted using a nested ANOVA design (p>0.001) to compare the effect of variables (i.e., moisture and emulsifier content) on hardness, color attributes and sensory properties. These statistical analyses were performed with Minitab Release software (Version 13.2, State College, PA, USA). ANOVA and least significant differences (LSDs) tests were also carried out for each character (at $\alpha < 0.05$) to detect differences between mean values.

Since our goal was to formulate chocolates with different amount of water and PGPR contents compatible with the control, the chocolate masses were formulated according to the relative emulsion bases. As it is clear from the Table 1, all ingredients in the finished products—except CBE—were equally decreased subsequent to the water level increase. To inspect the effect of CBE on the experimental attributes, the fat values were analyzed using analysis of covariance. Results indicated that the effect of CBE fluctuations on all properties were not meaningful ($p < 0.001$).

3 Results and discussion

3.1 Determining the least amount of emulsifier

Before starting the project, emulsions with lower amount of PGPR were mixed with chocolate masses. It was observed that upon mixing these emulsion bases with the chocolate masses the breakage happened and the viscosity of the products were increased. Consequently, higher levels of PGPR were tested. Eventually, it became clear that the volume of emulsifier have to increase subsequent to the water content increase. For example, to produce chocolates with 5% water content, emulsion bases should contain at least 6% PGPR; otherwise, the emulsion base breaks during mixing. Figure 1 shows the relationship between the minimum amount of emulsifier that has the potential to make chocolates and different amount of water contents. This line graph also displays that the figure follows an upward linear trend over the moisture content ($R^2 = 0.997$). Equation (4) describes this relationship.

$$E_{\min} = 0.254 \times W - 0.4233 \quad (4)$$

where E and W are the percentages of emulsifier and water content, respectively.

3.2 Textural properties

Figure 2 reveals the effect of water and PGPR addition on the hardness of samples after 30 days storage at ambient temperature. Afoakwa et al. [17] stated that hardness of ordinary

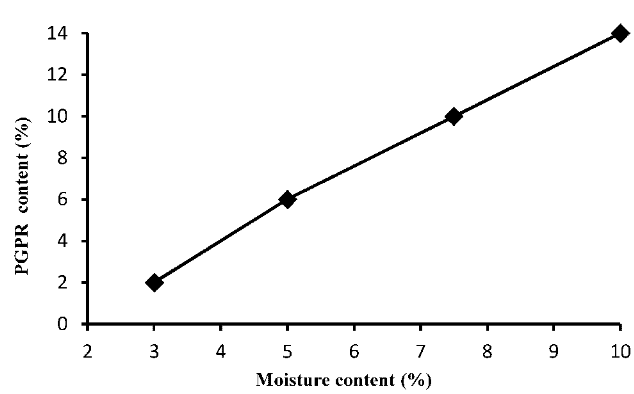

Figure 1. The minimum amount of PGPR in the emulsion bases which produce chocolates with different water contents.

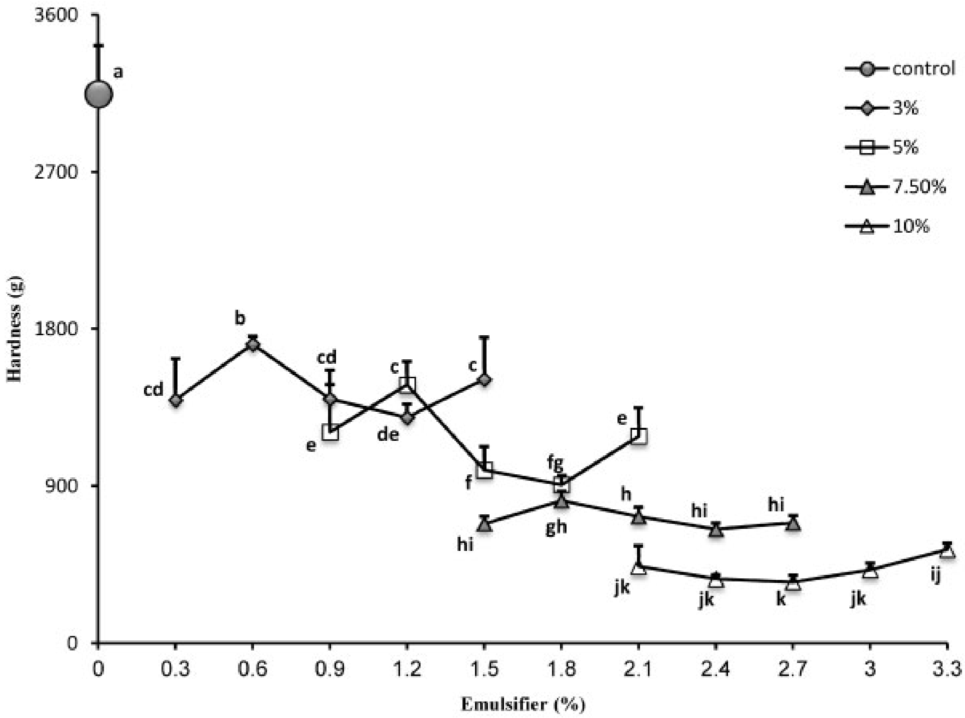

Figure 2. Effect of increasing PGPR and water contents on the hardness of milk chocolate. Different lower-case letters denote significant differences from the control ($p < 0.05$).

chocolate decreases with increases in emulsifier content, yet according to Fig. 2, these figures fluctuated especially in chocolates with 3 and 5% moisture quantity. It indicates that when the water content is low, the variation in hardness of water-containing milk chocolates does not follow any trend with increasing PGPR. In contrast, in chocolates with 7.5 and 10% moisture content, the hardness remained almost unchanged with increasing emulsifier content, which means that in chocolates with high water content, the influence of PGPR on the hardness is insignificant.

Figure 3 displays the impact of increasing moisture content on final product hardness at two constant values of PGPR (1.5 and 2.1%). Both lines show consistent, significant downward trends, following linear regression equations (R^2>0.95). The graph displays that doubling the water content of chocolate would reduce the hardness by up to ~2.5-fold at a given PGPR content. Moreover, specified increases in the amount of PGPR (from 1.5 to 2.1%) and water contents will lead to a slight decrease in the slope of the line.

Generally speaking, it can be inferred from the Fig. 2 that the simultaneous increase in the levels of water (3–10%) and PGPR contents (0.3–3.3%) resulted in a noticeable decrease in the hardness of milk chocolate ($p < 0.001$). This decline may be due to the lubrication effects of water and emulsifier which each, in turn, can reduce the friction between chocolate particles.

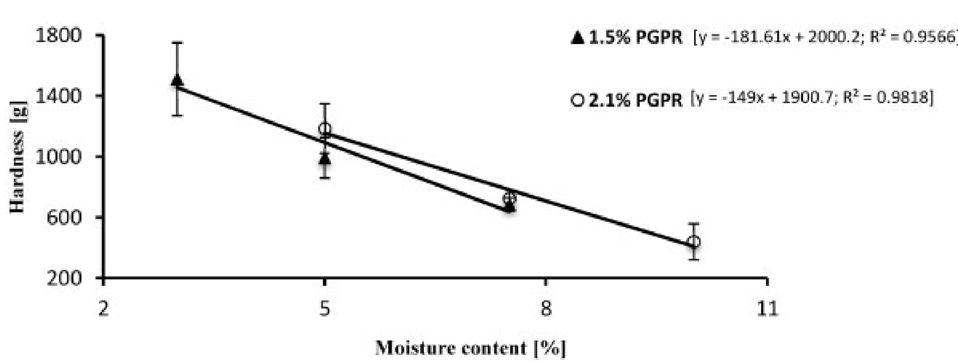

Figure 3. Comparing the effect of adding moisture content on the hardness of milk chocolate at two constant values of PGPR.

Table 2. Effect of emulsifier and water content on color parameters

Water content (%)	PGPR content (%)	Color measurements					
		b^*	a^*	L^*	C^*	h°	*WI*
3	0.3	$11.4 \pm 0.7^{a,A}$	$16.2 \pm 0.7^{bc,B}$	$28.1 \pm 1.7^{ab,A}$	$19.8 \pm 1.0^{abc,B}$	$35.3 \pm 0.7^{a,A}$	$254 \pm 15^{abc,AB}$
3	0.6	$11.5 \pm 0.7^{a,A}$	$16.5 \pm 0.6^{ab,B}$	$28.9 \pm 1.1^{a,A}$	$20.1 \pm 0.9^{ab,AB}$	$34.8 \pm 0.8^{ab,AB}$	$26.1 \pm 1.0^{a,A}$
3	0.9	$11.3 \pm 0.5^{ab,A}$	$16.4 \pm 0.6^{ab,B}$	$27.8 \pm 1.5^{abc,A}$	$19.9 \pm 0.8^{ab,B}$	$34.5 \pm 0.6^{abc,B}$	$25.1 \pm 1.3^{abcd,AB}$
3	1.2	$11.3 \pm 0.5^{ab,A}$	$16.4 \pm 0.5^{ab,B}$	28.2 ± 1.8ab,A	$19.9 \pm 0.7^{ab,B}$	$34.6 \pm 0.6^{abc,B}$	$25.4 \pm 1.6^{abc,AB}$
3	1.5	$11.7 \pm 0.6^{a,A}$	$17.0 \pm 0.5^{a,A}$	$27.8 \pm 0.8^{abc,A}$	$20.6 \pm 0.8^{a,A}$	$34.5 \pm 0.7^{abc,B}$	$24.9 \pm 0.7^{bcd,B}$
5	0.9	$10.6 \pm 0.8^{cd,B}$	$15.4 \pm 0.8^{de,C}$	$26.8 \pm 1.6^{cd,A}$	$18.6 \pm 1.1^{de,C}$	$34.5 \pm 0.9^{abcd,A}$	$24.4 \pm 1.3^{cde,AB}$
5	1.2	$10.7 \pm 0.9^{bc,B}$	$15.7 \pm 0.8^{cd,BC}$	$26.5 \pm 1.5^{d,A}$	$19.0 \pm 1.1^{cd,BC}$	$34.5 \pm 1.0^{bcd,A}$	$24.0 \pm 1.3^{def,AB}$
5	1.5	$11.2 \pm 1.1^{ab,AB}$	$16.3 \pm 1.0^{b,AB}$	$25.8 \pm 1.0^{de,A}$	$19.8 \pm 1.4^{abc,AB}$	$34.4 \pm 1.2^{bcd,A}$	$23.2 \pm 0.9^{fgh,B}$
5	1.8	$11.6 \pm 0.8^{a,A}$	$16.6 \pm 0.7^{ab,A}$	$26.3 \pm 1.4^{d,A}$	$20.2 \pm 1.1^{ab,A}$	$35.0 \pm 1.0^{ab,A}$	$23.6 \pm 1.3^{efg,AB}$
5	2.1	$11.1 \pm o.7^{abc,AB}$	$16.0 \pm 0.8^{bc,ABC}$	$27.0 \pm 2.3^{bcd,A}$	$19.5 \pm 1.0^{bcd,ABC}$	$34.8 \pm 0.8^{ab,A}$	$24.5 \pm 2.2^{cde,A}$
7.5	1.5	$9.5 \pm 0.7^{ef,AB}$	$14.3 \pm 0.7^{g,A}$	$24.0 \pm 1.5^{fg,AB}$	$17.1 \pm 1.0^{g,B}$	$33.5 \pm 1.1^{ef,AB}$	$22.0 \pm 1.4^{ij,A}$
7.5	1.8	$9.3 \pm 0.7^{f,B}$	$14.3 \pm 0.7^{fg,A}$	$24.1 \pm 1.3^{f,A}$	$17.0 \pm 0.9^{g,B}$	$33.0 \pm 0.9^{fg,ABC}$	$22.2 \pm 1.3^{hij,A}$
7.5	2.1	$9.2 \pm 0.9^{f,B}$	$14.5 \pm 0.7^{fg,A}$	$24.8 \pm 1.5^{ef,A}$	$17.2 \pm 1.1^{fg,AB}$	$32.4 \pm 1.5^{gh,C}$	$22.8 \pm 1.4^{ghi,A}$
7.5	2.4	$9.1 \pm 0.7^{f,B}$	$14.3 \pm 0.7^{fg,A}$	$24.3 \pm 1.5^{f,A}$	$17.0 \pm 1.0^{g,B}$	$32.5 \pm 1.1^{g,BC}$	$22.4 \pm 1.3^{ghi,A}$
7.5	2.7	$10.0 \pm 0.9^{de,A}$	$14.9 \pm 0.9^{ef,A}$	$22.8 \pm 1.5^{ghi,B}$	$18.0 \pm 1.2^{ef,A}$	$33.9 \pm 1.2^{cde,A}$	$20.7 \pm 1.3^{klm,B}$
10	2.1	$7.6 \pm 0.6^{g,B}$	$12.4 \pm 0.6^{h,B}$	$22.6 \pm 1.4^{hi,AB}$	$14.5 \pm 0.8^{h,B}$	$31.6 \pm 1.0^{hi,B}$	$21.2 \pm 1.3^{jkl,AB}$
10	2.4	$7.5 \pm 0.8^{g,B}$	$12.2 \pm 0.7^{h,B}$	$21.3 \pm 1.5^{j,C}$	$14.3 \pm 1.0^{h,B}$	$31.7 \pm 1.3^{hi,B}$	$20.0 \pm 1.5^{m,C}$
10	2.7	$7.4 \pm 0.5^{g,B}$	$12.2 \pm 0.7^{h,B}$	$22.1 \pm 1.6^{ij,BC}$	$14.3 \pm 0.9^{h,B}$	$31.1 \pm 0.7^{i,B}$	$20.8 \pm 1.4^{klm,ABC}$
10	3	$9.2 \pm 0.9^{f,A}$	$14.1 \pm 1.0^{g,A}$	$23.7 \pm 1.1^{fgh,A}$	$16.9 \pm 1.3^{g,A}$	$33.1 \pm 1.0^{efg,A}$	$21.8 \pm 1.0^{ijk,A}$
10	3.3	$9.4 \pm 0.9^{ef,A}$	$14.1 \pm 0.8^{g,A}$	$22.5 \pm 1.6^{hij,ABC}$	$16.9 \pm 1.1^{g,A}$	$33.7 \pm 1.3^{def,A}$	$20.6 \pm 1.5^{lm,BC}$
Control	0	11.4 ± 0.6^{a}	16.2 ± 0.5^{bc}	28.7 ± 1.0^{a}	19.8 ± 0.7^{ab}	35.2 ± 0.7^{ab}	26.0 ± 0.9^{ab}

Means ± SD (standard deviation) within a column with the same lowercase letters are not significantly different at $p < 0.05$ and means ± SD of chocolates with the same amount of water content within a column with the same uppercase letters are not significantly different at $p < 0.05$.

3.3 Color

Table 2 shows the effect of water and PGPR addition on the surface color of samples after 30 days storage at ambient temperature. The same processing and storage conditions were used for all chocolates; so the variations are only due to the different surface structures and compositions. As seen in Table 2 except for L^* and *WI*, the other parameters (a^*, b^*, C^*, and h°) follow similar trends, running almost parallel with changes in PGPR dosage. Furthermore, with simultaneous increasing of water and emulsifier percentages, decreasing overall trends were found for all color parameters. It means that irrespective of the factors which had been measured for 3% water contents, color parameters of other samples were significantly ($p < 0.05$) lower than that of the control. Since chocolates with fine particles appear lighter and more saturated, giving higher C^*, L^*, and *WI* values [20], it can be concluded that the texture tends to be coarser progressively, making the surface color appear darker when water content of compound chocolate exceeds 5% and more.

It is also clear from the Table 2 that in compound chocolates with the same amount of water content, all parameters fluctuated by increasing PGPR concentration; although the effect of PGPR content was insignificant ($p < 0.05$). Ostberg et al. (1995) claimed that the emulsifier concentration has a very strong influence on the stability of the emulsion; at low emulsifier levels, the emulsion destabilization is due to agglomeration of the water droplets while at high emulsifier levels, the emulsion is not stable as a result of the rapid coalescence [21]. So the fluctuations might be due to the fact that the inappropriate amount of PGPR causes the emulsion destabilization, the interaction of the hydrophilic surfaces of sugar crystals of chocolates with the pockets of water and dissolution of sugar in the water which, in turn, leads to the coarse texture and the lower L^* and C^* values [22]. Owing to the fact that L^* and *WI* values depend on the bloom surface area, they cannot absolutely be indicative of the particle sizes. Conversely, C^* value showed an upward trend with increasing PGPR content and accordingly it can be concluded that raising PGPR concentration had minimized the emulsion destabilization and sandy texture.

In the constant amount of PGPR (1.5 and 2.1%), all color parameters changed significantly ($p < 0.05$) with water content increasing. Figure 4 compares changes in chroma index as a function of water content. In both line graphs, C^* index decreases significantly with increasing water content. By increasing the water content up to 6%, the slope of the C^* index at chocolates with 2.1% PGPR was a slightly more rapid than that of 1.5%. This means that when water content in less than 6%, raising the PGPR concentration will aggravate the saturation. Furthermore, two lines have intersected at the point of 6% which signifies that when the moisture

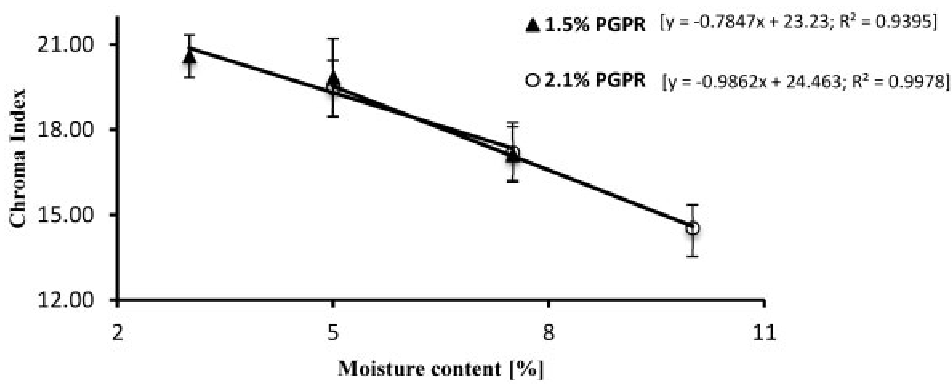

Figure 4. Comparing the effect of adding moisture content on the chroma index of milk chocolate at two constant values of PGPR.

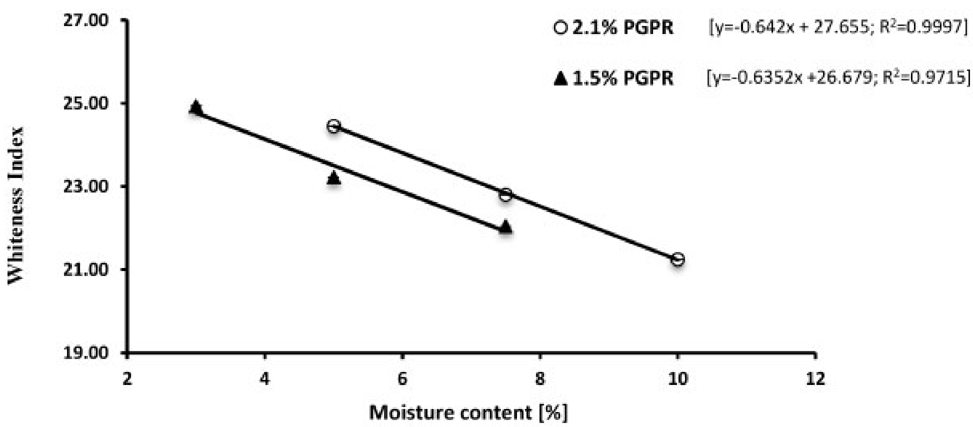

Figure 5. Comparing the effect of adding moisture content on the whiteness index of milk chocolate at two constant values of PGPR.

content is 6% or more, PGPR addition will not have any noticeable effect on C^* changes.

Lonchampt and Hartel (2006) enhanced the moisture content of milk chocolate up to 2% and proved that there is a linear correlation between water content and the whiteness value ($y = -8.12x + 52.5, r^2 = 0.93$). The higher the moisture content, the lower the final whiteness of the chocolate [23]. Similarly, water addition up to 10% caused the whiteness index of the same samples to decrease sharply (Fig. 5). This is owing to the fact that by increasing the water content, the chocolate medium becomes more dilute, so the reflection of light is less (low L^* value) and the surface appears darker. From the Fig. 5 it can also be concluded that specified increases in the amount of PGPR (from 1.5 to 2.1%) and water contents will lead to a slight increase in the slope of *WI*.

From ANOVA, hardness and appearance data were primarily dependent on the moisture and PGPR contents (Table 3) but the effect of PGPR was comparatively less significant ($p < 0.01$).

3.4 Relationship between surface whiteness and hardness

Afoakwa et al. [24], obtained the relationship between *WI* and hardness for under-tempered chocolate which is useful to

Table 3. ANOVA summary of *F* values of texture and color measurements

Process variables	Hardness	a^*	b^*	L^*	C^*	h°	*WI*
A: Moisture	522.12**	203.73**	167.47**	137.15**	195.02**	71.35**	102.35**
B: Emulsifier	5.63**	7.52**	6.31**	2.14**	7.1**	5.19**	2.42**

** Significant F-ratio at $p < 0.01$.

estimate the whiteness increasing rate during storage. Similarly, Eq. (5) represents that the linear relationship exists between whiteness index and relative hardness in water-containing compound milk chocolates:

$$\text{Whiteness} = 19.26 + 0.004 \times \text{Hardness}\,(R^2 = 88\%) \qquad (5)$$

By comparing Eq. (5) with Afoakwa's, it is readily confirmed and demonstrable that surface whiteness resulted from under-tempering has a more powerful effect on the hardness reduction than the whiteness arising from the water addition. Equation (5) also could be employed to estimate the sugar blooming in water-containing compound milk chocolates, leading to a greater perception of structure–appearance interrelationships during sugar blooming of water-containing compound milk chocolates and would be helpful for the further studies on the prevention of sugar bloom.

3.5 Sensory evaluation

The sensory properties evaluated by difference-from-control tests are shown in Table 4. As seen, water migration adversely influenced the appearance and integrity of some products after 30 days storage at ambient temperature. However, increasing water and PGPR contents up to 7.5 and 2.7%, respectively, has no significant negative impact on the color and glossiness attributes. Whereas, all samples with 10% moisture content showed noticeably more speckled color and less gloss than the control. This is due to the fact that emulsion-based chocolates exhibit poor stability (surfacing sugar bloom) [25]. In terms of sandiness, higher values represent a smoother texture. Apart from compound chocolates with 3% and two samples with 5% water contents (the ones with 1.5 and 1.8% PGPR), samples were felt to be equally as coarse as the control, showing that adding PGPR did not prevent sandiness. The ones with more than 5% water and 1.5% PGPR contents were perceived by the judges as significantly less hard than the control. Despite adding a great amount of PGPR in compound chocolate structure, off flavor was felt only in samples with 7.5 and 10% moisture contents saying that moisture content is a large contributor to off flavor than PGPR concentration.

Generally, while all samples were assessed moderate and good, the ones with 3% water content were indistinguishable from the control. Irrespective of the control, there were no meaningful differences within all chocolates of each category (i.e., the effect of increasing PGPR concentration was not meaningfully perceived by the panelists with respect to all sensory qualities ($p < 0.05$)). However, it can be concluded that the critical point for declining the quality

Table 4. Effect of PGPR and water addition on sensory characteristics of milk chocolate[a)]

Water content (%)	PGPR content (%)	Sensory attribuies					
		Color	Glossiness	Sandiness	Flavor	Hardness	Overall acceptability
3	0.3	$7.1^{abc.A}$	$6.7^{abcd,A}$	$6^{ab,A}$	$5.9^{ab,A}$	$6.5^{abc,A}$	$6^{ab,A}$
3	0.6	$7.35^{ab,A}$	$7.28^{ab,A}$	$6.15^{ab,A}$	$6.3^{ab,A}$	$7.75^{a,A}$	$6.1^{ab,A}$
3	0.9	$6.9^{abcd,A}$	$6.7^{abcd,A}$	$6.05^{ab,A}$	$5.9^{ab,A}$	$6.55^{abc,A}$	$5.9^{ab,A}$
3	1.2	$7.3^{ab,A}$	$6.9^{abc,A}$	$6.1^{ab,A}$	$6.15^{ab,A}$	$6.4^{abc,A}$	$6^{ab,A}$
3	1.5	$6.8^{abcd,A}$	$6.2^{abcde,A}$	$6.35^{ab,A}$	$5.85^{ab,A}$	$6.85^{ab,A}$	$5.75^{b,A}$
5	0.9	$6.3^{abed,A}$	$5.95^{abcde,A}$	$5.65^{b,A}$	$5.65^{ab,A}$	$6.2^{abc,A}$	$5.42^{b,A}$
5	1.2	$6.05^{abcde,A}$	$5.91^{abcde,A}$	$5.65^{b,A}$	$5.45^{ab,A}$	$6.55^{abc,A}$	$5.4^{b,A}$
5	1.5	$6.05^{abcde,A}$	$5.85^{abcde,A}$	$6.05^{ab,A}$	$5.3^{ab,A}$	$5.75^{bcd,A}$	$5.3^{b,A}$
5	1.8	$6.05^{abcde,A}$	$5.85^{abcde,A}$	$6.2^{ab,A}$	$5.4^{ab,A}$	$5.75^{bcd,A}$	$5.3^{b,A}$
5	2.1	$6.3^{abcd,A}$	$6.15^{abcde,A}$	$5.8^{b,A}$	$5.7^{ab,A}$	$5.95^{bcd,A}$	$5.55^{b,A}$
7.5	1.5	$5.75^{abcde,A}$	$5.7^{abcde,A}$	$5.4^{b,A}$	$5.1^{b,A}$	$5^{cd,A}$	$5.05^{b,A}$
7.5	1.8	$5.9^{abcde,A}$	$5.75^{abcde,A}$	$5.35^{b,A}$	$5.1^{b,A}$	$5.7^{bcd,A}$	$5.1^{b,A}$
7.5	2.1	$5.95^{abcde,A}$	$5.8^{abcde,A}$	$5.4^{b,A}$	$5.25^{ab,A}$	$5.6^{bcd,A}$	$5.29^{b,A}$
7.5	2.4	$5.95^{abcde,A}$	$5.8^{abcde,A}$	$5.2^{b,A}$	$5.1^{b,A}$	$5^{cd,A}$	$5.2^{b,A}$
7.5	2.7	$5.15^{cde,A}$	$4.7^{de,A}$	$5.6^{b,A}$	$4.9^{b,A}$	$5.1^{bcd,A}$	$4.8^{b,A}$
10	2.1	$5.3^{cde,A}$	$5.4^{bcde,A}$	$5.1^{b,A}$	$5.05^{b,A}$	$4.8^{cd,A}$	$4.95^{b,A}$
10	2.4	$4.15^{e,A}$	$4.5^{e,A}$	$5^{b,A}$	$4.6^{b,A}$	$4.3^{d,A}$	$4.7^{b,A}$
10	2.7	$5.2^{cde,A}$	$5^{cde,A}$	$5^{b,A}$	$5.05^{b,A}$	$4.3^{d,A}$	$4.9^{b,A}$
10	3	$5.65^{bcde,A}$	$5.55^{bcde,A}$	$5.15^{b,A}$	$5.1^{b,A}$	$4.8^{cd,A}$	$5^{b,A}$
10	3.3	$5.1^{de,A}$	$4.65^{de,A}$	$5.15^{b,A}$	$4.9^{b,A}$	$4.85^{cd,A}$	$4.7^{b,A}$
Control	0	7.69^{a}	7.84^{a}	7.95^{a}	7.32^{a}	7.84^{a}	7.79^{a}

[a)] Values expressed by median of three replications. Score 0 in the scale means "extremely bad" and score 5 means "moderate," and score 10 means "extremely good." Within a column, for each attribute, different lower-case letters denote significant differences from the control and different uppercase letters correspond significant differences between samples with the same water content ($p < 0.05$).

Table 5. Composition of the optimized emulsions and final chocolates

Primary water (%)	Emulsion PGPR (%)	Palm oil (%)	Final chocolate water content (%)	PGPR content (%)	Lecithin (%)	Palm oil (%)	Sugar (%)	Milk powder (%)	Cocoa powder (%)
17.2	10	72.8	3	1.5	0.7	31.9	45.6	12.8	4.5
30.5	10	59.5	5	1.5	0.7	31.2	44.7	12.5	4.4
47.2	18	34.8	7.5	2.7	0.7	29.2	43.5	12.2	4.2
63.8	22	14.2	10	3.3	0.7	27.7	42.3	11.9	4.1

of water- containing chocolates is 3% water content and 1.2% PGPR.

On the whole, analysis of values deduced from ANOVA and multiple mean comparisons as well as contrasting between C^* and L^* values shows that the optimal PGPR dosage which results in the least bloom surface area and the smoothest texture in final product are according to Table 5.

4 Conclusions

This study clearly identified the optimum combination dosage of water and PGPR in order to produce a water-containing milk chocolate which most resembles ordinary chocolate. It was concluded that the maximum percentages for adding water and PGPR which exactly resemble the control are 3 and 1.5%, respectively. Increasing water content up to 7.5 and 10% displayed negative significant effects on the all qualities. Since using the PGPR is restricted and using the mixture of different emulsifiers have exacerbating effect even in lower ratios, supplementary studies need to be done on the effect of using mixture of different emulsifiers with HLB less than 3.

The authors have declared no conflict of interest.

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