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ORIGINAL PAPER

Influence of Soft Cocoa Butter Equivalents on Color and Other Physical Attributes of Chocolate

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Abstract The physical characteristics and color of chocolate depend on the physical properties and crystallization behavior of the fat phase. In this study, the fat phase of chocolate samples contains cocoa butter from Ghana and soft cocoa butter equivalent (CBE). The laboratory-made chocolate samples were tempered at three different precrystallization temperatures (25, 27 and 29 °C), using three different concentrations of CBE (3, 5 and 7%), calculated as percentage of the chocolate. Physical characteristics of chocolate, namely thermoreographic parameters and solid fat content (SFC), were measured. The color of the chocolate was determined instrumentally, before and after thermocycle testing at 32/20 °C. It was found that CBE changed the melting properties of chocolate produced with cocoa butter from Ghana, which is of moderate hardness. It was determined that the optimum precrystallization temperature for chocolate mass with addition of CBE in the given conditions of measurement was 27 °C, the temperature that resulted in the best fat bloom resistance.

Keywords Chocolate · Cocoa butter equivalent (CBE) · Color · Fat blooming · Solid fat content (SFC)

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Introduction

The quality characteristics of chocolate such as gloss, snap, heat resistance, taste, texture and bloom resistance are predominantly influenced by the physical properties of cocoa butter. These properties are affected by the crystal structure of cocoa butter, specifically the size, number and type of crystals present in the cocoa butter [1].

To get an appropriate polymorphic crystal form in chocolate, the tempering phase is crucial, influencing the final quality characteristics such as color, hardness, handling, finish, and shelf life characteristics.

Fat crystallization behaviors during the tempering of chocolate play vital roles in defining the structure, mechanical properties and appearance of products. Wide variations in mechanical properties and appearance occurred in products with different particle size and temper regimes. Particle size is inversely related to texture and color, with the greatest effects noted on hardness, stickiness and lightness at all tempering regimes [2].

A well-tempered chocolate will have the following properties: good shape, color, gloss, contraction from the mold, better weight control, stable product hardness, more heat resistance (fewer finger marks during packaging) and longer shelf life [3].

Blooming causes whitening of both the surface and internal periphery of chocolate, with detrimental effects on texture and appearance. Hence, attainment of optimal temper during production of dark chocolate is vital for achieving the desired product texture and appearance. Both over-tempering and under-tempering result in quality defects affecting the mechanical properties and appearance of products [4].

In summary, fat bloom can be prevented by good control of temperature of chocolate (tempering), addition of foreign fat (through proper formulation), or a combination of both [5].

A substitute for cocoa butter must meet the following requirements: its melting behavior must be very similar to that of cocoa butter in order to achieve the same 'mouth feel' and, if cocoa butter is only substituted in part, the addition of the fat must not severely alter the crystallization and melting behavior of the cocoa butter [6].

Some vegetable fats are similar to cocoa butter in triglyceride composition and such cocoa butter equivalents (CBEs) can be added in any proportion to chocolate without having a significant effect on texture. Legally, such vegetable fats are permitted at levels up to 5% in the EU for a product to be sold as chocolate (Cocoa and Chocolate Products Regulations, 2003) [3, 7].

In this study, the addition of commercial CBEs of various characteristics in terms of hardness and their effect on the final product characteristics were mixed with cocoa butter from Ghana and the products examined. The research reported in this paper emphasizes the tempering phase, particularly the precrystallization temperatures employed for tempering.

The surface structure of chocolate is crucial in terms of the consumer's visual perception of chocolate quality. Food appearance is the result of a complex interaction of the incident light, its optical characteristics and human perception [8].

The objective of this study was to investigate the influence of a soft CBE on the color and physical properties of chocolate.

Materials and Methods

Materials

Chocolate mass was commercially produced and samples used in this study were taken at the end of conching process. The fat content of the chocolate mass was 34.55%.

Chocolate samples were prepared with chocolate mass and cocoa butter from Ghana, with and without addition of CBE, under laboratory conditions. Cocoa butter from Ghana is of moderate hardness; the soft CBE used was "Illexao 30-71", a commercial CBE produced by "Aarhus Olie" (Arhus Karlshamns, Sweden).

The melting point of the Ghana cocoa butter was 36.1 °C. and its solid fat content (SFC) was: 84.24% (20 °C), 76.23% (25 °C), 44.06% (30 °C) and 2.28% (35 °C).

The melting point range of Illexao 30-71 was 33–37 °C and the SFC range was: 71 ± 4%; $\sigma = 1.33$ (20 °C), 59.5 ± 3.5%; $\sigma = 1.17$ (25 °C), 40.5 ± 2.5%; $\sigma = 0.13$ (30 °C) and 4.0 ± 4%; $\sigma = 1.33$ (35 °C) [9].

The samples of chocolate mass were tempered at three different precrystallization temperatures (25, 27 and 29 °C) and three different quantities of CBE (3, 5 and 7%) were added, calculated as the percentage of the chocolate.

Methods

Preparation of Chocolate Mass Samples for the Precrystallization Process

The samples were prepared in a modified Brabender pharinograph laboratory crystallizer. The original kneader was connected to two ultrathermostats by means of two-way taps. This enabled immediate measurement of temperature changes in the kneader and within half a minute in the treated chocolate mass.

The process of precrystallization was controlled indirectly by the change of mass resistance during mixing, as registered on a force/time diagram or thermoreogram. The force was expressed as torque in N m. The torque value is a criterion for the viscous behavior of the chocolate mass and is dependent on the extent of crystallization in the chocolate mass [10].

Temperature–time regimes of certain process stages were modified as necessary to accommodate differences in cocoa butter and CBE concentrations.

The chipped chocolate sample mass was melted in laboratory glassware immersed in a 70 °C water bath. With occasional manual mixing, the mass melted within about 30 min, and was quantitatively transferred to a laboratory crystallizer. CBE was added to the chocolate mass in quantities of 10, 15 and 20% calculated on the total fat content (i.e., 3, 5 and 7% calculated as finished product). The total fat content of the chocolate mass increased from 34.55 to 39.13% in the samples with 20% added CBE. Fat levels in the reference samples and 10 and 15% CBE samples were adjusted to the same level by addition of cocoa butter.

Samples of chocolate without CBE added were prepared at each applied temperature of precrystallization and used as reference samples.

Tempering

The prepared and measured chocolate mass was poured into the laboratory crystallizer preheated to 55 °C, and tempered at this temperature for the first 30 min without mixing. The defined amount of CBE, as well as any cocoa butter required to correct for the total fat content of the chocolate mass was added, and tempering was continued for 30 min with agitation at the same temperature.

The laboratory crystallizer was connected to the ultrathermostat (25, 27 and 29 °C) and the chocolate was mixed until the thermoreographic curve maximum was achieved, plus 5 min.

The laboratory crystallizer was connected to the ultrathermostat with a water temperature of 35 °C. The chocolate mass was heated to this temperature, and after reaching a constant torque value, tempered for another 30 min to complete the process.

The examined precrystallized chocolate mass samples were molded into plastic forms 80 mm × 80 mm × 8 mm in size, previously heated to molding temperature (35 °C).

All molded samples were solidified by ultrathermostatically controlled cooling to 20 °C over 180 min (instead of the typical 18 °C over 120 min). These hardening conditions were employed because the usual conditions result in undesirable fat bloom when CBE is added. Laboratory samples of molded chocolate were wrapped in aluminum foil immediately after removal from the molds and kept in a thermostatic chamber at 20 °C for stabilization. The quality of the laboratory prepared samples was tested after 7 days of stabilization.

Analytical Methods for Evaluation of Laboratory-Made Chocolate Samples

Thermoreographic measurements involved measurement of the characteristic values of the thermoreographic curve: τ_1, nucleation time (min); τ_2, time to the achieving the torque maximum (min); M_o, initial torque (N m); M_o^{max}, torque maximum, (N m); M_o^{obl}, torque of precrystallization chocolate mass (N m) [10].

Solid fat content of chocolate was determined using a Bruker minispec 20 mq NMR apparatus in the Laboratory for Development, Industry of Oil and Vegetable Fats "Dijamant" A.D., Serbia [11, 12]. The SFC curves of chocolates with CBE added were compared to the SFC curves of reference chocolate samples. These resulted in one diagram of SFC profiles of chocolate samples with and without CBE tempered at the same precrystallization temperature (25, 27 and 29 °C). Samples of chocolate were carefully cut into small pieces, placed in a test tube and compressed with a stick to the working height of 1 cm. Tubes were kept in an ice water bath for 90 min and then 10 min on the first temper measurement temperature (10 °C). After that, the liquid signal was measured using the pulse NMR technique. The same procedure was repeated at all temperatures (20, 25, 27.5, 30, 32.5, 35, 40 °C) to read the SFC. The liquid signal of soybean oil was also read in parallel, tempered at 60 °C as a standard. The SFC of chocolate was calculated as the difference of the liquid signal of the chocolate sample and soybean oil. SFC values of chocolate samples, on which the SFC curves were generated, represent the average of four measurements [13].

Bloom testing (thermo-cycle test 32/20 °C) was performed by a thermal treatment designed to cause rapid graying. Chocolate samples were alternately heated to 32 °C for 12 h, and then cooled at 20 °C for 12 h [14]. One cycle lasted for 24 h. The duration (i.e., the number of cycles) of the thermo-cycle test was defined at 30, based on previous experience.

Loss of gloss was visually evaluated after each cycle during the thermo-cycle test 32/20 °C.

Color measurement (lightness of the surface, total color difference and curves of relative reflectance) were performed according to CIE, CIELab and Hunter systems, using a tri-stimulus photoelectric colorimeter MOM Colour 100, with software for calculations in all mentioned systems. The principle of color determination with this equipment is the additive mixing of colors (red, green and blue). Prior to measurement, the equipment is adjusted with an appropriate white standard or by using a standard of the most similar color to the object to be investigated. In this case, the white standard was used, according to regulation. After reading values X_1, X_2, Y and Z, the values x and y were calculated, and based on diagrams of chromatography, the dominant wavelengths and color pureness were determined. The Y value directly represents the criterion for average reflectance, or brilliance, of the object [15, 16].

Curves of relative reflectance were recorded using a MOM Colour 100 as a spectrophotometer. Applying 16 filters for 16 wavelengths ranging from 400 to 775 nm and a distance of 25 mm, reflectance curves for specific appearance and color were developed. Characteristic maximum reflectances were discussed in correlation with visual impression on investigated chocolate samples. The possibility of definition of value limits for relative reflectance (r) at wavelengths 550, 600, 700 and 775 nm as indication of chocolate blooming was also investigated [17].

The whiteness Index (WI) was calculated according to Eq. (1) [18, 19]:

$$\mathrm{WI} = 100 - \left[(100 - L^*)^2 + a^{*2} + b^{*2}\right]^{1/2} \tag{1}$$

The whiteness index is useful to quantify changes in texture properties between samples of CBE and chocolate [20, 21]. WI measures the kinetics of color change on the surface of chocolate caused by fat migration from the interior, which leads to certain changes in the structure and texture of the product [14, 22–24].

Statistical Treatment

In the statistical analysis, regarding the multiple linear regression—linear parameters, it is common to use the models which include the polynomials of the explanatory variables up to the second degree [25, 26].

Therefore, the linear regression equation was obtained by using the full quadratic model Eq. (2):

$$z = B_0 + B_1 c + B_2 t + B_3 c^2 + B_4 ct + B_5 t^2 \quad (2)$$

where B_0, … , B_5 are polynomial regression coefficients. The explanatory variables are: c concentration of CBE, t temperature of precrystallization of the chocolate mass. The response variable is: z characteristic values of the thermoreogram and color parameters.

In CIE, CIELab and Hunter systems, results were determined as the mean values of three measurements. The significance of the differences between the results obtained was analyzed by the Analysis of Variance (ANOVA) and Tukey Test.

For all calculations, statistical software Statistica 8.0 (Statsoft, Tulsa, USA) was used.

Results and Discussion

Thermoreographic Measurement

This paper presents the results of statistical analysis for those parameters of thermoreographic measurement with values dependent on the temperature of precrystallization or applied concentration of CBE.

The Value of Nucleation Time (τ_1) of the Chocolate Mass

Our first intention was to optimize the influence of precrystallization temperature and concentration of CBE on nucleation time. Therefore, we started from a common full quadratic statistical model.

The dependence of nucleation time of the chocolate mass (τ_1) on the concentration of CBE and on precrystallization temperature is described by the regression Eq. (3):

$$\tau_1 = 2365.375 + 8.597c - 206.585t + 0.281c^2 - 0.444ct + 4.563t^2 \quad (3)$$

where is τ_1 nucleation time, t precrystallization temperature, c concentration of CBE.

The high value of coefficient of determination (0.987) as well as the adjusted coefficient of determination (0.976) showed good acceptability of fit relative to Eq. (3). The coefficient of determination tends to an increase with the number of regression coefficients in linear regression. Regarding the high numbers of regression coefficients (6) to the number of data points (9), we should not rely only on the determination coefficients. Therefore, one should be careful when the number of regression coefficients are close to the number of data points. In such cases, the coefficients of determination with high value (close to unity) may not sufficiently explain the goodness of fit. However, we just noted this fact and extended the analysis on the confidence intervals of the regression coefficients, which is more important in this case. We used the approach of starting from the full quadratic model, investigating the significance of the regression coefficients, and rejecting the nonsignificant ones. This equation used the variables in their original units. Therefore, the confidence intervals for regression coefficients were investigated. However, statistical analysis of the main temperature effect (t value = 0.050) as well as the quadratic effect (t value = 0.026) indicated that we could accept a 95% confidence interval for the temperature effect. Contrarily, based on the t values (>0.05), and 95% confidence interval of the CBE concentration effect, the interaction of temperature and concentration (which includes zero) showed that we could reject the effect of CBE concentration on nucleation time. The same conclusion could be obtained by simple linear regression—nucleation time dependence on temperature, nucleation time dependence on CBE concentration.

It can be concluded that lowering the temperature of precrystallization shortens the time needed to start nucleation.

Figure 1 shows the influence of CBE concentration and precrystallization temperature on nucleation time.

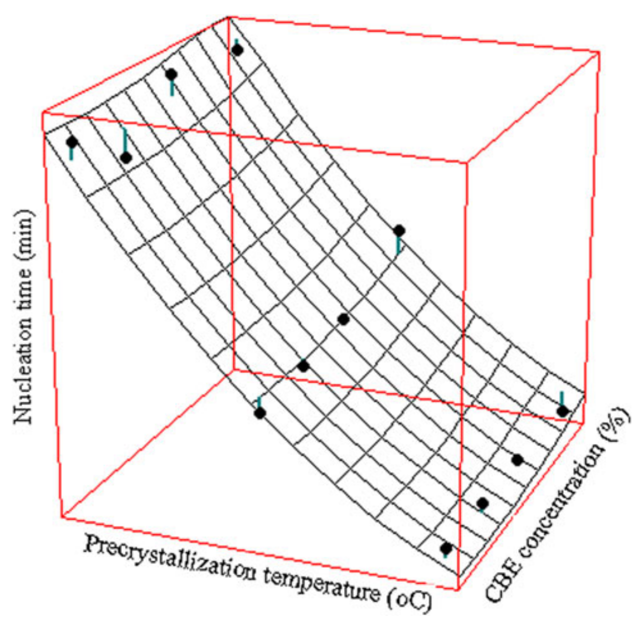

Fig. 1 Influence of precrystallization temperatures and concentration of CBE on nucleation time (τ1)

The Value of Maximum Torque (M_o^{max}) of the Chocolate Mass

The dependence of maximum torque of the chocolate mass (M_o^{max}) on CBE concentration and precrystallization temperature is described by the regression Eq. (4):

$$M_0^{max} = 606.16 - 27.734c + 6.609t + 0.453c^2 + 0.771ct - 0.813t^2 \quad (4)$$

where is M_o^{max} Torque maximum, t precrystallization temperature, c concentration of CBE see Fig. 2.

A high coefficient of determination value (0.984) as well as an adjusted coefficient of determination (0.970) showed a well-accepted goodness of fit relative to Eq. (4). Similarly, we should not accept those high values of determination coefficients without further examination of particular regression coefficients in Eq. (3). Therefore, the confidence intervals for regression coefficients were investigated. However, 95% confidence intervals showed that we should reject this quadratic equation because the confidence intervals of all regression coefficients include zero. If the coefficient is not significant, then the influence of a particular explanatory variable is also not statistically significant, despite a good fit of the experimental data with the regression equation. Therefore, we should reject the simultaneous influence of temperature and CBE concentration on the maximum torque. A separate influence based on a simple linear regression showed high correlation between temperature and torque maximum ($R^2 = 0.949$, adj. $R^2 = 0.944$) and very high negative correlation (95% confidence interval for slope is −40.004, −28.746). On the contrary, there is no correlation between CBE concentration and maximum torque (R^2 and adj. R^2 are close to zero).

Figure 2 shows that the increase of temperature reduces the value of the precrystallization maximum torque.

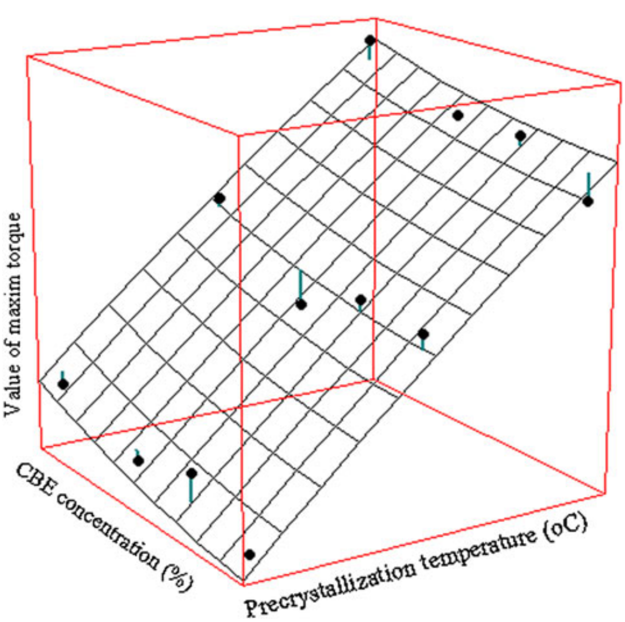

Fig. 2 Influence of precrystallization temperatures and concentration of CBE on torque maximum (M_o^{max})

Solid Fat Content

Error bars were within symbol size (not represented in Fig. 3) because the standard deviations of the replicated measurements were low.

The SFC of CBE Illexao 30-71 is lower than the cocoa butter SFC, except for the temperature range from 35 to 40 °C [27].

The study of SFC makes it easier to use different fats in the production process, and thus, the SFC profile is very useful information for predicting physical and textural properties of the final product and for prediction of its behavior during storage and transport [27]. Textural properties include consistency, spreadability and viscosity of molten chocolate and hardness (SFC) of final product [28].

By definition, CBEs are absolutely chemically equivalent to and compatible with cocoa butter. However, since they are intended for specific purposes in combination with cocoa butters of different qualities in production of different types of chocolates and chocolate-related products, it is to be expected that their presence will change the standard physical properties of these products.

With the increase of CBE content, the curves of investigated chocolates tempered at all three precrystallization temperatures showed completely different behaviors. During precrystallization at 25 °C, SFC curves were actually identical almost within the completely measured temperature range. At a precrystallization temperature of 27 °C, the added CBE reduced the SFC in all applied concentrations compared to reference chocolate. At a precrystallization temperature of 29 °C, the added CBE showed a certain illogical effect, since in the temperature range 10–27.5 °C the SFC profiles with 3 and 7% CBE were identical, and at the same time they showed lower values than SFC profiles of chocolate without added CBE and chocolates with 3% added CBE. In general, the lowest SFC values within the whole temperature range were for the chocolate tempered at 27 °C with 7% CBE.

The addition of CBE Illexao 30-71 at different concentrations and temperatures reduces the SFC of chocolate mass in relation to a reference chocolate (except in the temperature range 35–40 °C). These results are fully expected considering the given characteristics of lower SFC in comparison to cocoa butter from Ghana [9].

It is important to emphasize that the chocolate samples without addition and with addition of 3 and 5% CBE, tempered at 27 °C had higher SFC values compared to

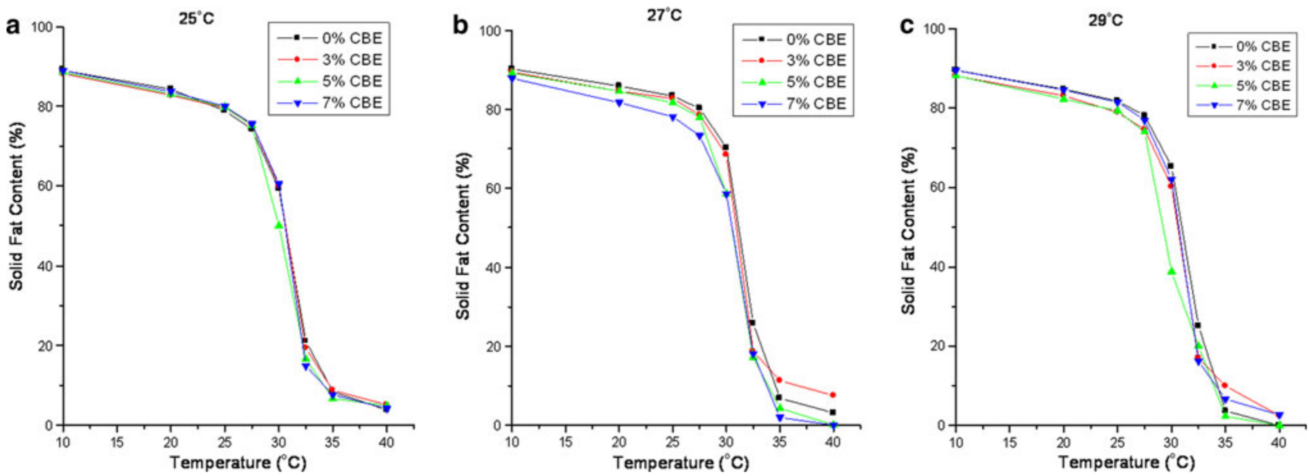

Fig. 3 SFC curves of chocolates with and without soft CBE at precrystallization temperatures of 25, 27 and 29 °C (error bars were within the symbol size)

other investigated samples. In addition, the chocolate sample tempered at 27 °C with 7% CBE added showed the highest SFC values compared to the other samples with the same quantity of CBE added.

Chocolate Shelf-Life Determination: Resistance to Blooming

Beside the color changes, the surface gloss of chocolate was also significant because it was determined that the temperature of precrystallization has a much greater impact on surface gloss than on the color [29].

Dynamics of changes in color and gloss of chocolate samples in dependence on the CBE concentration and precrystallization temperatures are presented in Fig. 4.

The total number of cycles until loss of surface gloss, i.e., blooming, or resistance to blooming, depended primarily on the applied tempering regime, and the dynamics of the surface blooming varied among investigated samples. However, after losing gloss in samples tempered at 25 °C and 27 °C with added CBE in all applied concentrations, greyish discoloration and its increase could not be visually determined even after 30 cycles. In chocolate samples tempered at 29 °C, visible signs of blooming appeared after the 15th. i.e., the 16th cycle.

It is assumed that the mixed crystal forms of investigated CBE and cocoa butter changed the physical properties, and their recrystallization during bloom testing when new forms of polymorphs developed, could not be visually observed.

Surface Color Lightness

In Table 1a, b the values of surface color for lightness by Hunter (L_{Hu}) before and after thermo-cycle test 32/20 °C of

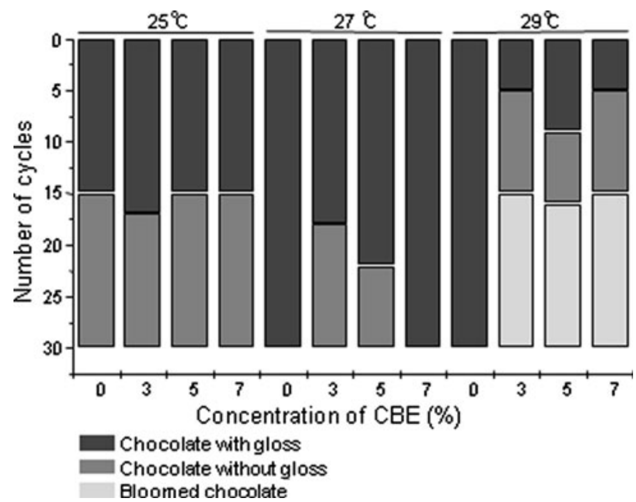

Fig. 4 Blooming intensity during the thermo-cycle test

chocolate samples are presented relative to dependence on CBE concentrations and precrystallization temperature.

The results of the color lightness of chocolate samples after the thermo-cycle test 32/20 °C showed that the color lightness increased in relation to CBE concentration. Therefore, with precrystallization chocolate mass at 25 °C, color lightness increased with higher CBE concentrations before and after the thermo-cycle test, whereas with precrystallization at 27 and 29 °C the lowest values for color lightness on chocolate surface were for the reference samples. The addition of CBE and successive increases in its concentration in chocolate samples caused increased color lightness values in comparison to the reference sample, but did not differ from each other.

The difference between L_{Hu} values before and after thermo-cycle testing showed the most uniform values

Table 1 Results of color measurement in CIE, CIELab and Hunter systems before and after thermo-cycle test are presented in dependence on CBE concentration and precrystallization temperature

	Precrystallization temperature											
	25 °C				27 °C				29 °C			
Concentration of CBE	0%	3%	5%	7%	0%	3%	5%	7%	0%	3%	5%	7%
(a) Before thermo-cycle test												
CIELAB system												
a^*	17.42^{j}	10.97^{e}	10.91^{d}	10.46^{b}	12.07^{i}	10.71^{c}	11.57^{h}	9.54^{a}	10.69^{c}	11.23^{g}	11.17^{f}	11.54^{h}
b^*	7.29^{a}	10.90^{a}	10.76^{a}	10.14^{a}	10.76^{a}	11.39^{a}	1.91^{a}	11.99^{a}	10.77^{a}	11.25^{a}	10.99^{a}	10.56^{a}
L^*	23.70^{a}	24.63^{b}	25.07^{c}	26.50^{e}	26.93^{h}	26.73^{g}	26.27^{d}	27.54^{i}	26.50^{e}	26.27^{d}	27.51^{i}	26.62^{f}
ΔE^*_{ab}	71.38^{e}	69.48^{d}	69.02^{d}	67.46^{bc}	67.44^{bc}	67.47^{bc}	68.16^{c}	66.58^{bc}	67.59^{c}	67.99^{c}	66.73^{ab}	67.61^{c}
ΔC^*_{ab}	17.36^{i}	13.94^{d}	13.81^{c}	13.05^{a}	14.65^{g}	14.12^{e}	15.09^{h}	13.80^{c}	13.65^{b}	14.38^{f}	14.16^{e}	14.13^{e}
ΔL^*_{ab}	−68.55^{a}	−67.61^{b}	−67.18^{c}	−65.75^{e}	−65.32^{h}	−65.52^{g}	−65.98^{d}	−64.71^{i}	−65.75^{e}	−65.98^{d}	−64.73^{i}	−65.63^{f}
ΔH^*_{ab}	9.70^{i}	7.83^{d}	7.81^{d}	7.64^{b}	8.16^{h}	7.78^{d}	8.06^{g}	7.45^{a}	7.74^{c}	7.93^{e}	7.90^{e}	7.99^{f}
CIE-system												
λ (nm)	620.0^{b}	593.0^{a}	594.0^{a}	594.0^{a}	594.5^{a}	593.5^{a}	594.0^{a}	591.0^{a}	593.0^{a}	593.0^{a}	594.0^{a}	594.5^{a}
θ	22.71^{a}	44.82^{f}	44.60^{e}	44.11^{d}	41.72^{b}	46.76^{j}	45.83^{i}	51.49^{k}	45.21^{h}	45.05^{g}	44.53^{e}	42.46^{c}
Hunter-system												
L_{Hu}	20.02^{a}	20.73^{b}	21.07^{c}	22.18^{e}	22.51^{h}	22.36^{g}	22.00^{d}	23.00^{i}	22.18^{e}	22.00^{d}	22.97^{i}	22.27^{f}
(b) After thermo-cycle test												
CIELab system												
a^*	9.70^{b}	10.46^{h}	9.74^{bc}	9.28^{a}	10.39^{g}	9.72^{bc}	10.04^{d}	9.77^{c}	10.23^{f}	11.33^{i}	10.48^{h}	10.11^{e}
b^*	9.87^{c}	9.64^{a}	10.35^{g}	9.78^{b}	10.19^{f}	10.07^{e}	9.95^{d}	10.39^{g}	10.05^{e}	10.90^{i}	10.70^{h}	9.75^{b}
L^*	32.98^{c}	30.27^{a}	34.29^{h}	36.00^{j}	33.54^{d}	34.08^{g}	33.83^{ef}	34.47^{i}	31.55^{b}	34.23^{h}	33.79^{e}	33.87^{f}
ΔE^*_{ab}	60.98^{i}	63.72^{k}	59.79^{c}	57.96^{a}	60.62^{h}	59.95^{d}	60.23^{f}	59.63^{b}	62.50^{j}	60.26^{f}	60.48^{g}	60.17^{e}
ΔC^*_{ab}	12.32^{b}	12.71^{fg}	12.69^{f}	11.97^{a}	13.03^{i}	12.47^{c}	12.62^{e}	12.75^{g}	12.82^{h}	14.20^{k}	13.46^{j}	12.53^{d}
ΔL^*_{ab}	−59.27^{c}	−61.97^{a}	−57.96^{i}	−56.25^{k}	−58.71^{d}	−58.16^{g}	−58.41^{ef}	−57.77^{j}	−60.70^{b}	−58.02^{h}	−58.46^{e}	−58.37^{f}
ΔH^*_{ab}	7.38^{b}	7.61^{e}	7.42^{b}	7.23^{a}	7.61^{e}	7.39^{b}	7.49^{c}	7.43^{b}	7.56^{de}	7.94^{g}	7.67^{f}	7.51^{cd}
CIE-system												
λ (nm)	593.0^{a}	593.5^{ab}	591.0^{a}	591.0^{a}	594.0^{ab}	593.0^{a}	594.0^{ab}	593.0^{a}	594.0^{ab}	594.0^{ab}	593.0^{a}	599.0^{b}
θ	45.50^{f}	42.66^{a}	46.74^{j}	46.50^{i}	44.44^{d}	46.01^{h}	44.74^{e}	46.76^{j}	44.49^{d}	43.89^{b}	45.60^{g}	43.96^{c}
Hunter-system												
L_{Hu}	27.44^{c}	25.19^{a}	28.54^{h}	30.01^{j}	27.91^{d}	28.37^{g}	28.16^{ef}	28.70^{i}	26.24^{b}	28.49^{h}	28.12^{e}	28.19^{f}

Values are means of three determinations

Values of the same row with the same superscript are not statistically different ($P < 0.05$)

CIELab system: a^*, Presence of red; b^*, Presence of yellow; L^*, Lightness; ΔE^*_{ab} , Total color difference; ΔC^*_{ab}, Color fullness; ΔL^*_{ab}, Total lightness difference; ΔH^*_{ab}, Total tonality difference; CIE system: λ, dominant view length; θ, color pureness; Hunter-system: L_{Hu} Lightness compared with each other and in relation to reference chocolate sample precrystallized at 27 °C.

Surface Color

In Table 1 the results of color measurement in CIE and CIELab systems before and after thermo-cycle testing are presented in dependence on CBE concentration and precrystallization temperature.

Before thermo-cycle testing, the characteristics of reference chocolate samples without CBE showed that the red tone decreased with increasing precrystallization temperature, while the yellow tone was the same at temperatures of 27 and 29 °C, and at the same time, was higher in comparison to the sample precrystallized at 25 °C. With the increase of CBE concentration in chocolate samples tempered at 25 °C, the red tone portion had decreased to a greater extent than at the other two temperatures. Yellow tone was decreased with higher CBE concentration at 25 °C, increased at 27 and at 29 °C, was hardly changed. The reference chocolate sample tempered at 25 °C was in the red part and all other samples were in the orange part of the spectrum. The values of total impression on color indicated that all chocolate samples precrystallized at 25 °C were more colored in relation to all other samples, which were similar to each other relative to surface lightness.

After thermo-cycle testing, all samples became brighter and less glossy, and were quite similar to each other in the ratio of red and yellow tones; they were all in the orange part of spectrum. Loss of gloss lessened in a linear fashion as CBE concentration increased, but only at a precrystallization temperature of 25 °C. For the samples with added CBE and tempered at 27 and 29 °C, similar values for lightness were obtained but in both cases were more opaque in relation to the reference sample.

Curves of Relative Reflectance

Figure 5a, b presents a reflectance model system consisting of two reflectance curves for totally bloomed commercial chocolate samples with different composition from two manufacturers. Commercial samples of chocolate were spontaneously bloomed due to changes in temperature caused by uncontrolled storage conditions. These samples were taken for reference to indicate the change in the color of chocolate caused by poor storage. Instrumentally measured curves of reflectance of these samples were compared with recorded curves of relative reflectance obtained for laboratory samples of chocolate with the addition of CBE.

In both commercially chocolate samples (a and b), the characteristic expressed peaks at wavelengths (λ) 550 and 600 nm in chromatic and at 700 and 775 nm in achromatic part of spectrum are obvious.

The chocolate sample with 3% CBE tempered at 25 °C (Fig. 5c) lost gloss after 17 cycles and did not bloom within 30 cycles, while the sample with 7% CBE tempered at 29 °C (Fig. 5d) showed loss of gloss after only 5 cycles blooming after 16 cycles.

Laboratory chocolate samples with no signs of blooming (Fig. 5c) showed significantly lower peak values at the characteristic wavelengths in chromatic and achromatic parts of spectrum in relation to the same parameters of reflectance curves obtained for totally whitish commercial samples of manufacturers (Fig. 5a) and (Fig. 5b), and for bloomed chocolate samples (Fig. 5d).

Thus, it can be concluded that the reflectance curves obtained can be a criterion for color quality and surface appearance estimation based on value *r*(%) in the chromatic part of spectrum. Since the curves were recorded in samples before the thermo-cycle test, it is obvious that it is possible to predict the appearance of blooming sooner in chocolates with higher *r*(%) values in comparison to chocolates with lower *r*(%) values in the achromatic part of the spectrum at wavelengths 700 and 775 nm. Paleness is the consequence of changes in chocolate structure [30–32], so the *r*(%) values at the mentioned wavelengths can serve as an indicator of the degree of resistance to fat bloom.

Total Color Difference of Chocolate (ΔE^*ab)

In Table 2 the measured values ΔE^*ab of laboratory-made chocolate samples with the addition of CBE are given in relation to a reference chocolate sample before and after thermo-cycle testing. The range of ΔE^*ab values refers to the portion of 3–7% CBE.

In comparison to reference chocolate without CBE, the values ΔE^*ab measured in samples tempered at 25 and 27 °C were perceptibly different before thermo-cycle testing than after the test. Considering the fact, that the human eye is able to notice only greater differences in color; such difference was observed only in samples precrystallized at 29 °C when compared to degree of differences of color before blooming.

Values of ΔE^*ab measured after thermo-cycle testing were in accordance with the visual estimation of loss of gloss and blooming occurrence during the thermo-cycle test 32/20 °C, namely the fastest gloss loss was noticed in chocolate samples tempered at 29 °C which had the highest ΔE^*ab values. Blooming was also observed only in samples precrystallized at this temperature. In samples tempered at 27 °C gloss loss occurred more slowly, and ΔE^*ab values measured after thermo-cycle testing were at their lowest.

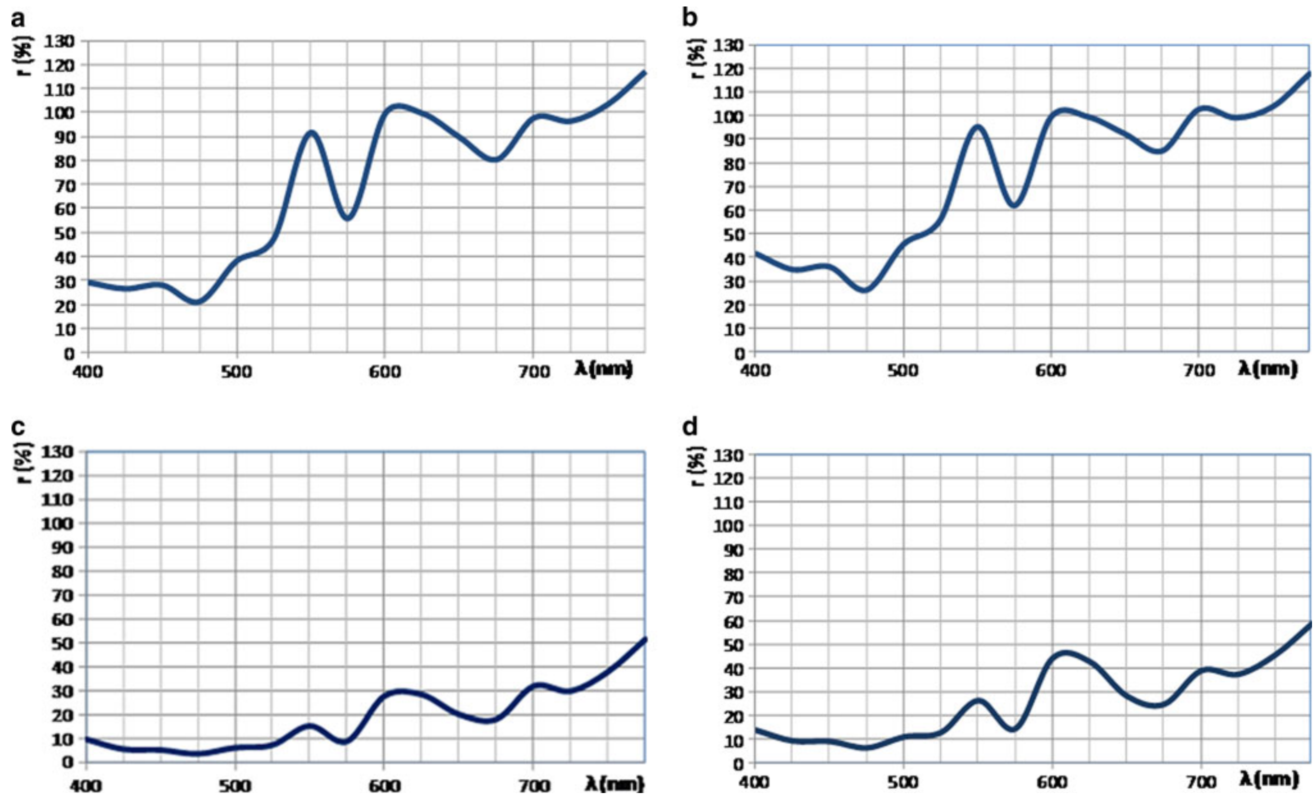

Fig. 5 Reflectance curves of bloomed commercial chocolates (**a, b**) and reflectance curves of investigated laboratory chocolate samples (**c, d**)

Table 2 Measured Δ*E*ab* values obtained for chocolate with CBE in relation to reference starting chocolate sample before and after thermo-cycle test

Precrystallization temperature (°C)	Before thermo-cycle test		After thermo-cycle test	
	Δ*E*ab*	Eye perception	Δ*E*ab*	Eye perception
25	7.44–8.20	Able to distinguish precisely	1.39–3.04	Able to notice
27	1.40–2.87	Able to notice	0.51–1.13	Almost able to notice
29	0.76–1.14	Almost able to notice	2.34–3.01	Able to notice

Δ*E*ab* Total color difference

In contrast, values Δ*E*ab* of chocolate samples tempered at 25 °C measured after thermo-cycle testing were in disagreement with visual estimation concerning the gloss losing which could be explained by possibly opposite dependencies between these parameters in samples tempered potentially named inappropriate (25 °C) and potentially appropriate tempering conditions (27 °C that is 29 °C).

Based on the results obtained of determinations of WI values and average differences, it can be assumed that the greatest changes in crystal structure occur during thermo-cycle testing in chocolate samples precrystallized at 25 °C and the least in samples precrystallized at 29 °C (Table 3). When discussed as it is usually done, these results are in contrast to values obtained by thermo-cycle testing and measurements of lightness and total impression of color. If the results are considered a result of the altered structural properties of compound crystals of cocoa butter and CBE, the greatest change in structure regarding the highest compatibility of crystals of two fats seems to occur at 25 °C, while the lowest compatibility occurred at 29 °C. It is postulated that the interaction of crystals of different origins was insufficient, which resulted in a somewhat looser crystal structure causing the unincorporated crystals to migrate towards the surface of the chocolate during the thermo-cycle test. These crystals triggered the occurrence of blooming as determined by both subjective and objective evaluation.

Table 3 WI values for chocolate surface by CIELAB system before and after thermo-cycle test

	Precrystallization temperatures											
	25 °C				27 °C				29 °C			
CBE Illexao 30-71 concentration	0%	3%	5%	7%	0%	3%	5%	7%	0%	3%	5%	7%
WI												
Before thermo-cycle test	21.40[a]	23.06[b]	23.52[c]	25.07[g]	25.16[h]	25.08[g]	24.42[d]	25.94[j]	24.95[f]	24.58[e]	25.84[i]	24.97[f]
After thermo-cycle test	31.57[c]	28.83[a]	32.77[h]	34.60[j]	31.97[d]	32.61[g]	32.34[f]	32.94[i]	30.06[b]	32.38[f]	32.12[e]	32.39[f]
Difference	10.17	5.77	9.25	9.53	6.80	7.53	7.91	7.00	5.11	7.80	6.28	7.42
Average difference	8.68				7.31				6.65			
Average difference[A]	8.18				7.48				7.17			

Values are means of three determinations

Values of the same row with the same superscript are not statistically different ($P < 0.05$)

WI Whiteness index

[A] Control (reference) sample not included

Conclusions

The addition of different levels of the investigated soft CBE and application of different precrystallization temperatures caused differences in various physical properties of chocolate.

The precrystallization temperature exhibited a dominant influence on the values of most of the measured physical parameters.

The amount of added CBE, due to the subsequent changes in physical properties of chocolate, affected the visual properties of the studied samples such as the number of cycles of thermo-cycle test and the gloss loss of the chocolate surface.

Recorded curves of reflectance in fresh chocolate samples that had higher values of relative reflectance in the achromatic part of the spectrum (700 and 775 nm) predicted the appearance of blooming sooner than in chocolate samples with lower values of relative reflectance in the same part of the spectrum.

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