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THE EFFECT OF STORAGE TEMPERATURE ON THE QUALITY AND FORMATION OF BLOOMING DEFECTS IN CHOCOLATE CONFECTIONERY

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ABSTRACT

The study aimed at assessing changes in the quality of certain types of chocolate products over the storage period with particular focus on the formation and development of fat and sugar bloom in chocolate products. Seven products were selected in collaboration with a chocolate factory to undergo monitoring and analysis and stored at four temperature regimens (6 °C, 12 °C, 20 °C and 30 °C). Five samplings were carried out over the storing period (18 weeks) for evaluation of the dynamics of changes in their quality. Each sampling was accompanied by sensory evaluation; selected physical attributes were also analysed: changes in colour (ΔE*ab) within the CIE (L*a*b) system and changes in hardness using the TIRAtest 27025. The results showed a significant effect of storing temperature on the intensity of changes in the quality of products. The results of sensory evaluation of selected products showed that the highest quality for the majority of descriptors was achieved by products stored at temperatures of 6 °C and 12 °C. As regards samples stored under the temperature regimen of 20 °C, the products started to show visible differences, caused primarily by the formation of fat bloom while storing at 30 °C proved to be extremely unsuitable for all the tested products. Since storing temperatures of 6, 12 and 20 °C did not considerably affect hardness and colour of each product, no distinct changes occurred under such temperature regimens. From the aspect of analytical measurements of colour and hardness of each product, storing at temperatures of 20 °C can be termed appropriate. In all the analyses, the effect of the temperature regimen of 30 °C was significantly negative due to defects caused by blooms on the chocolate, meaning that such temperatures are not advisable for storing chocolate products, even over a short term.

Keywords: chocolate; storage temperature; blooming; colour; hardness

INTRODUCTION

In chocolate, durability is dependent on several parameters including storing temperature and humidity, availability of oxygen in the immediate surroundings, which is directly related to the use of packaging materials; it also relates to additions of other ingredients such as fats, nuts etc. **(Nattress et al., 2004)**. Typically, there are two basic types of defects found on chocolate - fat bloom and sugar bloom, with the material losing its gloss and becoming covered with a fine whitish layer **(Afoakwa, 2010)**.

Sugar bloom is a less frequent phenomenon. Often it is also confused with fat bloom. The difference can be seen under a microscope or, quite simply, when heating the chocolate to 38 °C. While fat bloom disappears at such temperature, sugar bloom remains visible. Sugar bloom occurs when the temperature over the surface of the chocolate product drops below the dew point **(Čopíková, 1999)**. The causes for it are two: (1) storing the product at high humidity, or (2) rapid relocation of the product from a room with low temperature into one where temperature is high **(Afoakwa, 2010)**. As a result, the formation of sugar bloom can be in particular avoided by proper storing settings and by elimination of potential condensation of water vapour on the surface of the product **(Rašper, 1963)**.

As regards the development of fat bloom, there are two key groups of theories: a polymorphic transformation and phase separation **(McCarthy et al., 2003)**. The polymorphic transformation theory is based on the formation of fat bloom through the mechanism of transformation of thermodynamically unstable βV crystals of cocoa butter into polymorph modification VI **(Beckett, 2008; Nöbel et al., 2009)**. During the durability, Form V is naturally transformed into a more stable Form VI, which leads to the formation of fat bloom, i.e., aging occur. The process is greatly influenced by storing temperature **(Afoakwa et al., 2009; Beckett, 2008)**.

The theory of phase separation leading to the formation of fat bloom is based on triacylglycerols with different melting points found in fats used in chocolate products. Elevated temperatures may cause triacylglycerols with lower melting points to be pushed toward the surface and recrystallise **(Bui and Coad, 2014)**. Particularly prone to this phenomenon is filled chocolate confectionery, where the filling contains a large amount of highly mobile triacylglycerols (TAGs). Fats from the filling migrate through the shell towards the surface, where they can cause uncontrolled crystallisation, thus forming fat bloom. Other quality defects associated with the migration of fat are shell softening, filling hardening, and the overall sensory deterioration of the product **(Svanberg et al., 2011)**.

Fat blooming occurs namely due to improper storage of chocolate. When optimally tempered products are stored at high temperatures or exposed to direct sunlight, the chocolate dissolves and during the recrystallisation, in the absence of inoculation ensuring a direct formation of the stable form V, the gradual transformation of an unstable form into a stable form leads to fat bloom to develop **(Afoakwa, 2010)**.

Examples of fat that inhibits fat blooming include milk fat. Partial replacement of cocoa butter with milk fat has a beneficial effect on fat crystallisation in chocolate, the fact that it increases the resistance to blooming and significantly softens the texture by reducing the solid fat content, thus slowing down the rate of crystallisation, being the grounds for this **(Sonwai and Rousseau, 2010)**. Resistance of milk chocolate to fat bloom is however only minor in the current production, as the level of milk fat and its inhibitory effect is negligible due to the use of skimmed milk powder **(Bui and Coad, 2014)**.

The study aimed at evaluating changes in the quality of chocolate products over the period of storing them under four separate thermal regimens, thus assessing the influence and advisability of the storing temperatures for product storage.

MATERIAL AND METHODOLOGY

Materials

Seven products provided by Zora Olomouc were tested for the influence of storing temperature and the composition of chocolate mass of the product on the formation of fat/sugar bloom. The selection involved the following products:

- *Kaštany ledové* - a dark chocolate with a filling of cocoa and nuts (53%);
- *Milena* - a 50% milk chocolate with a 50% creamy filling containing a rum flavour;
- *Margot Artemis* - a double-layer soy-stick with a 37.5% coconut flavour and a 37.5% punch flavour**,** soaked in 25% milk chocolate;
- *Orion Krémová oříšková* - a milk chocolate with a hazel-nut filling;
- *BOCI fekete erdö* - a dark chocolate with a cherry filling;
- *Black magic - Orange sensation* - a soft, tangy orange fondant draped in dark chocolate;
- *Orion Pistácie* - a milk chocolate with a 28% pistachio-nut and 36% hazel-nut filling, containing pieces of pistachio nuts (1.5%).

All the samples of chocolate products were produced using a standard process with the use of conventional chocolate mass tempering. *Orion Pistácie* was produced in two variants: (i) standard chocolate mass content (35%) and (ii) higher chocolate mass proportion (45%).

After the products were taken to stock, entrance analysis was carried out and a part of the samples deep frozen for later use as standards as part of sensory analysis. The remainder was split into controlled temperature regimens - warehouses cooled to 6 °C and 12 °C and a laboratory room with constant temperature of 20 °C and with the thermostat set to 30 °C; then the samples were stored under such settings without any fluctuations of temperature.

Sampling was carried out and evaluated five times. Each sampling was accompanied by sensory evaluation, determination of changes in colour using spectrophotometer in the visible region of the spectrum and hardness by texturometer. Before each analysing, a period of 24 hours was maintained to equilibrate all the samples to the lab ambient temperature.

Sensory evaluation

A sensory profile method was used for determining sensory traits of the chocolate products. Measuring perceptions for sub-descriptors used unstructured graphical scales with verbal description of the end-points with a length of 10 cm. To make mutual comparison possible as part of the respective descriptor, samples of each product from all the storing temperatures, including the standards, were administered at once. All of the sensory evaluation

Table 1 Color differentation scale **(Třešňák, 1999)**.

ΔE^*_{ab}	**Description**
0.0 – 0.2	Imperceptible
0.2 – 0.5	Minute
0.2 – 1.0	Perceptible
0.5 – 1.5	Slight
1.0 – 2.0	Recognizable
1.5 – 3.0	Clearly perceptible
2.0 – 4.0	Not yet discordant
3.0 – 6.0	Medium
4.0 – 8.0	Moderately discordant
Over 6.0	Prominent or moderately disturbing
12.0	Very prominent
16.0	Disturbing

sessions were underway in a dedicated lab under standard conditions, i.e. ISO 8586-1 (evaluators) and ISO 8589 (the premises) and the temperature of 20 °C.

The results of graphical scales were obtained by measuring the distance of the mark from the right scale end representing the lowest (0) product quality to the scale start placed to the left that represents the best (10) quality, and are graphically rendered in the form of radar charts as an average rating of all evaluators (n = 8). The sensory profiles of the products during the storing period clearly show the differences between each of the storing temperature regimens.

Colour measurement

Konica Minolta Spectrophotometer CM 3500d (KONICA, Japan) was used for determining the colour and its changes during the storing period. The modes selected for the colorimetric determination of colour in chocolate products using reflectance (d/8) were one involving gloss elimination (SCE - specular component excluded), D 65 (illumination mode: 6500 Kelvin) and 8 mm slot. Spectrophotometer measurements of colour present a welcome complement to sensory analysis. The CM-S100w program enables expression of colour in a colour space CIELAB (balls) according to the International Commission on Illumination. The values of L* (lightness) represent the range from "0" (black) to "100" (white). The colour coordinates +a* to -a* (the axis from red to green), and +b* to -b* (the axis from yellow to blue) take positive or negative values depending on the location within the three-dimensional system **(Třešňák, 1999)**.

Hardness measuring

Texture measurements were performed using a universal testing machine for the measurement of physical properties – TIRAtest 27025 (Germany). The penetration test was used for testing the chocolate products involving a probe of a stick shape penetrating into the sample, so obtaining a record of the force [FH] necessary to push the punch to the selected depth. The diameter of cylindrical probe was 3 mm; penetration speed was 100 $mm.min^{-1}$.

Statistical analysis of data

The acquired data were analysed using MS Excel. Statistical analysis was carried out for all the sourced data using STATISTICA (Edition 12) - ANOVA (analysis of variance with interactions, testing on the significance level of $p = 0.05$).

RESULTS AND DISCUSSION

Sensory evaluation

In sensory evaluation of chocolate, appearance and texture of the product are of particular importance **(Neumann et al., 1990)**. Fat bloom on the surface of the chocolate has a negative impact on the appearance and overall acceptance of chocolate products **(Bui and Coad, 2014)**.

The example of the sensory profile for *Milena* specifically shows a distinct deterioration of all the descriptors of the product when stored at 30 °C. The same results were achieved for *Margot Artemis*. The samples were sensorially unacceptable in terms of both appearance and taste (Figure 1). There was overall hardening of the product, the filling dried up and manifest in loose and crumbly consistency. In *Kaštany*, on the contrary, this level of storage temperature resulted in considerable reduction of hardness and a loss of plasticity of the filling due to migration of fat components from the filling onto the product surface. In chocolate products, the typical deterioration associated with fat migration is manifest in softening, fat bloom and unacceptable textural changes within the product due to the liquid glycerides being released from the filling onto the product surface **(Timms, 1984; Ziegleder, 1997)**.

Sensory evaluation of samples of chocolate sticks stored under the temperature regimens of both 6 °C and 12 °C showed that these appeared to be the most favourable settings for storage. Their quality almost copied the evaluation of the standards. The exception, however, was found for the *Milena* stick which was seen to develop sugar crystals in its filling. The defect was probably caused by the stiffening of incompletely dissolved sugar crystals in the water phase of the filling due to the samples being relocated into settings with a low temperature.

Storing temperature of 20 °C became improper particularly for *Margot Artemis* and *Kaštany* from the aspect of fat bloom development. The most significant blooming occurred on the surface of *Margot Artemis*, where fat bloom began to develop as early as a month of storing. Initially, the bloom formed along the sides of the product and around the cracks on the surface. By the end of the experiment, it had been present on as much as 50% of the product surface. Fat bloom also appeared inside the *Kaštany* products, more specifically on the filling where it accumulated mainly in the corners of the individual squares. According to **Adenier et al. (1993)**, fat bloom initially accumulates at the edges of openings or along cracks on the surface layer of the chocolate. **Briones and Aguilera (2005)** report in their study that white spots appeared on the chocolate surface after 33 days of storing, probably due to the rapid migration of the liquid fat through defects or pores in the surface layer. Visually, the chocolate turned whitish almost throughout the surface at the end of the storing period.

In samples of chocolate sticks stored under such temperatures, deterioration generally occurred in more sensory descriptors, which namely involved gloss, scent, taste and overall acceptance. The results were also confirmed by **Bui and Coad (2014)** who report that as the percentage of fat bloom increases, all of the sensory attributes diminish. Increased rate of bloom therefore strongly correlates with a decrease in the visual appeal of the product. Similar conclusions were reached by **Ali et al. (2001)**, who studied the effect of temperature (18 °C and 30 °C) during the storing period of two months in chocolates filled with dry coconut flesh. For samples stored at 18 °C no blooming was found, while as regards the second temperature regimen (30 °C) the onset of blooming was observed as early as one week of storing. The results of sensory evaluation also showed that the colour, texture and overall acceptance of samples stored at 30 °C were significantly (p <0.05) lower compared with control samples and those stored at 18 °C.

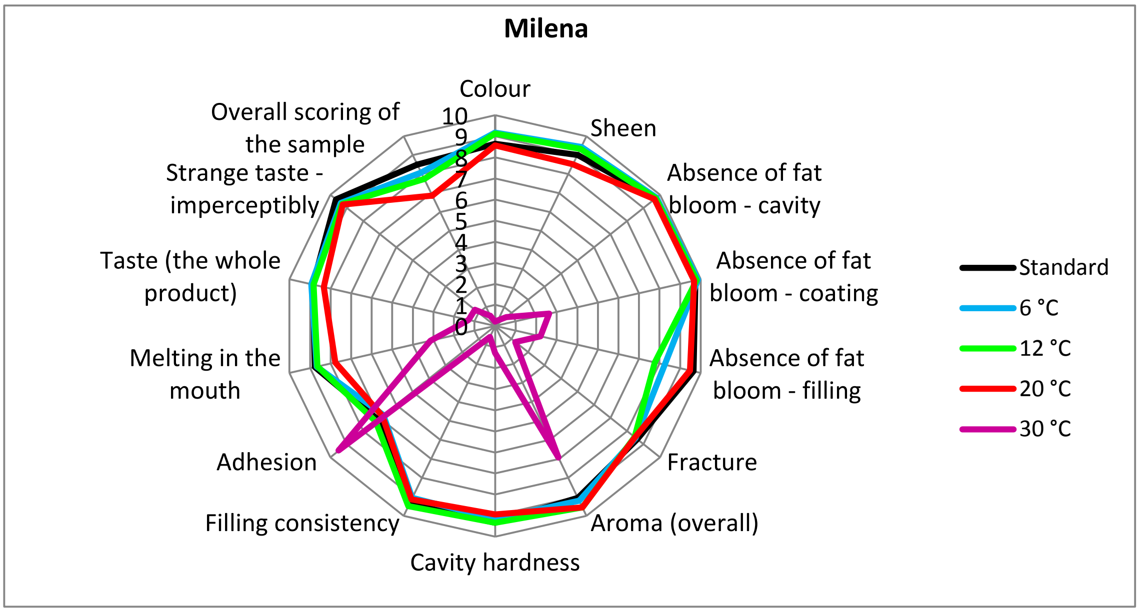

Figure 1 Sensory profile for *Milena* (sampling 5).

Evaluating the fondants showed during the storing period a significant influence of temperature regimes on changes of their sensory quality. The sensory profile produced (Figure 2) shows a considerable presence of sugar bloom for the samples stored at 30 °C. Crystals of sugar were present on both the cavity and the coating of the samples. The filling had dried up and there was overall hardening of the product due to water precipitated on the surface, which was additionally confirmed through subsequent analysis of texture.

Samples stored at temperatures up to 12 °C were found to have lost gloss, thus the overall acceptance of the product was impaired.

Conversely, the best results were reached in sensory evaluation for *Black magic - Orange sensation* fondants when stored at 20 °C. These samples were seen to have undergone minimal changes when gloss and colour was changed least of all the temperature regimens. The orange flavour and scent also unfolded in a pleasant way. Room temperature thus seems to be the most advisable way of storing these products.

For the *Krémová oříšková* chocolate bar, any greater difference or deficiency as regards the evaluated descriptors was not found between the storage regimens of 6 °C, 12 °C and 20 °C even week 18 of production date in (Figure 3). Comparable results were also observed in the reminder of chocolate bars.

The best resistance to changes even under high thermal stress in the settings with a storage temperature of 30 °C as found in the nut chocolate can be considered a positive trait. For other chocolate bars, *BOCI fekete erdö* and *Orion Pistácie*, there was overall softening, loss of fine consistency of the filling, deterioration of the look through the material becoming pale due to fat bloom, the presence of rancid off-taste, and naturally the final rating of the sample acceptance being impaired. **Nattress et al. (2004)** also reports that the storage period of dark chocolate significantly affects bitterness, as well as the perception of sweet, sour, metallic, burnt and rancid taste. It is also a factor for hardness, viscosity and the onset of melting.

Research of **Jinap et al. (2000)** into fat bloom in chocolates stored at 18 °C, 30 °C and 35 °C for 8 weeks shows that no blooming was found during storage at 18 °C, while storing at 30 °C and 35 °C was seen to result in the development of fat bloom after week 4 and week 1, respectively.

Likewise, the results of the study by **Bui and Coad (2014)** in monitoring the sensory quality of milk chocolates during storage show that the quality of all the products stored at 35 °C significantly reduced compared with the 25 °C regimen. The quality was deteriorating exponentially with time. The highest sensitivity to deterioration was shown in the Appearance and Overall Acceptance descriptors.

Colour measurement

Analytical measurement of colour is widely used in studying surface changes of chocolate, which particularly applies to turning pale caused by fat blooming to evolve **(Kumar et al., 2003)**.

Colour space CIE L*a*b* allows to identify, count, and measure objective variances between the different colours with relative ease. This difference, consisting of deviations ΔL^*, Δa^*, Δb^*, is best expressed by term ΔE^*, which is a square root of the sum of the individual deviations squared. A scale indicating the degree of disagreement between two colours was devised to facilitate the communication (Table 1).

Table 2a makes it evident that during the period of storing the *Kaštany* and *Margot Artemis* chocolate sticks there was a change in colour compared with control (K0). While the samples turned darker under the temperature regimens of 6 °C, 12 °C and 20 °C, the 30 °C mode caused them to turn paler to a significant extent.

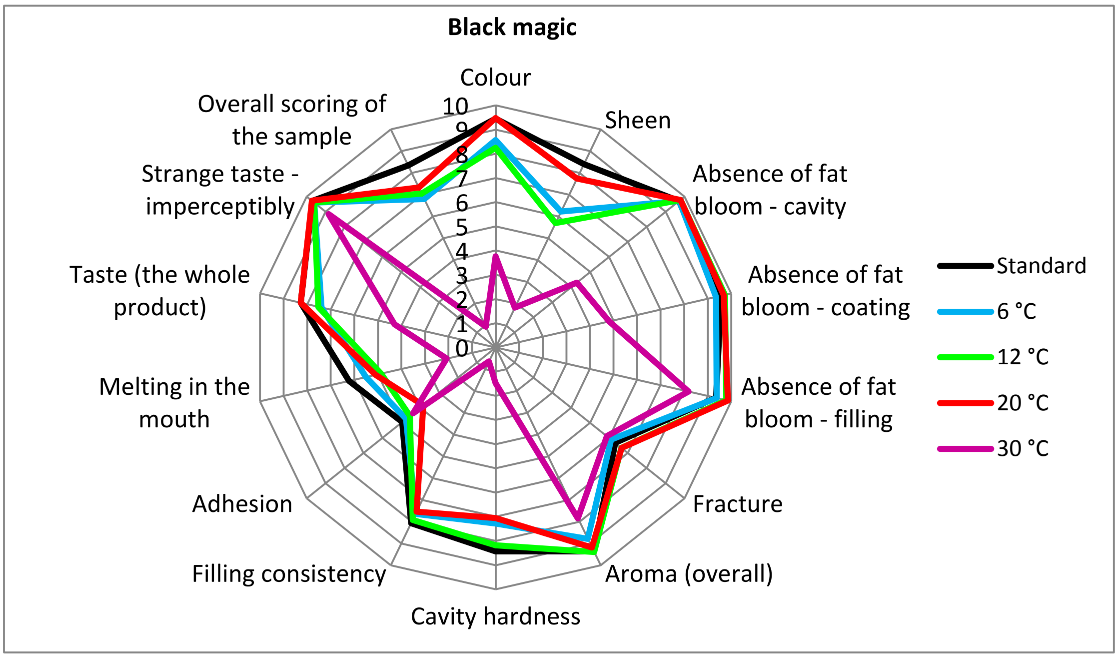

Figure 2 Sensory profile for *Black magic - Orange sensation* (sampling 5)

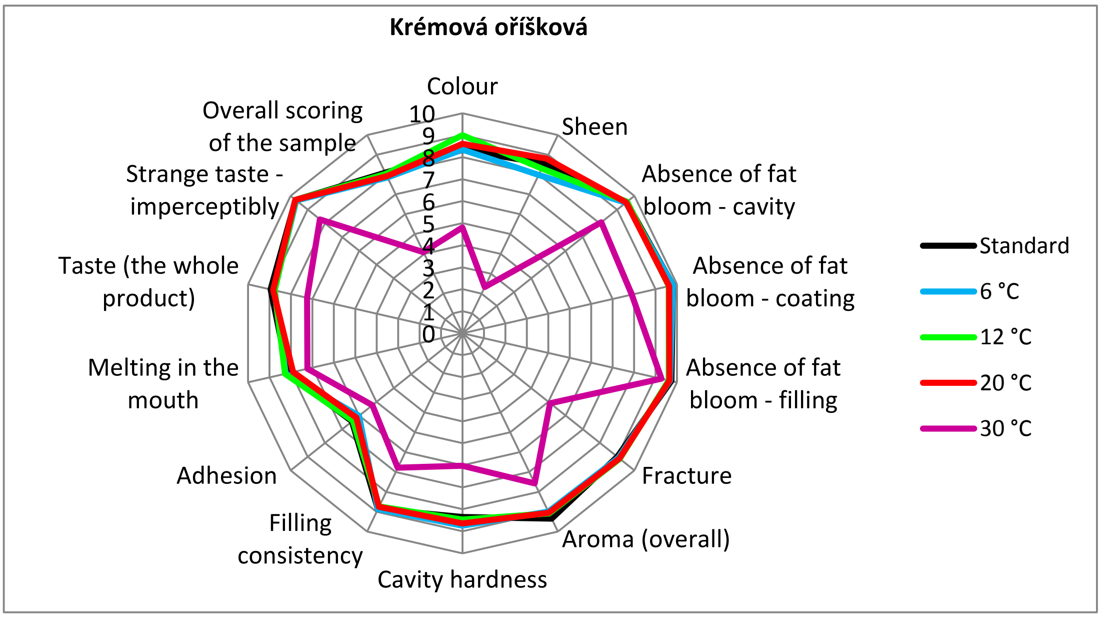

Figure 3 Sensory profile for *Krémová oříšková* (sampling 5)

The chocolate stick of *Milena* and the *Black magic* fondants were observed to significantly change colour under all of the storage regimens (Table 2b). In the event of *Milena*, similarly to the other sticks stored at temperatures of up to 20 °C, there was darkening of the samples, while they turned pale at 30 °C. Unlike control, *Black magic* fondants exhibited very visible lightening of the chocolate surface under all the storing regimens, which was probably caused by the development of sugar bloom.

Differences in colour as per temperature regimen were statistically significant ($p = 0.007$) even in chocolate bars. It results from Table 2c that *BOCI fekete erdö* samples were found to undergo the greatest extent of darkening when stored at 12 °C. In all the cases, the storage regimen of 30 °C was significantly manifest in a negative increase in the product lightness. A similar trend was observed for pistachio chocolate. The best results were those achieved for *Krémová oříšková* čokoláda, a product which did not exhibit visible changes in colour during storage except the temperature regimen of 30 °C. The measurements confirm the results arising from sensory analysis.

Highly significant differences ($p = 0.001$) were found for all the values (L*, a* and b*). The b* values are characteristic of the coordinate on the axis from blue to yellow. The shift of values to yellow within the measurement characterises the development of fat bloom.

Table 2a Differences in colour of chocolate products.

	Kaštany					*Margot Artemis*				
Temperature [°C]	K0	6	12	20	30	K0	6	12	20	30
L*	29.48	28.41	28.56	28.61	31.62	36.03	34.45	34.60	34.86	40.53
a*	8.28	7.70	7.65	7.70	9.43	10.53	10.56	10.62	10.27	10.71
b*	8.17	7.13	7.08	7.16	10.39	13.06	12.44	12.55	12.21	15.18
ΔE^*_{ab}	**0**	**1.60**	**1.55**	**1.45**	**3.29**	**0**	**1.70**	**1.52**	**1.48**	**4.98**

Table 2b Differences in colour of chocolate products.

	Milena					*Black magic*				
Temperature [°C]	K0	6	12	20	30	K0	6	12	20	30
L*	38.87	36.31	36.38	36.90	40.87	29.97	34.06	33.26	33.71	34.14
a*	10.13	10.17	10.07	9.96	10.21	8.23	8.16	8.18	8.10	8.15
b*	14.27	13.36	13.24	13.37	15.77	8.46	10.35	10.42	10.37	10.16
ΔE^*_{ab}	**0**	**2.72**	**2.69**	**2.17**	**2.51**	**0**	**4.51**	**3.83**	**4.21**	**4.51**

Table 2c Differences in colour of chocolate products.

	BOCI fekete erdö					*Krémová oříšková*				
Temperature [°C]	K0	6	12	20	30	K0	6	12	20	30
L*	27.95	26.10	24.94	25.02	25.45	37.82	37.62	37.25	37.55	40.12
a*	6.70	6.68	6.63	6.70	7.97	10.65	10.63	10.55	10.49	10.18
b*	6.40	6.30	6.27	6.39	8.81	14.87	14.47	14.21	14.27	15.71
ΔE^*_{ab}	**0**	**1.86**	**3.02**	**2.93**	**3.70**	**0**	**0.45**	**0.88**	**0.68**	**2.49**

Fat bloom induced by exposing the product to high temperatures causes chocolate to gradually change its colour change, lose gloss and appear greyish on the surface **(Briones and Aguilera, 2005)**.

Changes in colour were noted between the experimental and control samples during storage at 30 °C even by **Bui and Coad (2014)** establishing that the storage period mostly influenced the L* value. For a* value no change was proved, thus no shift of values from red to green occurred. A positive change was observed for value b* in the yellow colour intensity, which made the products to become paler over time.

The same conclusion was reached in their study by **Mexis et al. (2010)** who report that significant changes in colour were observed as a result of fat bloom. If having a fat bloom cover, the chocolate product tends to disperse more light, so appearing to be paler and less rich-coloured **(Afoakwa et al., 2008)**. **Hartel (1999)** reports that the whitish haze in chocolate blooming is caused by light dispersion of fat crystals.

Hardness measuring

For consumers, appearance and hardness are the key attributes when choosing and deciding on the acceptability of chocolate, while taste is considered to be important when identifying the product. The final hardness of chocolate is influenced by several factors including formulas, production techniques, tempering, polymorphism (fat crystal stability) and the cooling temperature. Hardness of chocolate is a good indicator of proper temperature control and stability of the fat crystal network being formed **(Afoakwa, 2010)**.

Differences between the storage temperature regimens were statistically significant (p = 0.001) for all the analysed products. Storing temperature thus significantly influences hardness of each product.

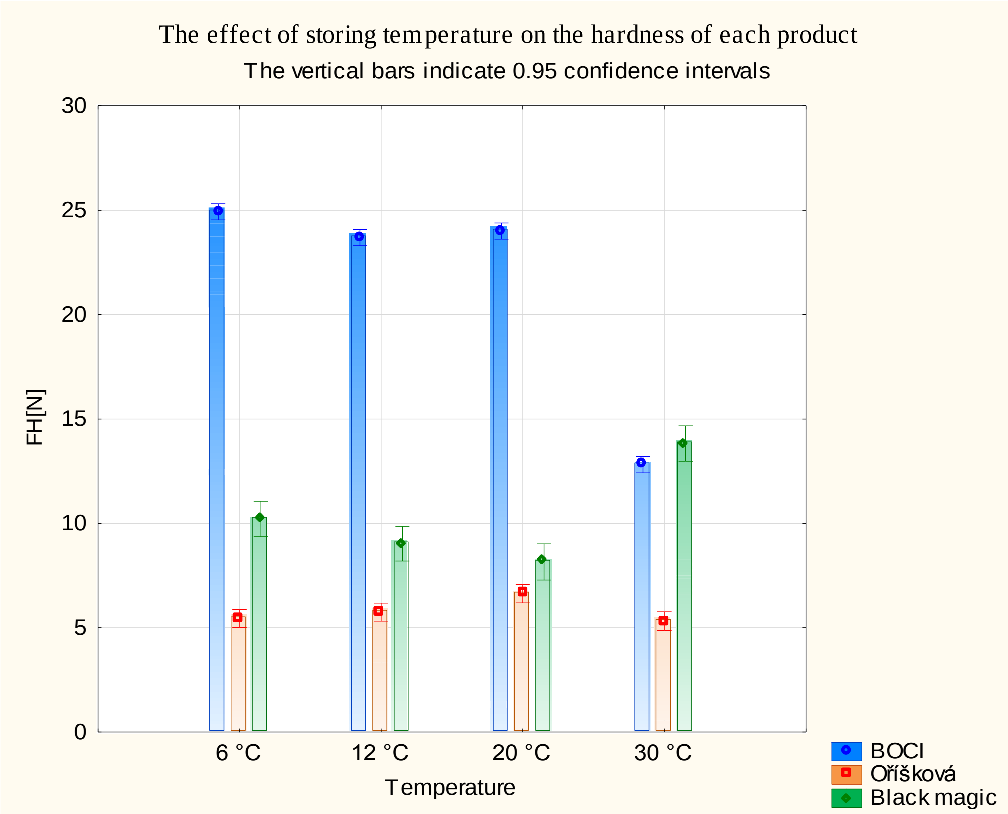

Figure 4 The effect of storing temperature on the hardness of each product.

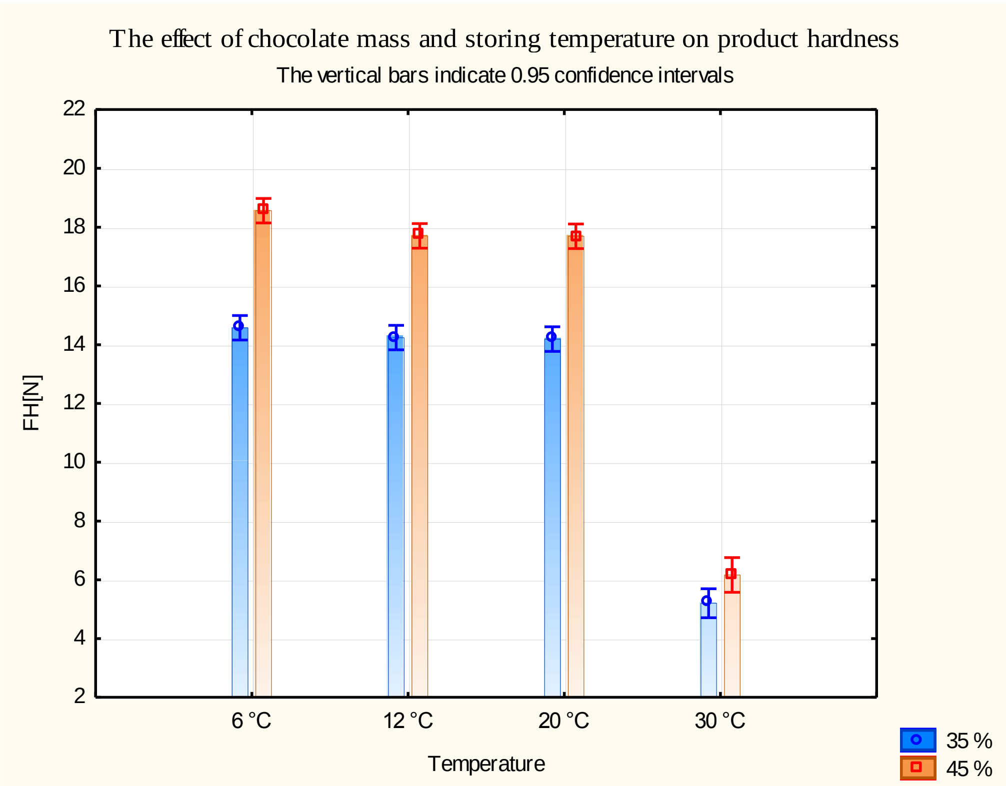

Figure 5 The effect of chocolate mass and storing temperature on product hardness.

The chart (Figure 4) makes it obvious that the highest level of hardness was found for *BOCI fekete erdö* when stored at 6 °C. This product also reflected the most the negative effect of temperature when stored at 30 °C with the samples reducing hardness by more than 10 N. We can assume that this case reflected the influence of the liquid filling on the overall texture of the product. Similar results were obtained for *Kaštany* which was probably due to a significantly different composition of the fat used in the filling where the rather high proportion of unsaturated fatty acids causes the mass melting point to decrease and the fat to migrate to the surface of the product, hence the subsequent softening.

In filled chocolate products where the filling contains lipids with low melting points, such lipids tend to migrate to the surface of the product over time, which with the highest probability initially involves lipids with the lowest melting point and the best fluidity. Such migration may cause the chocolate to become sticky and soft, while the filling becomes stiffer; the migration has even an impact on the structure of the surface **(Ali et al., 2001; Ziegleder, 1997)**. The results of **Mexis et al. (2010)** show as well that changes in texture accompanied by a change in colour caused by lightening through fat blooming were leading to the entire chocolate product becoming softened. All these attributes reduce the acceptability of the product for consumers. Fat migration can largely occur already at room temperature (17 °C – 23 °C) and accelerate as the temperature increases. Migration is reduced as the solid fraction of lipids increases **(Wootton et al., 1970; Wacquez, 1975)**.

For fondant products, storing temperatures of 30 °C caused them to substantially increase in hardness compared with all other products. It is due to the fact that the filling is drying out and thereby hardening due to the composition of the filling.

The highest stability of texture was seen in the *Krémová oříšková* chocolate bar that retained its textural properties to the best extent even after 18 weeks of production under any storage regimen. It also proved the best resistance to extreme storage conditions at 30 °C. In *Milena* and *Margot Artemis*, texture was not very significantly influenced by storage temperature with differences being only units of Newtons.

Since storing temperatures of 6, 12 and 20 °C did not considerably affect hardness of each product, no distinct changes in hardness occurred under such temperature regimens. The study of **Ali et al. (2001)** also makes it possible to state that migration of fats with lower melting points was very slow for storage under 18 °C and the changes were minimal as regards chemical composition, hardness, gloss and polymorphic stability.

The experiment included the effect of the formula on the quality and shelf life of chocolate products being evaluated. Evaluating hardness for *Orion Pistácie* (Figure 5) makes it evident that the variants produced with use of a higher proportion of chocolate mass (45%) achieve higher hardness during storage. While softening is almost impossible to notice for the temperature regimens of up to 20 °C, for 30 °C it is significantly more intense. Yet the beneficial effect of composition of the chocolate mass used can be observed for this case as well.

CONCLUSION

The results of sensory evaluation of selected products shows that the highest quality for the majority of descriptors was achieved by products stored at temperatures of 6 °C and 12 °C. The properties of these, both visual and gustatory, were comparable with those of standards and achieving similarly high scores. As regards samples stored under the temperature regimen of 20 °C, the products started to show visible differences, caused primarily by the formation of fat bloom while storing at 30 °C proved to be extremely unsuitable for all the tested products.

From the aspect of analytical measurements of colour and hardness of each product, storing at temperatures of 20 °C can be termed appropriate. In all the analyses, the effect of the temperature regimen of 30 °C was significantly negative due to defects caused by blooms on the chocolate, meaning that such temperatures are not advisable for storing chocolate products, even over a short term.

When evaluating the effect of the composition of chocolate mass for the *Orion Pistácie* products, the higher proportion of chocolate mass was reflected mainly in the hardness. Unlike the standard production, products with the formula containing 45% chocolate mass featured a significant, 35% increase in hardness under all storage regimens.

The best results were achieved by *Krémová oříšková* in all the analysing operations, a product that was not found to have any significant shortcomings even after 18 weeks of storage. This product also received good rating even for the storage regimen with a high thermal stress.

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