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Prediction of migration fat bloom on chocolate

The objective of this study was to investigate whether it is possible to predict migration fat bloom based on measurements shortly after production. At different storage times shortly after production (0, 1, 4 h), the chocolate batches, varying in tempering method, tempering degree and amount of added butter oil, were evaluated by DSC, pNMR and texture analysis. Discriminant analysis and principal component analysis were combined to investigate the potential towards prediction. The batches were classified into groups depending on the time when white spots appeared ($<$8 wk, 8–13 wk, $>$13 wk). A good separation (100% correct classifications, 100% using cross-validation) was obtained using the afore-mentioned analyses and storage times. It was also shown that it is possible to exclude DSC analyses or analyses at 0 h storage time without compromising the classification performances too drastically. The study further elucidated that the tempering method has no significant effect on visual fat bloom development. Furthermore, undertempered chocolates bloomed quicker than well-tempered ones, while fat bloom was delayed on overtempered chocolates. Addition of 6% butter oil promoted fat bloom development, while no significant difference was detected between chocolate with no added butter oil and chocolate with 3% butter oil added.

Keywords: Migration, fat bloom, chocolate, prediction.

1 Introduction

A bloomed chocolate is characterized by the loss of the initial gloss of the surface, giving rise to a more or less white aspect. Fat bloom can have different appearances, from a uniform dull grey to a marble aspect, as well as from small individual white points to large white spots on the chocolate. It can be due to many factors, including improper processing conditions, composition and temperature. One of the problems in characterizing bloom is its plurality of shape and also of formation conditions. Moreover, differences between products complicate the scientific analysis. Effectively, the kind of fat and emulsifier, the presence and kind of center on which the chocolate is coated are all parameters that can affect the formation and shape of bloom. Fat bloom has been studied since the beginning of the last century, with an increase in the knowledge of when and where it occurs. Numerous theories have been proposed to explain bloom formation, but so far none has covered all the multiplicity of bloom or taken into account all of the scientific data [1].

Two main types of fat bloom can be discriminated: fat bloom on plain chocolate and fat bloom on filled chocolate. Fat bloom development on plain chocolate has already been studied intensively. Several situations are known to lead to the development of this type of fat bloom: improper tempering [2], cooling too quickly, [3], or storage temperatures that are too high or fluctuating [4, 5]. Theories of fat bloom development on plain chocolate during storage fall into two main groups: phase separation and polymorphic transformation. The phase separation theory is based on the separation of the high- and low-melting triacylglycerols in cocoa butter, with the high-melting triacylglycerols causing fat bloom [6, 7]. The polymorphic transition theory is based on fat bloom forming as cocoa butter crystals change from a βV to a βVI polymorphic form [8]. Fat bloom development on plain chocolate can be controlled by means of proper tempering, proper cooling conditions, proper storage temperatures, *etc.* [9].

Filled chocolates are often characterized by a high oil content center. These products are more prone to bloom than plain chocolate. This type of fat bloom is caused by migration of lipid fractions of the filling into the chocolate. Fat migration has been described by Talbot [10, 11], Ziegleder *et al*. [12, 13], and Ziegleder [14]. Most fillings are mainly composed of vegetable fats differing from cocoa butter. Cocoa butter in chocolate contains mostly POP, POS and SOS. Hazelnut oil, for example, contains mainly triolein (OOO) and other triacylglycerols based on linolenic acid (LOO, LLO, LLL). Liquid lipids or solid crystals in a liquid matrix can migrate to the surface. The uneven distribution leads to an intense migration of the

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lipid fractions of the filling into the chocolate and a weak diffusion of solid cocoa butter of the chocolate layer into the filling. The liquid components diffuse much faster than the solid ones, and this leads to a one-sided migration from the filling into the chocolate. Fat bloom development occurs by recrystallization of the migrated fats on the surface [14]. The mono-unsaturated triacylglycerols of cocoa butter dissolve in the liquid fat and can also migrate to the surface, where they crystallize [14]. It is not clear yet if fat bloom occurs by crystallization of the di- or tri-unsaturated triacylglycerols of the filling or by the crystallization of the mono-unsaturated triacylglycerols of the cocoa butter. According to Ziegleder [14], it is a combination of both phenomena that causes fat bloom. It is known that production parameters and storage conditions play a role in migration speed. However, it is not clear yet how migration fat bloom can be successfully prevented or delayed. In the literature, the difference between polymorphic fat bloom on plain chocolate and migration fat bloom on filled chocolate is often overlooked, and results are often generalized.

The objective of this study was to investigate whether measurements (DSC, pNMR, texture analysis) performed shortly after production (0, 1, 4, 24 h) allow the prediction of when migration fat bloom will develop at later storage times. Such a predictive tool would have the advantage that the chocolate manufacturer can quickly adjust his production process and that chocolate with a high risk of fat bloom development can be kept from the market. Beside this, the influence of tempering and addition of butter oil on the visual migration fat bloom development was studied.

2 Materials and methods

2.1 Chocolate production

The chocolate samples were produced by Barry Callebaut (Wieze, Belgium). The chocolate was poured over circular moulds of 3 mm height and 2.5 cm diameter. Only one filling (hazelnut filling) was used, and after tempering, the chocolate was cooled for 15 min at 12 °C. The cooled chocolate samples were placed on the filling and stored in a climate chamber at 20 °C and with a relative air humidity of 65%. Fourteen different batches were produced. Two different types of industrial tempering machines were used: one with a long (L) residence time and one with a short (K) residence time. The chocolates also differed in the amounts of added butter oil (0, 3, 6%) and in tempering degree (1, undertempered; 5, well tempered; 9, overtempered).

2.2 DSC

The samples for DSC were quench cooled (15 min in solid CO_2) to 'block' crystallization, to enable analysis at a later time and at a different location. The influence of quench cooling on the results was investigated, and no effect of quenching could be detected [15].

Analyses were performed on a TA 2010 DSC (TA Instruments, Brussels, Belgium) with a refrigerated cooling system (TA Instruments). The DSC was calibrated with indium (TA Instruments), azobenzene (Sigma-Aldrich, Bornem, Belgium) and undecane (Acros Organics, Geel, Belgium) prior to analyses. Nitrogen was used to purge the system. Hermetic aluminum pans were used, and the reference was an empty pan. The sample size varied between 2 and 10 mg. Each analysis was executed in triplicate (on three different disks).

The samples were put into the DSC at room temperature, and the following time/temperature program was used: cooling at a rate of 8 °C/min to −20 °C; keeping isothermal for 5 min; heating at a rate of 5 °C/min to 65 °C.

Van Cauteren [16] investigated the effect of the heating rate. A lower heating rate results in a disfigured profile of the crystal structure of the chocolate, due to recrystallization during heating. A higher heating rate causes thermal lag. As a compromise, a heating rate of 5 °C/min was used.

From the melting profiles, several parameters were extracted: peak maximum, peak depth, peak width, onset temperature and area. The area was enclosed by a horizontal sigmoid baseline [17], and the endothermic peak corresponds to the amount of heat involved in the melting process. The total area was divided into three areas by a perpendicular drops at 23.5 °C and at 28.5 °C, as presented in Fig. 1.

Foubert et al. [18] demonstrated that by using an objective calculation algorithm to determine the start and end points of integration, the variability caused by the operator during the integration procedure could be eliminated. The determination of the start and end point of the melting process was performed using a similar calculation algorithm. In a first step, the inflection point (at the higher temperature side of the melting peak) was determined. This is the point where the second derivative becomes zero for the first time. In a second step, the point (on the lower temperature side of the melting peak) at which a tangent line contains this inflection point is determined as the end point. The integration was performed with the Universal analysis software version 2.5H (TA Instruments, New Castle, USA).

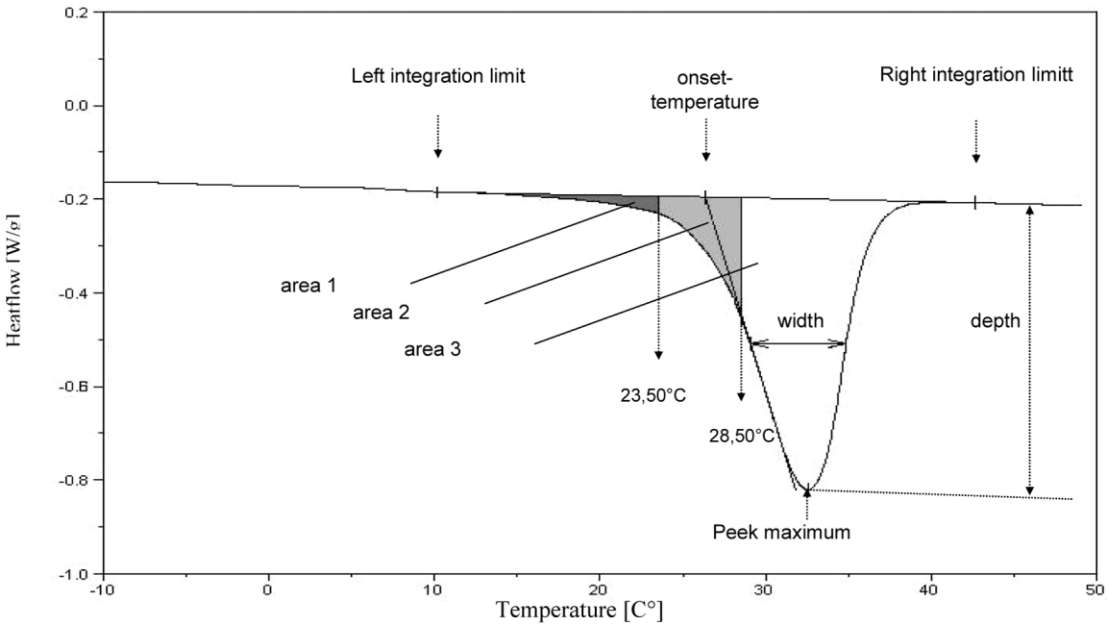

Fig. 1. DSC profile of a chocolate sample.

2.3 pNMR

The solid fat content at 20 °C of the chocolate samples was determined by pNMR. Each analysis was performed in duplicate (two different disks). The analyses were performed with a pulsed nuclear magnetic resonance apparatus (pNMR) Bruker Minispec 120 (Bruker, Karlsruhe, Germany). The method of Petersson [19] was used in a slightly adapted way. The liquid signal was measured at 40 °C (instead of 60 °C). As mentioned by Petersson [19], it was possible to make this SFC determination in chocolate because of the indirect method, which only employs the liquid signal from the sample (*i.e.* liquid fat signal).

2.4 Texture analysis

On the chocolate samples, a penetration test was carried out with a TA.500 Texture analyzer (Lloyd Instruments, Hampshire, UK). A plastic conical probe (diameter base, 8 mm; height, 30 mm) was used: The samples were penetrated at 0.75 mm/min over a distance of 1.5 mm. The analyses were carried out at room temperature. The maximum force (N) needed for penetration gives an indication of the hardness of the samples. Each analysis was executed sevenfold (on seven different disks).

2.5 Visual fat bloom assessment

A professional panel assessed the visual fat bloom development after certain storage times. The meaning of the different values for bloom intensity is as follows:

- 0: the product shows no difference compared to the original product
- 1–2: the product loses its gloss, but does not show any white spots
- 3: the product starts to show white spots or a grey film
- 4: the product clearly shows white spots or a grey film
- 5: the product has turned completely white

The visual fat bloom assessment was carried out by three people who gave one combined score (one score for three people) for each of two plates.

2.6 Principal component analysis [20]

Principal component analysis (PCA) is a mathematical procedure that transforms a number of correlated variables into a number of uncorrelated variables, called principal components. These principal components are linear combinations of the original variables. The coefficients of the original variables in these linear combinations are chosen so that the first principal component accounts for as much of the variability in the data as possible and each succeeding component accounts for as much of the remaining variability as possible. Instead of working with all original variables, PCA can be performed and only the first two or three principal compo-

nents can be used in subsequent analyses. The objective of PCA is thus to reduce the dimensionality (number of variables) of the data set while retaining most of the original variability in the data. SPSS for Windows 10.0.5 (SPSS Inc., Chicago, USA) was used to perform the PCA. Since the variables differed in magnitude, PCA was performed on the normalized variables. A Varimax rotation was applied to the principal components with an eigenvalue above 1.

2.7 Discriminant analysis [21]

Discriminant analysis aims at quantifying how well two or more groups of individuals can be separated, given measurements for these individuals on several variables. Discriminant analysis generates a set of discriminant functions based on linear combinations of the variables. The distance of the individuals to the group averages can be calculated based on these discriminant functions, and each individual is then allocated to the group it is closest to. This may or may not be the group the individual actually belongs to. The percentage of correct allocations is an indication of how well groups can be separated using the available variables. However, allocating the individuals using this procedure tends to have a bias in favor of allocating the individuals to the group to which they belong. After all, the group averages are determined from the observations of that group, and it is not surprising to find that an observation is closest to the group average it helped to determine. To overcome this bias a "jackknife classification" (or cross-validation) can be performed. This involves allocating each individual to its closest group without using that individual to help determine the group averages. The discriminant analysis was performed on normalized variables with SPSS for Windows 10.0.5 (SPSS Inc., Chicago, USA).

2.8 Experimental design

A full factorial experimental set up with three factors was designed: tempering method, tempering degree and amount of butter oil. The degree of tempering was varied as follows: undertempered (1), well tempered (5), and overtempered (9), as measured by a temper meter (Temper meter E2; Sollich, Bad Salzuflen, Germany). The numbers between brackets correspond to the classic interpretation of tempering curves [22]. The amount of butter oil was 0%, 3% and 6%. A schematic overview of the full factorial design is given in Fig. 2. The central point was evaluated in duplicate. For the short residence time tempering, no overtempered chocolates were made. Due to the high viscosity, these samples could not be manipulated.

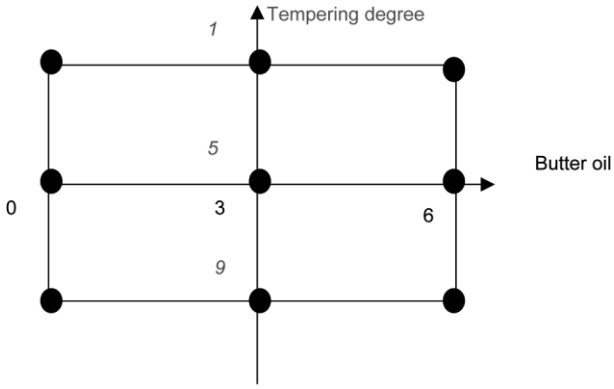

Fig. 2. Schematical overview of the full factorial design (●: represent the points to be measured).

The samples were stored at 20 °C to allow normal fat bloom development and analyzed at 0 h, 1 h, 4 h and 24 h (DSC, pNMR, texture analysis), to check whether it was possible to develop a predictive model for migration fat bloom. It was not the objective to promote bloom, but to allow normal fat bloom development. Further visual analyses were carried out every 2 wk during up to 24 wk of storage.

3 Results and discussion

3.1 Visual assessment of fat bloom intensity

Fig. 3 shows the time necessary for each batch to reach fat bloom intensity 3. When chocolate reaches this bloom intensity, it becomes unacceptable for commercial purposes. The graph shows for each batch the mean values and the error bars (one standard deviation) of the time needed to reach fat bloom score 3. A GLM analysis (General Linear Model, SPSS for Windows, 12.0; SPSS Inc., Chicago, USA) was performed with the time to reach fat bloom score 3 as the dependent variable; the fixed factors were tempering type (short/long), tempering degree (undertempered, well tempered, overtempered) and amount of butter oil (0%, 3%, 6%). This analysis showed a significant ($\alpha = 0.05$) effect of butter oil. The samples with 6% butter oil bloomed more quickly than those with 3% and 0% butter oil. Between the latter two, no significant ($\alpha = 0.05$) difference was detected.

The effect of 6% butter oil can be explained by the raise in liquid fat content (lower SFC; see Fig. 4), which increases the mobility of the fats in the chocolate. This leads to more migration and a faster fat bloom development [23].

On the other hand, milk fat is a known antibloom agent [10, 24–26]. For antibloom properties on dark chocolate, Minfie [27] recommends 4% milk fat (12% on total fat) for

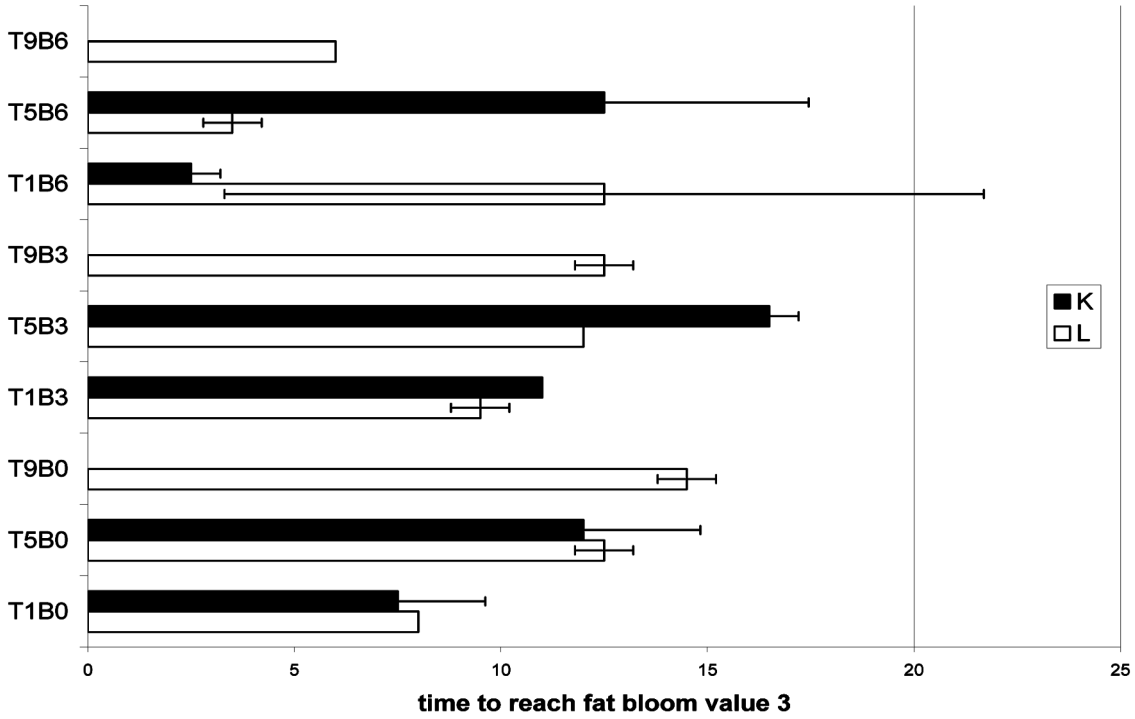

Fig. 3. Time (weeks) to reach fat bloom value 3 (error bars represent one standard deviation). Tempering type: short (K), long (L); tempering degree: undertempered (T1), well tempered (T5), overtempered (T9); amount of butter oil: 0% (B0), 3% (B3), 6% (B6).

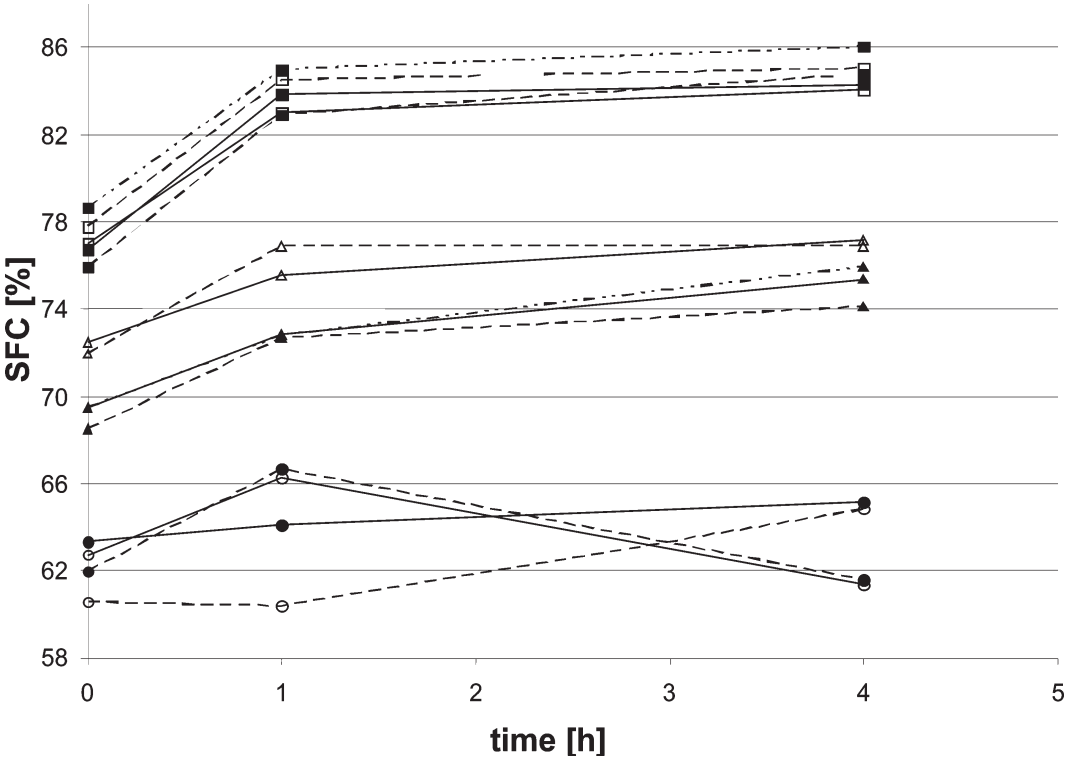

Fig. 4. Evolution of the SFC values during storage time. Open symbol: short residence time tempering; closed symbol: long residence time tempering; square: 0% butter oil; triangle: 3% butter oil; circle: 6% butter oil; ___: undertempered (T1); - - -: well tempered (T5); –.-.-.: overtempered (T9).

optimal performance, but 2% (6% on total fat) should be effective. The results in this study illustrate that 6% butter oil is too much and even enhances fat bloom development (Fig. 3).

In addition, the GLM showed a significant ($\alpha = 0.05$) interaction between tempering type (short/long) and tempering degree (undertempered, well tempered, overtempered). After splitting up the data according to these factors, the GLM analysis proved that for each individual tempering degree, there was no significant ($\alpha = 0.05$) effect of tempering type. On the other hand, for the short tempering type, a significant ($\alpha = 0.05$) effect of tempering degree could be noted. For the long tempering type, tempering degree was only significant at a significance level of 10%. It should be noted that the rather big error bar for the long-tempered batch T1B6 (undertempered, 6% butter oil) may have distorted the results.

3.2 Evolution of the solid fat content during storage

The solid fat content of the different chocolate samples was measured during storage. Fig. 4 shows the evolution of the solid fat content (SFC) of the various chocolate batches shortly after production. A GLM analysis was performed on these data. The SFC of the chocolate samples was selected as the dependent variable; the fixed factors were tempering type (short/long), tempering degree (undertempered, well tempered, overtempered), amount of butter oil (0%, 3%, 6%) and time after production (0, 1, 4 h).

The results show a significant ($\alpha = 0.05$) effect of butter oil. The samples with 6% butter oil have a lower SFC compared to those with 0% and 3% butter oil. The latter have a lower SFC than the samples with 0% butter oil.

These results can easily be explained by taking the effect of butter oil into account. An increase in the amount of added butter oil results in the increase in the amount of liquid fat and thus in a decrease in the amount of solid fat.

In addition to the overall effect of butter oil, a significant interaction between tempering type and tempering degree was noticed. After splitting up the data, the long-tempered samples showed no significant effect of tempering degree, while the short-tempered samples, on the contrary, exhibited a significant effect of tempering degree. The more tempered, the higher is the SFC content.

Furthermore, an effect of time was statistically proven. The SFC increased for each type of chocolate with increasing time. This can be explained by a further crystallization of the chocolate samples.

3.3 Evolution of hardness during storage

The hardness of the different chocolate samples was investigated during storage. On the data collected shortly after production (0, 1 and 4 h after production), GLM analyses were performed. The hardness of the chocolate samples was selected as the dependent variable; the fixed factors were tempering type (short/long), tempering degree (undertempered, well tempered, overtempered), amount of butter oil (0%, 3%, 6%) and time after production (0, 1, 4 h).

These analyses revealed several interactions between the factors tempering type, tempering degree, butter oil percentage and time after production (all except tempering type x tempering degree). The data were split up to investigate the effect of each individual factor. For each tempering degree (undertempered, well tempered, overtempered) the same trend for the effect of butter oil was visible. The hardness increased significantly as the amount of added butter oil decreased. This effect can be explained by the effect of butter oil on the liquid fat content. The more butter oil is added to the chocolate, the more the liquid fat content of the chocolate increases. As the liquid fat content increases, the chocolate becomes softer. The softening effect of butter oil is widely known and is an undesirable characteristic, especially in dark chocolate, which is known for its characteristic hard snap [20].

For none of the tempering conditions was there a significant effect of time on SFC. The effect of tempering degree was only significant at 4 h. The undertempered samples proved to be softer than the overtemperd ones.

3.4 Principal component analysis and discriminant analysis

Principal component analysis was used to reduce the number of variables extracted from DSC analyses, retaining as much as possible of the original variability. Each DSC analysis provides 11 variables [total area, area1, area2, area3 (nominal values); area1%, area2%, area3% (percentages relative to total area); onset temperature, maximum temperature, peak depth, peak width] (Fig. 1), which, multiplied by three storage times (0 h, 1 h and 4 h), leads to 33 variables for each individual production.

Discriminant analysis carried out on the principal components, SFC and hardness values is used to classify the 14 productions into three groups, using the time at which fat bloom intensity 3 is reached as response variable: before week 8, between week 8 and week 13, later than week 13. An overview of the conducted discriminant analysis and the percentages of correct classifications are given in Tab. 1.

Tab. 1. Overview of the conducted discriminant analysis and the corresponding classification percentages based on principal components (PC) (derived from DSC data), solid fat content (SFC) and hardness (Hardn.) at 0, 1 and 4 h after production.

PCA	PC1	PC2	PC3	PC4	SFC 0 h	SFC 1 h	SFC 4 h	Hardn. 0 h	Hardn. 1 h	Hardn. 4 h	Correct class.%	Correct cross-class.%
DSC 0, 1, 4 h												
A	×	×	×	×	×	×	×	×	×	×	100	100
B	×	×	×		×	×	×	×	×	×	100	57.1
C		×	×		×	×	×	×	×	×	100	64.3
D			×		×	×	×	×	×	×	100	100
E			×		×	×	×				64.3	14.3
F			×					×	×	×	64.3	28.6
G					×	×	×	×	×	×	100	71.4
DSC 1, 4 h												
H	×	×	×			×	×		×	×	100	78.6
I			×			×	×		×	×	100	100
J			×			×	×				57.1	42.9
K			×						×	×	78.6	21.4
L						×	×		×	×	92.9	85.7
DSC 0, 1 h												
M	×	×	×		×	×		×	×		92.9	28.6
N			×		×	×		×	×		71.4	42.9
DSC 0, 4 h												
O	×	×	×		×		×	×		×	78.6	28.6
P			×		×		×	×		×	78.6	28.6

In a first step, PCA was conducted on all DSC variables obtained at the three storage times (0 h, 1 h, 4 h). In a second step, discriminant analysis was used to investigate which principal components lead to the best classification. The principal components and the percentage of the total variance of the data set explained by each of them are given in Tab. 2. In a third step, it was investigated which techniques were necessary to obtain a good classification. A fourth step determined which storage times could be left out without compromising the classification performance.

3.4.1 Step 1: All available information (all PCA from DSC plus pNMR and TA) in discriminant analysis

PCA conducted on the DSC results collected 0, 1 and 4 h after production resulted in four principal components with eigenvalue over 1. The first set of discriminant analyses uses these four principal components, combined with the SFC and hardness values obtained at these three instants (trial A). Using the regular classification, 100% of the batches are correctly allocated. Using the "jackknife classification" or cross-validation, this value remains 100%. A visual representation of the separation is given in Fig. 5. This graph represents the value of the second discriminant function *versus* that of the first discriminant function for each of the individual productions. It can be derived from Fig. 5 that the separation is based on the first discriminant function only. It explains almost all of the variability of the data (99.1%).

Tab. 2. Percentage of total variance explained by the principal components of the conducted PCA on DSC data obtained at 0, 1 and 4 h after production.

PCA	PC1	PC2	PC3	PC4	Total
DSC 0, 1, 4 h	68.522	15.214	5.68	4.163	93.580
DSC 1, 4 h	72.496	13.189	6.425		92.110
DSC 0, 1 h	64.753	20.691	7.448		92.891
DSC 0, 4 h	68.283	15.269	6.384		89.936

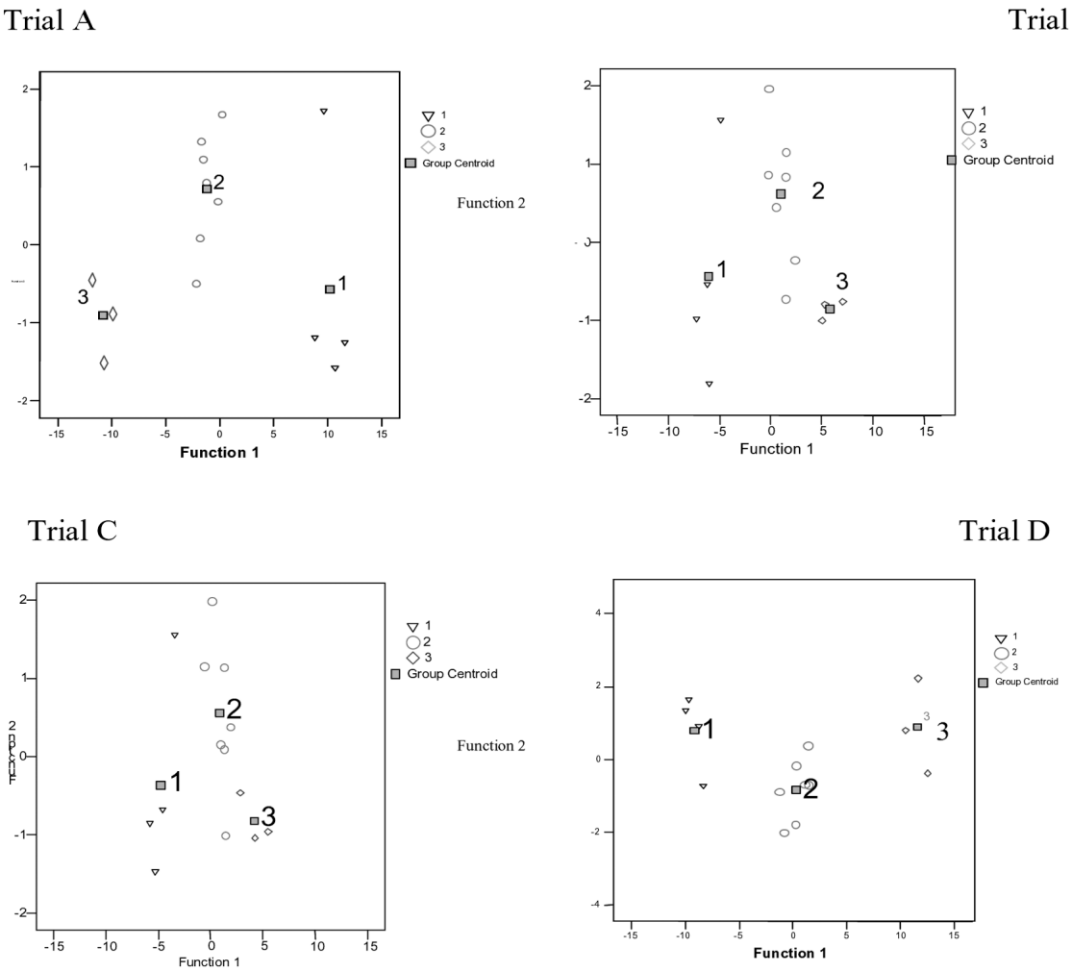

Fig. 5. Trial A: Four PC + SFC + hardness at 0, 1, 4 h after production (100%, 100% cross). Trial B: PC 1–2-3 + SFC + hardness (0, 1, 4 h) (100%, 57.1% cross). Trial C: PC 1 + 3 + SFC + hardness (0, 1, 4 h) (100%, 64.3% cross). Trial D: PC 3 + SFC + hardness (0, 1, 4 h) (100%, 100% cross). 1 = before week 8, 2 = between week 8 and week 13, 3 = later than week 13.

3.4.2 Step 2: Reduction of the number of principal components in discriminant analysis

In a second step, it was investigated whether all principal components are needed to obtain a good classification. The discriminant analysis conducted with principal components 1, 2 and 3 (trial B) and principal components 2 and 3 (trial C), combined with SFC and hardness values, leads to 100% correct classification using regular classification, but when cross-validation is used, these percentages drop to 57.1% and 64.3%, respectively. The discriminant analysis conducted with only the third principal component (plus SFC and hardness values, trial D) leads to exactly the same classification percentages as the one carried out in trial A: 100% correct classification, even when cross-validation is used. The visual representations of trial A and trial D (see Fig. 5) reveal a broader distribution of the batches, which makes it easier to split them into groups. In trial B and trial C, on the other hand, the individuals lie closer to each other, which makes a good separation more difficult and explains the lower percentages found in the cross-validation.

From these results, it can be concluded that of the principal components, only the third principal component is necessary to get a good classification. The first and second principal components, however, account for most of the total variance. The reason for this is that these principal components are mainly determined by the amount of added butter oil and are thus of minor importance for the prediction of fat bloom. The third component is thus found to be the most important one and is mainly determined by the areas extracted from the DSC analyses at 4 h storage time.

3.4.3 Step 3: Reduction of number of techniques included in discriminant analysis

In a further step, it was investigated which techniques are necessary to obtain a good classification. To this end, the discriminant analysis was carried out with the third principal component and the SFC values at the three storage times (trial E) or the hardness values at the three storage times (trial F). Tab. 1 shows the classification percentages for these trials. Discriminant analysis based on the third principal component and the SFC values at the three storage times leads to 67.3% correct classification using the regular classification method and 14.3% using cross-validation. When discriminant analysis was carried out on the third principal component and the hardness values at the three storage times, the percentages were 64.3% for the regular classification and 28.6% for cross-validation. Trial G investigated whether it was possible to get a good separation based on SFC and hardness values at the three storage times, without considering the DSC analyses. Using the regular classification, 100% of the individual productions are correctly allocated; using cross-validation, this value decreases to 71.4%, which is still an acceptable separation.

These results show that the SFC and hardness values are necessary to provide a good separation, but that DSC can possibly be left out. Excluding DSC results invokes a decrease in correct classification for the cross-validation, but the split into groups is still acceptable.

3.4.4 Step 4: Reduction of storage times included in discriminant analysis

In this step, it was investigated which storage times could be left out, while still allowing a good classification. The principal component analyses carried out on different combinations of two storage times led in each case to three principal components (Tab. 2). The third principal component proved again to be the most important one, as explained in paragraph 3.2.1. Trial I was based on the third principal component derived from the DSC results at 1 h and 4 h after production and the SFC and hardness values at these storage times. This combination of variables led to 100% correct allocation, both with the regular classification method as with cross-validation. Discriminant analysis was also performed on the third principal components extracted from the DSC results at 0 h and 1 h after production (trial N), and 0 h and 4 h after production (trial P) combined with the SFC and hardness values on these storage times. For trial M, this resulted in 92.9% correct classification using the regular classification method and 28.6% using cross-validation. Trial P resulted in 78.6% correct classification using the regular classification method and 28.6% using cross-validation.

Fig. 5 (trial D) and Fig. 6 (trial I) represent the different trials that give 100% correct classification with the two classification methods. It can be derived that the classification is mainly determined by discriminant function 1, as stated above. It can also be concluded that, although they give the same classification percentages, the split into groups presented in Fig. 5 (trial D) has a superior quality compared to the one presented in Fig. 6 (trial I). Considering the difference, it is clear that an acceptable separation can be obtained by performing analyses on only two storage times (1 and 4 h after production), but not with any other combination of storage times.

4 Conclusion

Addition of 6% butter oil led to faster fat bloom development. The bloom-inhibiting effect at lower concentrations of butter oil could not be confirmed, but this may be explained by the fact that only 3% of butter oil were investigated.

The results of this research show that analyses with the selected techniques (DSC, pNMR, texture analysis) shortly after production (0 h, 1 h, 4 h) provide enough information to predict migration fat bloom development. It is also shown that analyses at 0 h can be left out without compromising the classification too much. Texture analysis and pNMR were shown to be inevitable for a good separation.

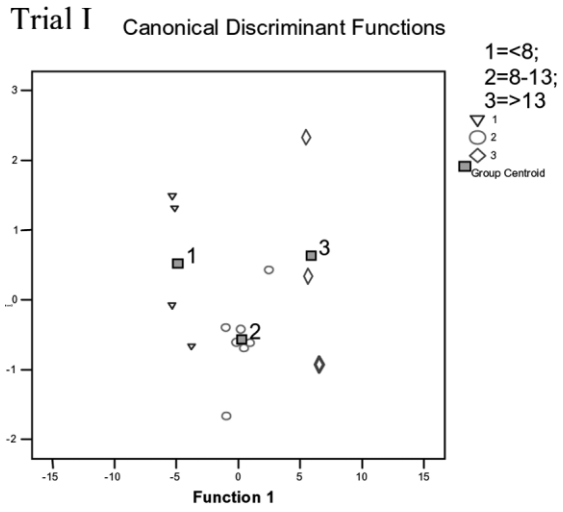

Fig. 6. PC 3 + SFC + hardness at 1, 4 h after production (100%, 100% cross).

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