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Automated image analysis tool for migration fat bloom evaluation of chocolate coated food products

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Abstract

Migration fat bloom remains a major problem in the production of coated confectionary products where a layer of chocolate is added around a filling or other fat containing substrate. Fat bloom quantification is typically done by a human panel scoring samples in time using a low resolution discrete scale. In view of developing a mechanistic model for migration fat bloom, it is important to have a higher resolution. In this paper, a new, high resolution quantitative method based on image analysis is developed. The method is able to detect both the evolution of fat bloom in terms of the disappearance of gloss and the development of ''whitish'' portions at the chocolate surface. It was successfully applied to distinguish the difference in fat bloom development rate between samples containing different fat concentrations (0, 3 and 6g/100g) coated on fillings containing different amounts of fat (25 and 75g/100g). In the 25g/100g filling fat case, blooming occurred at a very late stage and was caused by the disappearance of gloss. In the 75g/100g filling fat case the development of a ''whitish'' surface was responsible for the change in acceptability. The newly developed image analysis method is a solid alternative for the panel procedure.

Keywords: Migration fat bloom; Image analysis; Confectionary; Chocolate coated products

1. Introduction

By far, most important reason for the shelf life limitation of chocolate products is the occurrence of fat bloom. A bloomed chocolate is characterized by a change in colour and loss of gloss giving a greyish white appearance to the chocolate surface. 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. Obviously, when the product reaches this state, it can no longer be sold and, hence, results in product losses (Lonchampt & Hartel, 2004).

There are different kinds of fat bloom: fat bloom on block chocolates and fat bloom on filled chocolates. Theories of fat bloom development on plain chocolate fall into two main groups: phase separation of the high- and low-melting triacylglycerols with the high-melting triacylglycerols causing fat bloom and polymorphic transformation from a βV to a βVI polymorphic form (Bricknell & Hartel, 1998). Fat bloom on filled chocolates is believed to originate from migration of filling fats to the surface of the product (Ziegleder, 1997).

However, the exact mechanism for both cases is not yet completely understood and, hence, current actions taken to avoid or delay the occurrence of fat bloom are merely based on trial and error. There is also no thorough insight in the influence of chocolate and filling composition and of processing variables on the rate of fat bloom occurrence. Moreover, there may be interactions between these factors as well. An additional problem is the considerable time delay between the chocolate production and the occurrence of the problem.

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Mathematical models have been proven to be powerful tools to develop understanding of complex phenomena taking place (Foubert, Vanrolleghem, Vanhoutte, & Dewettinck, 2002). However, these models need thorough calibration and validation prior to being used in practice in a reliable manner. This implies that high-quality measurements of all important variables are needed. Thus, a high-resolution scale is needed in order to distinguish several degrees of fat bloom.

In practice, however, the fat bloom assessment is often performed on a semi-quantitative basis by using a (trained) human panel evaluating chocolate samples based on a low-resolution scoring scale (e.g. 5 levels). Moreover, this approach is quite subjective as different members of the panel might use a different ''reference'' level and, hence, tend to give higher or lower scores compared to other panel members. This gives rise to large variations (i.e. low confidence level), making the results doubtful from a statistical point of view.

In literature also, some instrumental methods to quantify fat bloom have been described.

Whiteness Index (WI) is the most widely used colour parameter in chocolate storage studies. It is determined by measuring the L^*, a^* and b^* values using a commercial colorimeter and converting them to WI values according to the following equation (Bricknell & Hartel, 1998):

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

However, Lonchampt & Hartel (2006) discovered that the WI did not change significantly despite visual detection of numerous white spots. Apparently, the WI method of characterizing bloom is thus not as sensitive as the visual determination.

Apart from using a colorimeter, it is also possible to obtain the L^*, a^* and b^* values and thus the WI value using a computer vision system combined with image analysis (CVSIA). Kumara, Jinap, Che Man, and Yusoff (2003), Briones and Aguilera (2005) compared both methods. The former concluded that the WI using the colorimeter had low coefficients of variance below 1% while the measurement using the CVSIA showed relatively high coefficients of variance between 0.1 and 14%, but they could not detect any significant differences between the two methods. The latter on the other hand did detect significant differences between the data obtained by both techniques. They ascribed this to the fact that the CVSIA technique acquires an image of the whole sample under controlled and reproducible conditions and a computer with specialized software is used to conduct pre-defined visual tasks, while with a colorimeter an average value from a few locations over the surface is obtained.

Briones and Aguilera (2005) also suggested two other parameters to be derived using the CVSIA technique. The first is the percentage of bloomed surface calculated as the sum of the areas having a whitish background and the areas showing white specks. These were in turn determined by dividing the grey-scale histogram into three zones: pixels over a grey value of 250 were assigned to white specks; those in the interval between 30 and 249 were defined as belonging to the whitish background and pixels between 0 and 29 were ascribed to the original background. For the second parameter, analysis of the Fourier spectrum of an image permits extraction of a single descriptor that represents the image texture, i.e. the spatial variability of the grey levels of pixels over the whole image, based on the contents of the image. They observed that this descriptor E^* (energy of Fourier) stayed close to 0 for the first 36 days of storage meaning that the image texture remained unchanged. Major changes occurred between days 39 and 45 followed by a slower progress until the end of the storage period. The shape of the curve seemed to indicate that texture image development (as represented by E^*) trails development of the whitish background by a few days.

Pastor, Santamaria, Chiralt, and Aguilera (2007) measured the chocolate gloss using a commercial gloss meter and measurement angles of 60 and 85°. These large angles of light incidence allowed to differentiate samples with low gloss by intensifying the specular gloss component. They detected a significant influence of measurement position on the gloss, reflecting once again the heterogeneity in the surface of the material.

This paper, introduces a new high-resolution method based on automated image analysis to follow fat bloom. In parallel, the same chocolate samples were scored using a panel to be able to compare both methods.

2. Materials and methods

Six different batches of chocolate coatings on a filling material were produced by Barry–Callebaut (Wieze, Belgium). The batches differed in level of added butter oil (0, 3 and 6 g/100 g) in the chocolate layer and the ratio of hazelnut filling (50 g/100 g sugar and 50 g/100 g hazelnuts) and standard chocolate in the filling material (25 or 75 g/100 g hazelnut filling). The samples were produced in small cylinders (height: 5 cm, radius: 2 cm) by adding a 0.5 cm chocolate layer on top of a 3.5 cm filling layer. The different samples were stored at 20 °C and monitored in time for 1 year (or shorter in case fat bloom was fully developed at an earlier stage) by analyzing three samples on a (2-) weekly basis. At the end of the period, the number of samples was reduced to two as fat bloom developed slower as expected. Analysis consisted of fat bloom evaluation by (1) a panel and (2) a newly developed image analysis procedure.

The panel consisted of three people, independently giving scores to three samples of the same batch. The mean and standard deviation of the nine values were then calculated and further used. They scored the samples on a scale between 0 and 5. 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: they product clearly shows white spots or a grey film,
- 5: the product has turned completely white.

To feed the image analysis algorithm, pictures of the samples need to be taken. For this purpose, an image analysis set up was built (Fig. 1) in order to standardize the procedure of taking pictures. The set up consisted of a digital camera (Sony DSC V1 5 MP 4× optical zoom) and two TL-D light sources (Philips, The Netherlands). The samples were placed on a support at a height of 6.5 cm from the table. On this support, a white piece of paper was placed to form the background of the images. The camera was mounted parallel above the sample with a focal distance of 10 cm. Light sources were mounted on both sides of the sample at a height of 40 cm and a horizontal distance of 13 cm from the sample. The light sources are needed to ensure a constant luminescence which is important for the further analysis of the pictures. To ensure this, luminescence was measured with a Lux meter (LM631 Fluke).

The resulting pictures from the digital camera are in TIFF format and have a resolution of 5 Megapixels (2592 × 1944). The pictures are in 24-bit RGB-colour format (8-bits for Red–Green–Blue) resulting in a file size of 14Mb per picture.

An example of a typical picture with and without fat bloom is shown in Fig. 2. Each picture shows a circle representing the surface of the chocolate sample on a whitish background. Due to standardization, the chocolate sample is always at the same location in the picture. In total, 750 pictures were taken.

3. Image analysis procedure

In order to set up the procedure, the goals had to be clearly defined. Due to the nature of fat bloom development, two different aspects should be detectable (1) the disappearance of the gloss and (2) the appearance of "whitish" areas on a "dark" background. The collected pictures were analysed using an image analysis procedure developed in the IMAQ Vision Builder (National instruments, USA).

An important part of the procedure is the extraction of the Region of Interest (ROI) in the pictures, as one is not interested in the background. The developed procedure is outlined below and consists of four steps: (1) picture format conversion, (2) selection of ROI, (3) analysis of ROI and (4) automation of procedure.

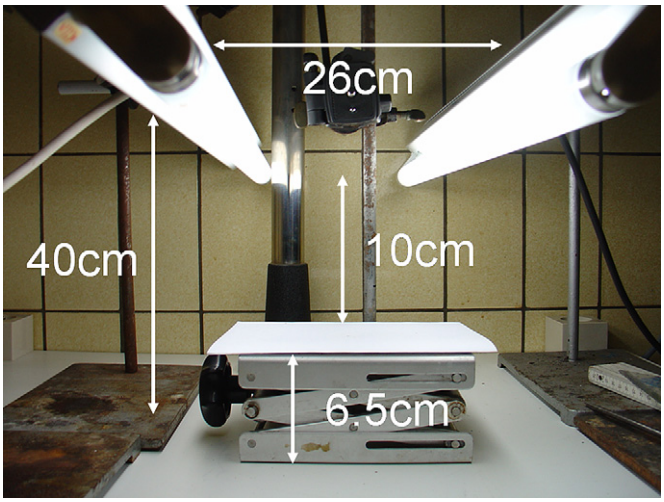

Fig. 1. Image analysis set up.

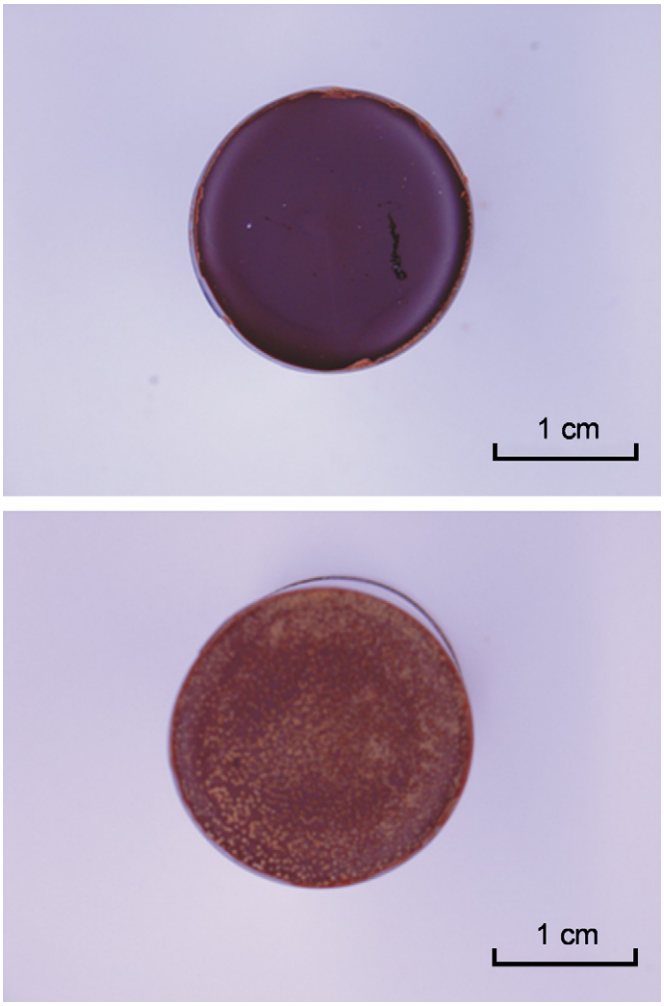

Fig. 2. Typical pictures resulting from the image analysis set up: without fat bloom (top), with fat bloom (bottom).

3.1. Step 1

As mentioned before, every picture consists of three 8-bit colour layers (RGB). However, the colour information is too complex for this application and would not yield the necessary information needed to reach the defined goals. Therefore, the pictures were first converted into the HSL colour-scale (Hue, Saturation, Luminescence). In this scale, luminescence represents the picture in an 8-bit resolution greyscale (0–255). The latter will allow for distinction between white and darker areas on the chocolate surface which is one of the defined goals. The luminescence can be calculated from the RGB data with the following equation (MacDougall, 2002):

$$L = 0.299R + 0.587G + 0.114B$$

Note that this conversion reduces the memory needed for storage as only one out of the original three planes (RGB) is

maintained. An example of this conversion is shown for the fat bloom picture of Fig. 2 (Fig. 3).

3.2. Step 2

A standard picture typically consists of a background and a circle representing the chocolate sample. Obviously, only the chocolate surface is of interest. Hence, this part needs to be extracted from the picture. In order to do so, an edge detection algorithm called ''spoke'' was used. This algorithm defines two concentric circles and calculates a number of line profiles along lines perpendicular to the circles. In this application, the first circle radius was chosen to be zero (i.e. representing one point). This is useful as all pictures are standardized and this point can be chosen inside the chocolate surface. Fig. 4 shows the selected lines along which line profiles are calculated. It can be seen that along these lines a clear difference in greyscale will occur when moving from the chocolate surface to the background. This is illustrated in Fig. 5, where 255 represents white and 0 represents black in the greyscale. Based on all line profiles along the lines shown in Fig. 4, the algorithm can compute a circle that represents only the chocolate surface. This circle is also drawn in Fig. 4. In order to avoid boundary effects, the radius is reduced by 200 pixels. By using a mask function, this ROI was extracted from the picture and used for further analysis.

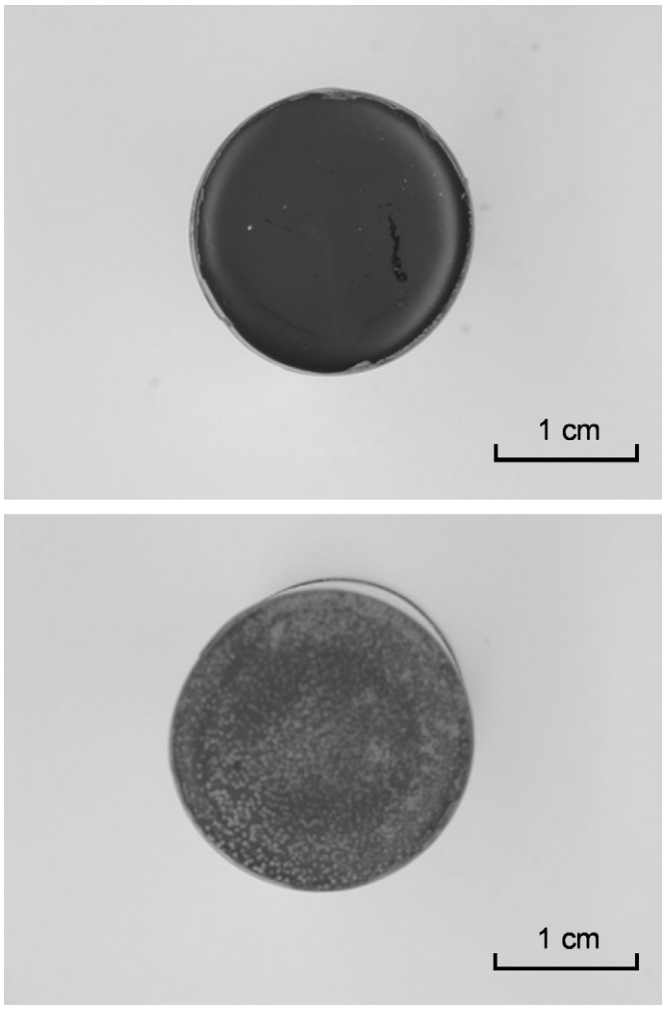

Fig. 3. Example of a picture transformed from the RGB-colour scale to the luminescence layer of the HSL colour-scale.

3.3. Step 3

Steps 1 and 2 resulted in the luminance (greyscale) layer of the chocolate surface. This region can now be analysed. The analysis consists of calculating a histogram based on the greyscale pixel information. Such a histogram reveals the number of pixels that exhibit a certain grey value. A typical histogram for a bloomed and a non-bloomed sample is shown in Fig. 6. Here, it should be noted that the radius of the optimal circle of the non-bloomed sample was reduced by even more than the 200 pixels mentioned in step 2. The reason for doing so is that some light reflection occurs near the cylinder walls as the sample surface has a small slope near the walls. This should not be taken into account here (as it will influence histograms in a non-standard way) and cannot be avoided from an experimental point of view. When comparing bloomed and non-bloomed histograms, it can clearly be observed that blooming (in terms of development of whitish area) can be distinguished by the proposed procedure. In fact, a shift to higher grey values (i.e. ''whiter'' values) is observed, as well as the development of a more pronounced tail in the histogram. In order to compare histograms of several samples, a mean pixel value is calculated as the summarizing parameter of one histogram.

Apart from being able to detect the ''whitish'' areas, another goal of the image analysis method was to detect the loss of gloss. For this, the reflection discussed earlier (and ignored in the histogram determination of non-bloomed samples) was used. Indeed, the reflection phenomenon faded out over time as gloss was disappearing. The occurrence of this reflection can easily be checked by performing step 2 and 3 iteratively (on the same sample) for different circle radii, starting with the one resulting from step 1 and subsequently decreasing it. This will result in a change in histogram as

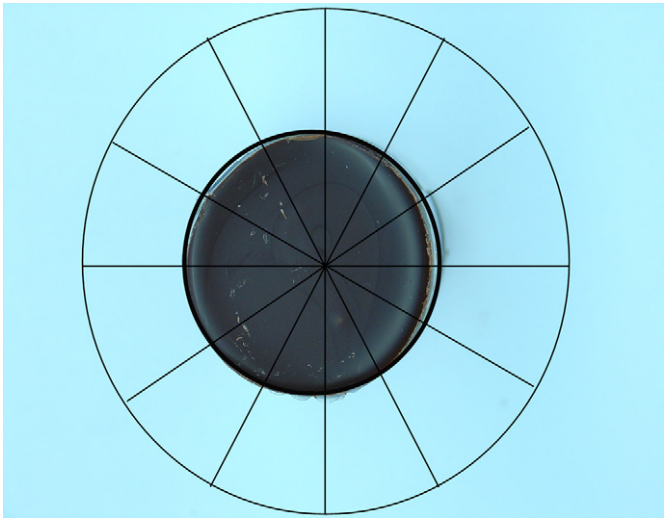

Fig. 4. Illustration of the edge detection algorithm to determine the ROI.

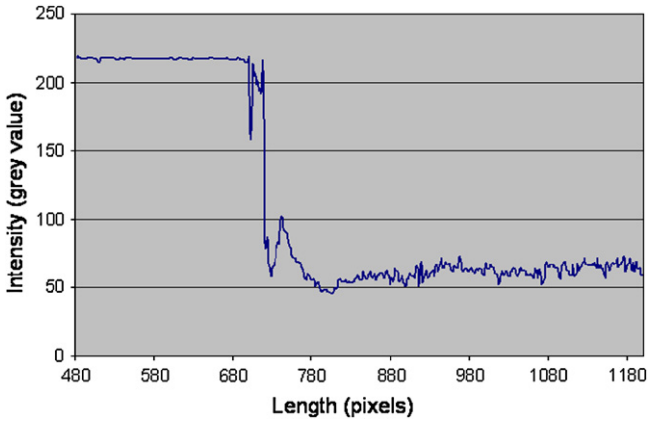

Fig. 5. Example of a line profile along a line going from the chocolate surface to the background.

function of radius if the reflection is present, whereas no difference will be observed when reflection is not present. This is illustrated in Fig. 7, where histograms are shown for the full radius (0) and a radius decrease of 200 pixels (−200). It can clearly be observed that the full radius histogram has a lower peak and large tails, whereas this is not the case for the reduced radius case. Further decreasing the radius did not result in changes in the shape of the histogram anymore.

3.4. Step 4

The outlined procedures were automated by writing a Virtual Instrument (VI) in LabView (National Instruments). Upon picture selection by the user, the VI outputs the histogram, their summarizing parameters and whether or not gloss has disappeared.

4. Experimental results and discussion

4.1. Results from the panel method

The results of the panel evaluation are shown in Fig. 8. As the panel consisted of three people and three samples of each batch were scored per panel member on each time instant, standard deviations based on nine repetitions are indicated as error bars.

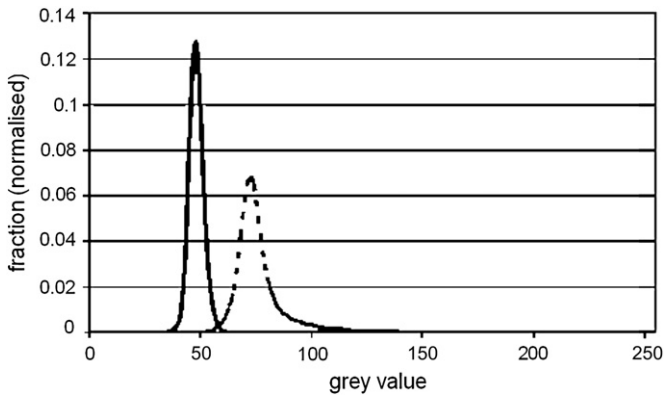

Fig. 6. A typical greyscale histogram of a chocolate surface for a bloomed (- - -) and non-bloomed sample (——).

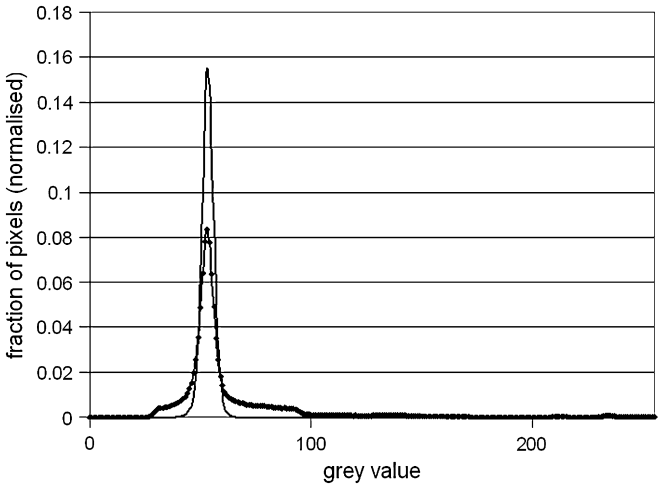

Fig. 7. Illustration of the procedure to detect the presence of gloss on the chocolate sample. Histograms of the original circle with radius R (—◆—) and a circle with a radius R −200 pixels (——).

For the 25 g/100 g hazelnut filling fat samples (Fig. 8, top), it can be observed that only the case of 0 g/100 g added butter oil reaches the value of 5 (completely bloomed). The other two (added butter oil 3 and 6 g/100 g) did not reach this value. In practice, the product is, however, considered as not being marketable once a value of 3 has been reached. This would imply 42 and 51 weeks for, respectively, added butter oil contents of 0 and 3 g/100 g. In case of 6 g/100 g butter oil, the threshold is not even reached after 68 weeks. These values are rather high and it should be noted that this is due to the thickness of the chocolate layer used in this research which is not realistic but was chosen for research purposes only. It can also be noticed that the curves are not smooth and that scores move up and down. The latter is not really expected (apart from the bump occurring around weeks 12–14, as there were technical problems with the cooling chamber), but whether this is an artifact of the sample set up (at each time instant other samples were scored as samples were destroyed for other analyses) or the scoring method itself could not be concluded. The standard deviations are also large. It was observed that these deviations were stemming both from variation between the three samples and variation between panel members. The latter confirms the subjective character of this panel method.

For the 75 g/100 g hazelnut filling samples (Fig. 8, bottom), observations are similar as the ones discussed above. All samples, however, reached a value of 5 in a much shorter time frame (i.e. 37 weeks), which is due to the higher amount of hazelnut fat present in the filling which obviously speeds up the fat migration through the chocolate layer. Also, here one can observe non-smooth profiles and large standard deviations. A value of 3 is reached at weeks 24, 27 and 29 for butter oil contents of 0, 3 and 6 g/100 g respectively (note that the bump in the butter oil 0 g/100 g around week 14 is discarded as a problem with the cooling chamber was experienced).

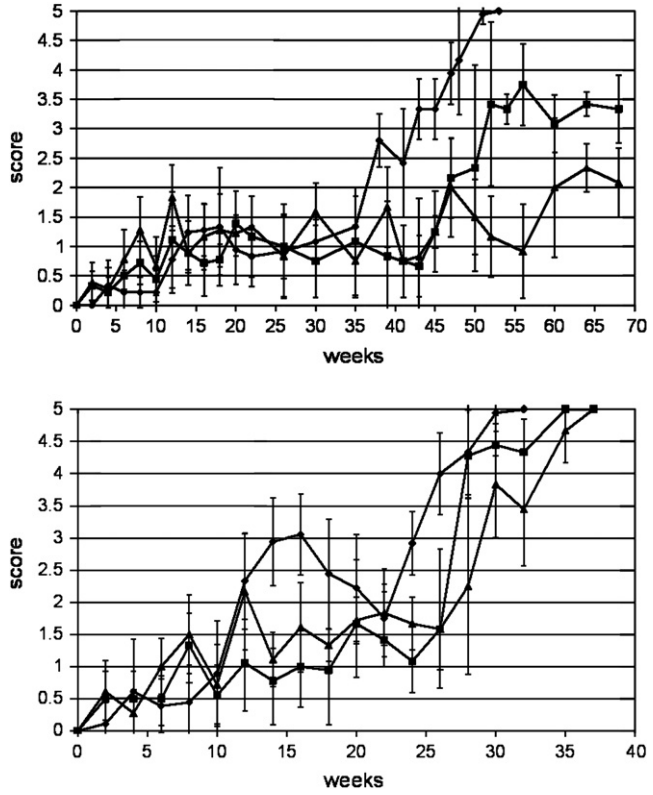

Fig. 8. Results of the panel evaluation (scores) of the six batches including standard deviations. Filling fat content 25 g/100 g (top) and 75 g/100 g (bottom). Butter oil concentration: 0 g/100 g (—◆—), 3 g/100 g (—●—) and 6 g/100 g (—▲—).

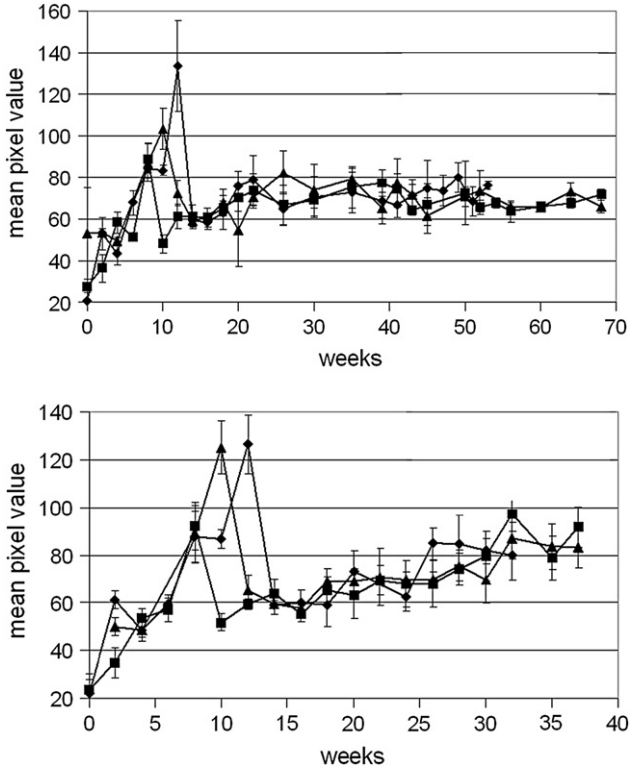

Fig. 9. Results of the image analysis of the six batches including standard deviations. Filling fat content 25 g/100 g (top) and 75 g/100 g (bottom). Butter oil concentration: 0 g/100 g (—◆—), 3 g/100 g (—●—) and 6 g/100 g (—▲—).

4.2. Results from the image analysis procedure

The results of the image analysis procedure are shown in Fig. 9. As three samples were analysed for every time instant and two pictures were taken per sample, standard deviations (based on six repetitions) are displayed as error bars.

For the 25 g/100 g hazelnut filling samples (Fig. 9, top), an increasing mean pixel value is observed for all added butter oil contents. The value starts between 20 and 30 and reaches a steady state or equilibrium value around a mean pixel value of about 70. From this increase, it can be concluded that fat bloom has developed as higher greyscale values indicate a ''whiter'' colour. The fact that a steady state is reached could mean that the bloom has fully developed in all cases. However, it might also mean that the bloom is developing at a very small rate, which might be possible as the amount of migrating fat is small in these samples. Apart from the time period around week 12 (due to problems with the cooling chamber), the profiles look a lot smoother compared to the panel results. Also the standard deviations are smaller indicating more reliable results.

For the 75 g/100 g hazelnut filling samples (Fig. 9, bottom), similar results were found. Mean pixel values start at a value between 20 and 30 and increase up to values around 80–90. It should be noted that these end values are somewhat higher compared to the 25 g/100 g hazelnut filling samples. Moreover, it can be seen that no steady state has yet been reached. The latter means that changes at the surface are still occurring. This might be explained by the high amount of hazelnut fat present in the filling. Again, a bump is observed around week 12. Apart from that, the profiles look smooth and the standard deviations are relatively small.

4.3. Comparison of the panel and image analysis procedures

When comparing the panel and image analysis procedure two issues can be discussed. First, the reaching of a steady state seems to be in contradiction. For example, in the 25 g/100 g hazelnut filling case, the panel suggests a pseudo steady state up to weeks 35–45 after which an increase is observed. In the image analysis procedure, a steady state is observed from week 20 onwards and is maintained until the end of the experiment. However, the final increase observed by the panel results in a change in classification from acceptable (below 2) to unacceptable (above 2). Based on only the greyscale, this change cannot be detected by the image analysis procedure. From this, it can be concluded that the change observed by the panel is not due to a development of a ''whitish'' surface. Hence, the change is possibly due to a disappearance of gloss as will be discussed below. For the 75 g/100 g hazelnut filling samples, the results are not contradictory. In the panel scoring, a pseudo steady state holds until weeks

22–27 after which a sudden increase is noted. This can also be observed in the image analysis results, be it less pronounced. Also, the order in which this happens (first butter oil 0, then 3 and 6 g/100 g) is similar for both methods. However, at the end of the observation period the bloom seems to be not fully developed as observed from the image analysis results. For the panel method, the occurrence of a steady state could not be observed as sampling stopped when all panel members scored the sample with a maximum value of 5. In this case, the change from acceptable to unacceptable can be detected with the image analysis method and can be explained by a development of a ''whitish'' surface. Based on these observations, a threshold mean pixel value of 75 could be proposed for the image analysis method for deciding on the acceptability of the chocolate sample. This threshold would result in the similar conclusions for the 75 g/100 g hazelnut filling samples for both methods (Table 1). However, this threshold would still detect acceptable samples for the 25 g/100 g hazelnut filling case as this threshold of 75 is not always exceeded (except for the case of 6 g/100 g butter oil). Hence, the method needs to be extended for this case as a pixel threshold is not enough to draw a correct conclusion in terms of acceptability for some of the samples. Next, the issue of gloss disappearance will be discussed which provides a solution to the latter problem for the 25 g/100 g hazelnut filling cases.

4.4. Determination of gloss disappearance by image analysis

The gloss disappearance was determined by the image analysis procedure described in the Materials and Methods. The results for the six batches are shown in Table 2. For the 25 g/100 g hazelnut filling samples, the disappearance of gloss coincides well with the increase after pseudo steady state in the panel results (Fig. 8, top). This confirms the fact that the observation of the panel is not the development of a ''whitish'' surface, but merely the disappearance of gloss as suggested in the previous section. For the 75 g/100 g hazelnut filling samples, the disappearance of gloss occurs at a later instant than the occurrence of a ''whitish'' surface. Hence, in this case the change in acceptability is not due to disappearance of gloss.

From these observations, it can be concluded that the combined image analysis procedure – determination of ''whitish'' surface and disappearance of gloss – can be used to detect the onset of fat bloom and, hence, is a valid alternative for the panel method. A mean pixel value threshold of 75 is suggested combined with the onset of gloss disappearance. The image analysis procedure has some advantages over the panel procedure: (1) the standard deviations are much lower indicating more reliable and objective results, (2) conditions are standardized, (3) the resolution is higher making the method more sensitive, (4) it can be easily automated, (5) no skilled personnel is needed, the latter two reducing the staff cost significantly and (6) can differentiate between the fat bloom caused by gloss disappearance and by formation of a ''whitish'' surface. The latter could be due to a different mechanism and, hence, being able to distinguish them through a measurement technique could become useful when modeling these mechanisms.

Table 1
Comparison of both methods in terms of sample acceptability (expressed as weeks) using a pixel threshold of 75 (for the 75 g/100 g filling fat cases)

	Butter oil (g/100 g)		
	0	3	6
Panel	23	27	27
Image analysis	25	29	28

Table 2
Results of the gloss disappearance by using the image analysis procedure (expressed in weeks)

		Butter oil (g/100 g)		
		0	3	6
Filling fat (g/100 g)	25	43	50	30
	75	26	28	32

5. Conclusions

Two procedures for detecting migration fat bloom were compared (1) a human panel giving scores between 0 and 5 and (2) a newly developed image analysis procedure. The image analysis procedure consists of two parts (1) determination of ''whitish'' parts on the chocolate surface determined by shifts in a greyscale histogram and (2) the disappearance of gloss based on the disappearance of a reflection band.

Both procedures were tested on six batches (different in added butter oil content of the chocolate and amount of hazelnut fat in filling) over a time-period during which fat bloom developed. A mean pixel value threshold value of 75 was adopted to detect the change in acceptability of the chocolate samples. In the 25 g/100 g filling fat case, the blooming occurred at a very late stage. It was proven that the detection of acceptability was due to the disappearance of gloss. In the 75 g/100 g filling fat case, the development of a ''whitish'' surface was responsible for the change in acceptability. For these samples, disappearance of gloss appeared at a later stage.

It can be concluded that the newly developed image analysis method is a solid alternative for the panel procedure.

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References

Bricknell, J., & Hartel, R. W. (1998). Relation of fat bloom in chocolate to polymorphic transition of cocoa butter. *Journal of American Oil and Chemistry Society, 75*(11), 1609–1615.

Briones, V., & Aguilera, J. M. (2005). Image analysis of changes in surface color of chocolate. *Food Research International, 38*(1), 87–94.

Foubert, I., Vanrolleghem, P. A., Vanhoutte, B., & Dewettinck, K. (2002). Dynamic mathematical model of the crystallization kinetics of fats. *Food Research International, 35*, 945–956.

Kumara, B., Jinap, S., Che Man, Y. B., & Yusoff, M. S. A. (2003). Comparison of colour techniques to measure chocolate fat bloom. *Food Science and Technology International, 9*(4), 295–299.

Lonchampt, P., & Hartel, R. W. (2004). Fat bloom in chocolate and compound coatings. *European Journal of Lipid Science and Technology, 106*(4), 241–274.

Lonchampt, P., & Hartel, R. W. (2006). Surface bloom on improperly tempered chocolate. *European Journal of Lipid Science and Technology, 108*(2), 159–168.

MacDougall, D. B. (2002). Color measurement of food. Principles and practice. In D. B. MacDougall (Ed.), *Color in food. Improving quality* (pp. 33–63). Cambridge: Woodhed Publishing Limited.

Pastor, C., Santamaria, J., Chiralt, A., & Aguilera, J. M. (2007). Gloss and colour of dark chocolate during storage. *Food Science and Technology International, 13*(1), 27–34.

Ziegleder, G. (1997). Fat migration and bloom. *The manufacturing Confectioner* 43–44.