Journal of Imaging Science and Technology® 56(2): 020402-1–020402-6, 2012.

Barcode Technique to Visualize and Quantify Chocolate Milk Stability

Flemming Møller
DuPont Nutrition Biosciences ApS, Edwin Rahrs Vej 38, 8220 Brabrand, Denmark
E-mail: flemming.moller@danisco.com

Abstract. *Chocolate milk instability was monitored by time series of images. It is demonstrated how a time series of images can be summarized into a single image, named a stability barcode. The stability barcode is generated by collapsing time series frames to pixel columns and arranging the pixel columns to form the stability barcode. It is demonstrated how image filtering can be used in generation of different and more specific stability barcodes. Chocolate milk defects such as layers could be seen in barcodes generated using a median filter, curdling could be seen in barcodes generated using a standard deviation filter and marbling could be seen in barcodes made using an H-dome filter. Graphs for comparing the destabilization kinetics were deduced from the stability barcodes. The stability barcodes gave a visual summary of chocolate milk instability—the kinetic graphs a precise comparison of specific types of instability. © 2012 Society for Imaging Science and Technology.*
[DOI: 10.2352/J.ImagingSci.Technol.2012.56.2.020402]

INTRODUCTION

Chocolate milk is the most popular flavored milk product worldwide. It is also one of the most difficult flavored milk types to produce. Several factors should be controlled when producing chocolate milk. First, a good grade of cocoa powder should be selected with good flavor and good bacterial quality. As the cocoa particles are not soluble, large cocoa particles tend to sediment at the bottom during storage. Stabilizer compounds are added to chocolate milk to prevent sedimentation and enhancement of the perceived quality. Most stabilizers used in chocolate milk form a weak gel-like structure by interactions with milk proteins. This structure remains intact, while the milk is undisturbed, suspending the cocoa particles in its network, but breaks down as soon as the milk is gently shaken or disturbed during drinking.[1,2]

A stable chocolate milk is visually homogenous throughout the shelf life of the product. The most common types of instability seen in chocolate milk are sedimentation, fat creaming, top whey layer, marbling, or curdling. The formulation, processing, and storage conditions of the chocolate milk can greatly influence the instability type and kinetics of its development.[1]

Received Jun. 28, 2011; accepted for publication Mar. 28, 2012; published online May 22, 2012.
1062-3701/2012/56(2)/020402/6/$20.00.

This article focuses on visualizing chocolate milk defects and stability as a function of time. The aim of this study is to summarize a chocolate milk movie into one image, a stability barcode. Different types of chocolate milk defects can be detected using image filters and hence visualized in stability barcode images. From the stability barcodes can kinetic curves be deducted. Kinetic curves are a precise tool for comparing different chocolate milk formulations—the stability barcodes are for a fast overview of any instability in a chocolate milk.

STABILITY EVALUATION

Chocolate milk can develop instability as a function of storage time, conditions, and composition. The most common types of instability are listed in Table I.[3]

Defects are often due to poor raw materials or processing, i.e., alkalization or too large cocoa particles, too much or too little stabilizer blend, insufficient homogenization, or heat treatment conditions. Layer defects are typically seen in the top or bottom of the product container. Bulk defect are typically seen in large parts of the product—bulk defects are often easily removed by gentle product shaking, unlike layers which can be very difficult to remove by shaking. *Marbling* can be described as a variegated pattern in large parts of the product container. *Curdy* is seen as inhomogenity when pouring product out of a container. It is thought that the curdy inhomogenity is a local gelation taking place in the chocolate milk. A white haze is often associated with curdy products; the white haze is thought to be caused by the gel pressing out to be large protein particles. The *color* may change as a consequence of layer formation[1] or due to oxidation.

Quantification of chocolate milk stability can be done by consumers or better a trained sensory panel.[4] The Turbiscan instrument has for several years been the only instrument for an objective measurement of physical stability of dairy products.[2] The Turbiscan measures the turbidity of a product as function of the height of the emulsion in a vertical tube. Laser light (850 nm) is reflected by the product and increases with the concentration locally present in the product. Furthermore, the measurements can be performed as a function of time. This allows the monitoring of the time-dependent behavior of the chocolate milk.

Table I. Types of instability found in chocolate milk.

Layers	Bulk
Sedimentation	Marbling
Creaming	Color
Whey separation	Curdy (white haze)

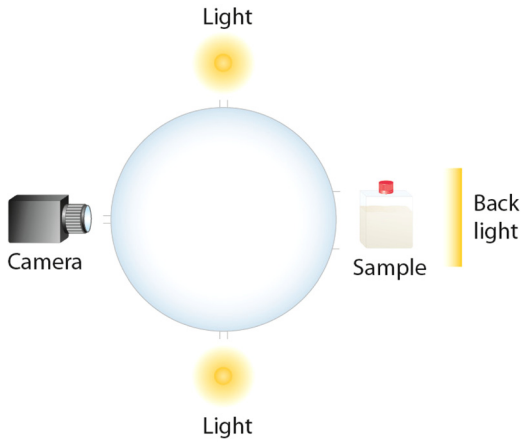

Figure 1. Illustration of instrument setup. A flask with sample is placed at an opening in an integrating sphere. The light source is ten diffuse LEDs and one LED backlight. A multiwavelength image is acquired with a gray tone camera by strobing one LED at a time.

Typical behaviors that can be observed are layers, which appear as a change of the turbidity as a function of height, and phase separation that is recognized by a clear and sharp interface between two phases.

The Turbiscan instrument is good for layer defect but it cannot detect bulk changes such as marbling, curdling, or color changes—The properties that can be seen in human beings, and this is the motivation for developing an image based method for detection of chocolate milk stability.

IMAGING DEVICE

The stability of the chocolate milk was evaluated using a VideometerLiq instrument (Videometer A/S, Hørsholm, Denmark). The instrument is composed of a camera, light emitting diodes (LED) placed in an integrating sphere and a backlight (405–850 nm). The equipment produces diffuse lighting, which ensures homogenous and reflection free images. The instrument generates multispectral images by strobing ten diffuse LEDs and a backlight one at a time. Figure 1 sketches the system setup. The wavelengths used were 405, 450, 470, 505, 525, 570, 630, 660, 700, and 850 nm diffuse LEDs and an 850 nm backlight. The resulting multispectral image is 460×1450 pixels, which correspond to 19×60 mm. Disposable sterile flasks with chocolate milk are placed in the VideometerLiq instrument. An auto sampler that can hold six samples which makes it easy to generate time series of images. Time series of images is necessary for visualization and quantification of any instability.

Table II. Composition of chocolate milk evaluated.

Composition	1	2	3	4	5	6
Total fat	1.48	1.48	1.48	1.48	1.48	1.48
Total MSNF*	2.56	5.48	5.99	5.48	5.48	8.01
Total dry matter	8.63	11.55	16.74	11.55	11.55	14.51
Total carbohydrate	5.58	7.1	12.05	7.1	7.1	8.6
Total protein	1.16	2.3	2.5	2.3	2.3	3.4

*MSNF = milk solid nonfat.

The light's penetration depth into soft materials like chocolate milk is wavelength dependent, i.e., long wavelengths penetrate further than short wavelengths. Long wavelengths are best for bulk properties and short wavelengths are best for measuring surface properties.[4]

CHOCOLATE MILK

To demonstrate different types of chocolate milk instability were six products produced by a standard dairy process (homogenization at 200 bar/70 °C and 137 °C/4 s) and varying the composition, see Table II.

A picture of the six chocolate milks 3 days after production is shown in Figure 2. Samples 1, 2, 4, and 5 appear stable. A closer look reveals that samples 2 and 5 show curdling (white haze/clouds). Sample 3 shows sedimentation and sample 6 marbling and creaming. In Fig. 2 does all samples seem to have a horizontal line one third down in the product—this is a camera artifact/light, since this could not be seen by human beings or the analytical setup.

All chocolate milks were evaluated for 3 days, and a total of 132 spectral images per sample were recorded. Figure 3 shows selected 505 nm images of sample throughout the evaluation period (505 nm had a high signal to noise ratio and was used for all work in this article). The first image from the time series (leftmost image in Fig. 3) shows stable chocolate milk with some air bubbles at the top. A bright top layer is forming soon after production which increases in thickness as a function of time. The same sample also develops marbling (bulk instability) seen as an inhomogeneous structure which forms after production.

STABILITY BARCODES

A time series of images can be converted into one image by collapsing each frame to a pixel column and let the width represent time—all pixel columns are then stacked to one 2D image. Conversion of movie frames to a 2D image is known as movie barcodes.[5] The conversion from a 2D image into a 1D column is done by applying standard image filters and then stacking the median pixel value in each 2D image row (from 2D to 1D). The width of the 1D column is scaled to reflect the period between two frames. All the scaled 1D columns are placed according to their order and together generate the stability barcode, see Figure 4.

In Figure 5, the median barcodes for the six evaluated chocolate milks of Fig. 2. The first measurement (first frame)

Figure 2. Picture of the chocolate milks evaluated at the end of analysis (3 days).

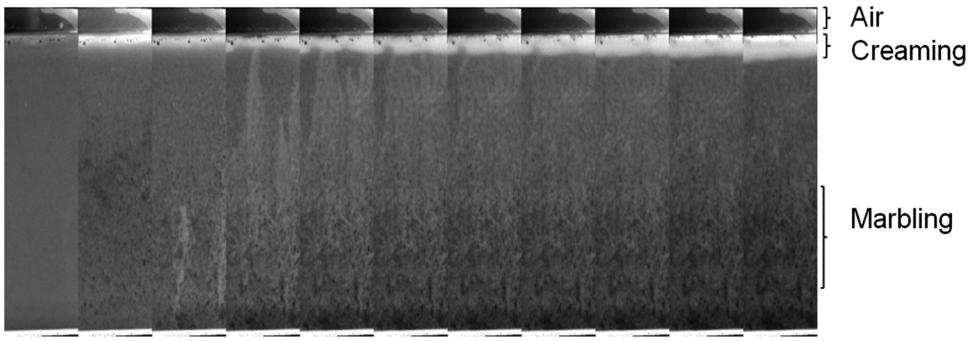

Figure 3. Selected images (11) at 505 nm of sample 6. Fat creaming and marbling defects are seen. The images are taken throughout the evaluation period. The freshly produced chocolate milk is seen to the left, the rightmost image is the same chocolate milk 3 days after production.

is subtracted from each barcode; thereby any intensity differences due to formulation (Table II) and processing removed. The subtraction of the first frame corresponds to centering of data, i.e., for a stable chocolate milk will the barcode remain constant at zero, a sample that becomes darker will have negative values and lightning of a sample will be seen as positive barcode values.

All samples show two very narrow and intense lines which can be explained by sunlight entering the instrument—the third evaluation day was cloudy.

Median barcodes can be used for detection of layers and color changes, see Fig. 5. Layers are seen as horizontal zones, i.e., samples 3 and 5 show sedimentation, sample 6 creaming, and samples 2 and 5 show a whey layer. Fat creaming and whey separation can both be seen as a top layer; the difference is that fat is seen as a white layer and whey as a transparent or black layer, seen, respectively, as a red and blue layers in Fig. 5. A chocolate milk can change color and at the same time be physical stable; this is seen for sample 4. Sample 4 becomes darker after its second exposure to the sun (vertical line seen in the middle of all samples)—no physical change is seen.

Structure development in the chocolate milk can be visualized by using classical image filters to generate the barcode. Marbling in samples 3 and 6 can be detected by calculating *H-domes*[6] on the original frames and summing each row up into the stability barcode, see Figure 6. H-domes are a local maximum finder and are therefor good at finding spots in chocolate milk. Calculating the *standard deviation* in each row and summing up into a barcode generates the result seen in

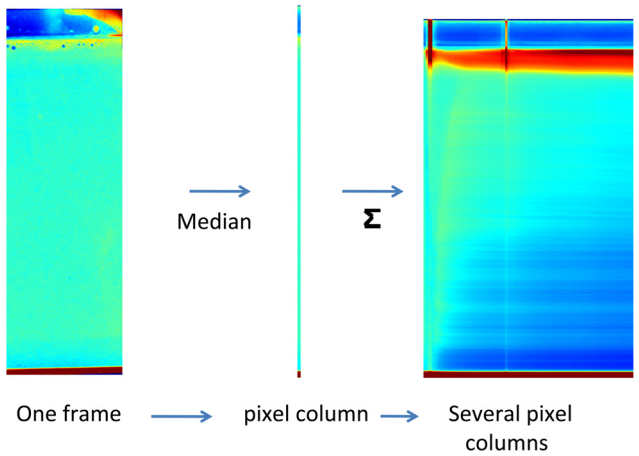

Figure 4. Procedure for generating a stability barcode. Left image is the first frame from the evaluation of sample 6. The median is calculated for pixels in each row of the picture and shown in the middle image. This is repeated for all frames, which then a summarized in the right image; the stability barcode. The x-axis in the stability barcode is a time scale, the y-axis corresponds to the height of image frames and a jet color scale is used.

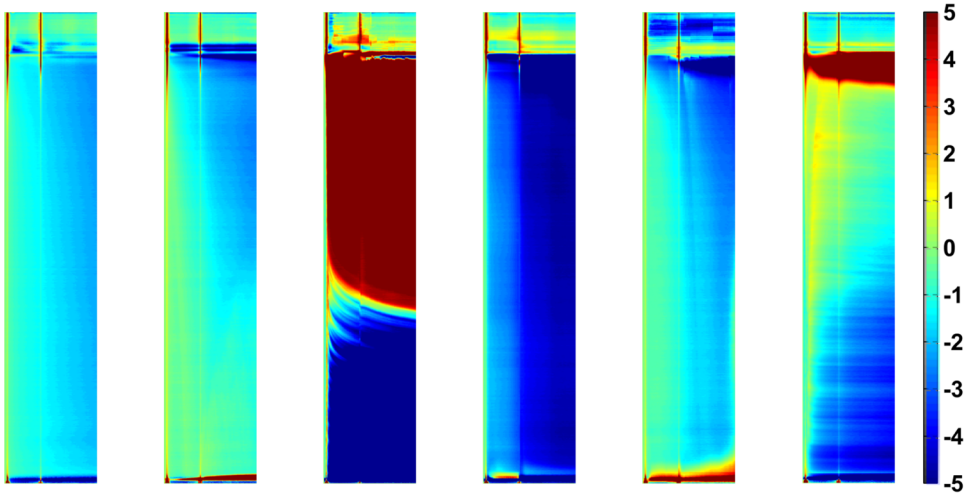

Figure 5. Median barcodes for the 6 chocolate milks. Each barcode represents 3 days of analysis at 505 nm. The x-axis represents time. Column points are calculated by a median filter of the original image rows. No change is represented by green, a darker or lighter color by blue and red, respectively.

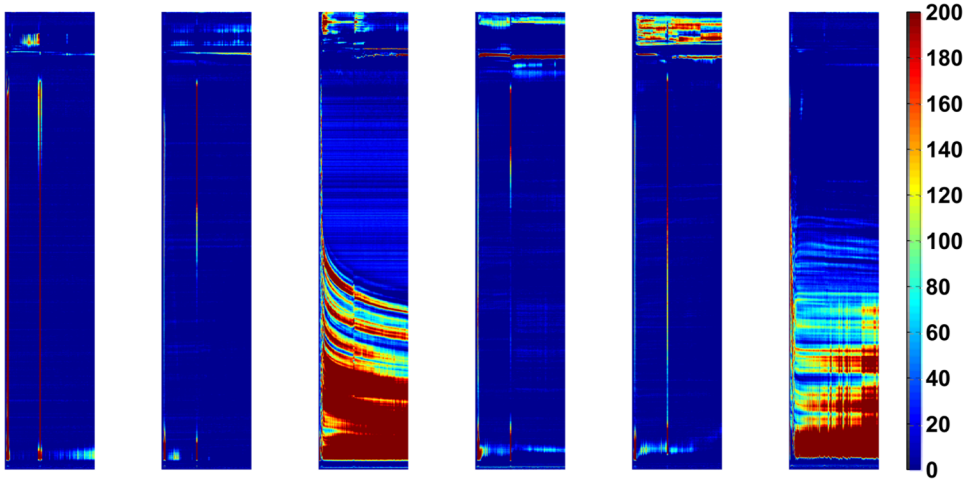

Figure 6. H-domes barcodes for the 6 chocolate milks. Each barcode represents 3 days of analysis at 505 nm. The x-axis represents time. Samples 3 and 6 show marbling developing immediately after production.

Figure 7. The standard deviation shows both marbling and the white haze associated with curdling (samples 3 + 6 and 2 + 5).

KINETIC CURVES

Graphs showing how layers or bulk defects develop as a function of time can be deduced from the barcode images. This is done by defining three regions in each sample: the top, middle, and bottom regions. Unpublished work has shown that the most robust way of quantifying a layer development is by plotting relative intensity changes in these zones. Calculating layer thickness can be difficult (setting a threshold) and gives the same conclusions as the relative method.

The three regions are defined as 15% of the top, middle, and bottom of the flask. Kinetic curves from the three regions and using the three different filters (median, H-dome, and standard deviation) are shown in Figure 8. All kinetic curves start at 0 (by subtracting the first measurement); a stable sample with no destabilization or color change will have a constant value (0) throughout the evaluation period.

Median Barcode

Layer defects are best seen using the median filter and looking at the top and bottom regions (leftmost column, top, and bottom graph). Sample 3 is very unstable and has a high level of sedimentation, which is seen as rapid decrease in reflection. Due to the severe cocoa sedimentation, sample 3 is also changing color in the top and middle parts of the flask; this is seen as increased reflection. Sample 6 shows an increased reflection in the median-top graph this is due to a fat layer forming at the top of the flask. The median-top graph also indicates less reflection from sample 4 due to a whey or water layer forming on the top of the sample. The median-middle graph is good for detecting any color changes: sample 4 becomes darker maybe as a result of

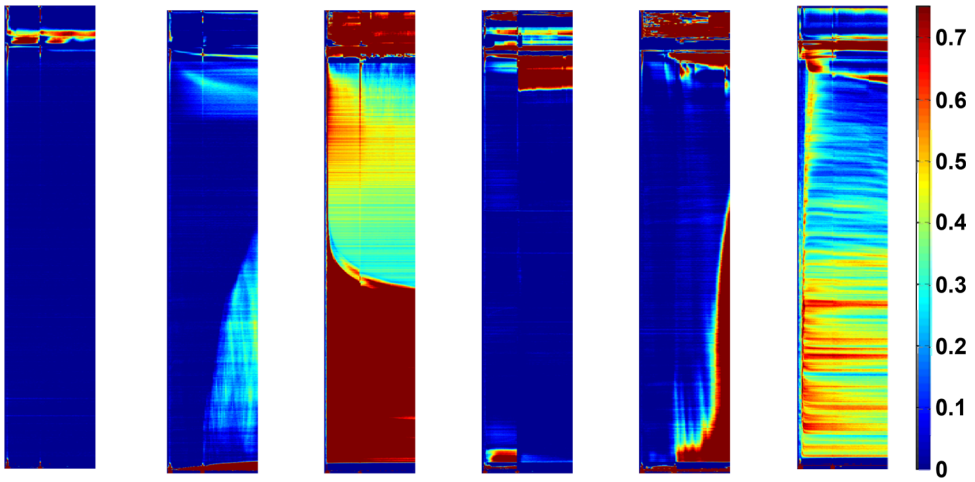

Figure 7. Standard deviation barcodes for the 6 chocolate milks. Each barcode represents days of analysis at 505 nm. Blue colors indicate a homogeneous product. A high standard deviation is seen for samples with marbling (samples 3 and 6) and for samples with curdling (samples 2 and 5).

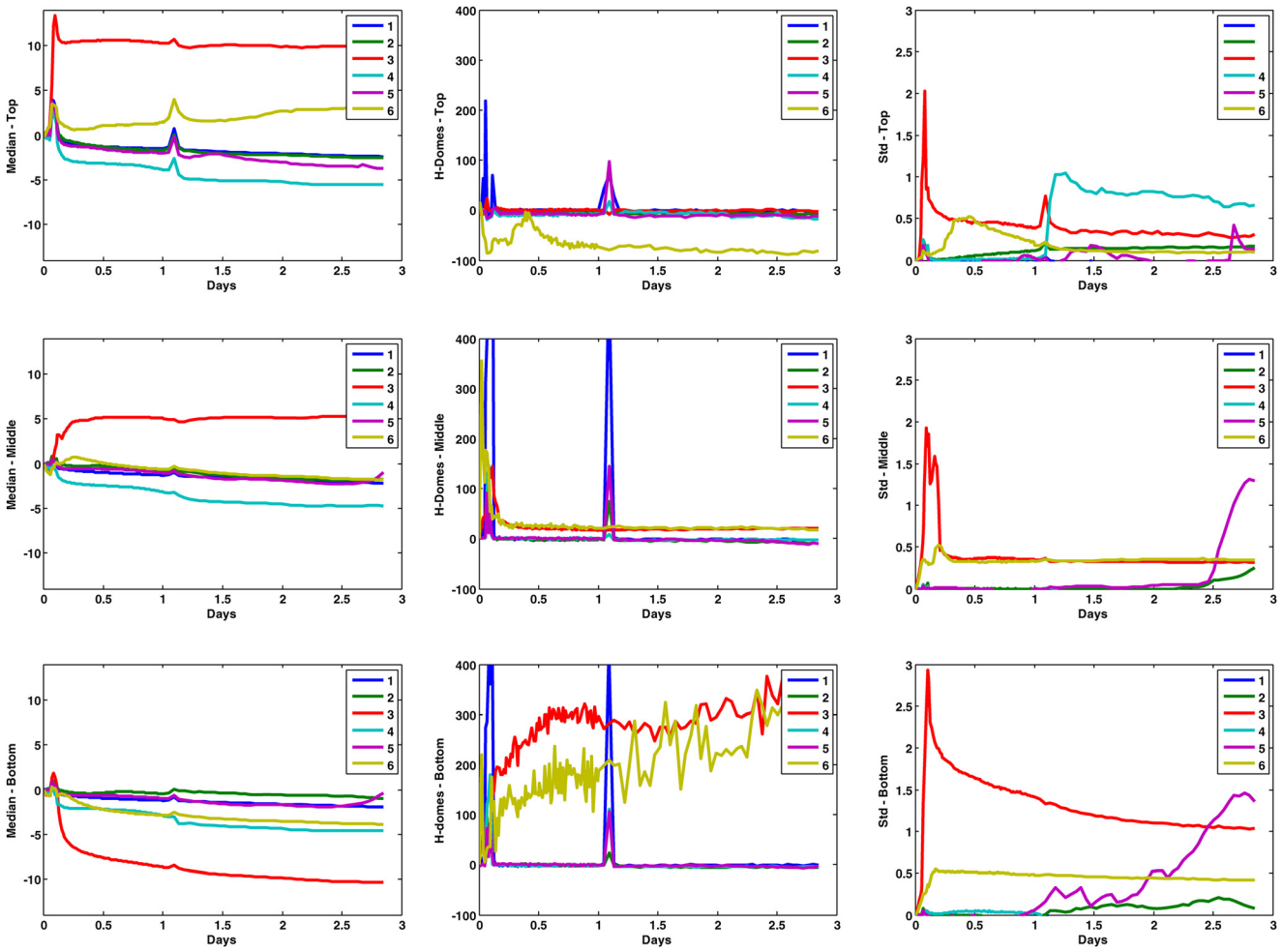

Figure 8. Kinetic curves for the 6 chocolate milks. The three rows illustrate intensity changes in the top, middle, and bottom regions. Graphs in the left column were deduced from median barcodes, graphs in the middle column were deduced from the H-dome barcodes, and the right column from the standard deviation barcodes.

aggregation or oxidation of particles (particle sizing was not performed). Sample 3 becomes light due to sedimentation of the cocoa particles.

H-domes Barcode

The H-domes' kinetic graphs are seen in the middle column. The marbling in samples 3 and 6 is detected using the H-dome filtering. The marbling is mainly seen in the bottom of the flask and only in the bottom graph. As the instrument was exposed to direct sunlight, there are two spikes which are easily seen (on day 0 and day 1).

Standard Deviation Barcode

The rightmost column in Fig. 8 shows kinetic curves generated using a standard deviation filter (top, middle, and bottom). Samples 2, 3, 5, and 6 all show a change in the kinetic curve. The H-domes showed that samples 3 and 6 developed marbling. The standard deviation in the middle or bottom part of the flask is able to detect the white haze associated with curdling (samples 2 and 5).

To find the best chocolate milk formulation, results from the different kinetics curves should be combined. Defects such as creaming, sedimentation, and marbling are highly undesired. By this measure, is samples 1, 4, and maybe 2 prove to be the best formulations.

Sample 1 is the only formulation without defects, samples 2 show curdling, and sample 4 a little whey layer and color change.

CONCLUSION

It was demonstrated how destabilization of chocolate milk could be visualized by converting a time series of images into a single image, a stability barcode. Kinetic curves quantifying different types of chocolate instability could be deduced from the stability barcodes.

By using image filters such as median, H-domes, and standard deviation it was possible to visualize and quantify defects such as sedimentation, whey separation, creaming, marbling, color change, and development of white haze associated with curdling.

Finding the optimal chocolate milk formulation should be done by combining results from the different kinetic curves. The optimal product would normally be one with no development in any of the kinetic measures.

ACKNOWLEDGMENTS

This work was partly supported by the Centre for Imaging Food Quality project, which is funded by the Danish Council for Strategic Research (Contract No. 09-067039) within the Programme Commission on Health, Food, and Welfare.

REFERENCES

[1] T. van den Boomgaard, T. van Vliet, and A. C. M. van Hooydonk, "Physical stability of chocolate milk", Int. J. Food Sci. Technol. **22**, 279–291 (1987).
[2] T. E. Grotenhuis, R. Tuinier, and C. G. de Kruif, "Phase stability of concentrated dairy products", J. Dairy Sci. **86**, 764–769 (2003).
[3] V. B. Alvarez, "Fluid milk and cream products", *The Sensory Evaluation of Dairy Products* (AVI Van Nostrand Reinhold, New York, NY, 2009), pp. 119–120.
[4] B. Saleh, *Introduction to Subsurface Imaging* (Cambridge University Press, Cambridge, United Kingdom, 2011), Chap. 6.
[5] M. White, "Jason Salavon: Emblem", Artlies, Issue 47 (2005).
[6] L. Vincent, "Morphological grayscale reconstruction in image analysis: Applications and efficient algorithms", IEEE Trans. Image Process. **2**, 176–201 (1993).