Evaluation of color stability of ice cream with Spirulina platensis by image processing

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Abstract. The current study aimed to evaluate the color stability of ice cream samples with added *Spirulina platensis* powder by image processing. The change in color characteristics was monitored during 30 days of storage at -18°C. Images of the examined ice cream samples are processed with iceColor software to extract representative color for every sample under different lighting conditions. The used software implements three methods for color extraction: scalar-defined median color, vector-defined median color, and average color for pixels that fall in the selected area. All defined representative colors are compared versus instrumentally measured colors by Minolta chroma meter (CIE L*a*b* system) using correlation analysis. The results indicate that the highest correlation coefficient (about 0,99 as absolute value) is calculated for images captured using embedded flash. There is also a strong correlation between the other two lighting conditions (above 0,7). Based on the experimental results, it can be suggested that control of color changes during the storage period could be performed using image processing for images captured with embedded flash or without any additional lightning when the reduction of energy consumption is more important than precision of color measurement.

1 Introduction

In recent years, food consumer demands have become more and more associated with the consumption of "clean label" products. This growing appeal leads to changes in global market trends and production practices. Manufacturers and scientific interests are focused on the development of new technological approaches to adapt production, preservation, stabilization, and packaging methods for foods without altering their sanitary safety and sensory identity.

Color is one of the main quality indicators of products related to the aesthetic perception of food [1]. This is a type of sensation obtained by stimulating the retina with light rays of different wavelengths. The indicators related to visual perception are color tone, saturation, brightness, gloss, roughness, etc. Usually, these characteristics are associated with specific taste, aroma, and quality of foods. According to this, many scientific investigations are related to the development of specific methods and procedures to evaluate the food color parameters. According to Pathare et al. (2013) [2], the study of the color changes of food products can be used as an indirect determination of the stability of pigments in them. Colorimeters give measurements that can be related to human eye-brain perception and give tristimulus (L, a*, and b*) values directly [3]. Colorimeters are generally quite robust and desirable for routine quality control measurements.

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Computer vision is an alternative technique for color evaluation and quantification [4, 5]. Image analysis is used to objectively measure the food color because it provides some obvious advantages over a conventional colorimeter, namely the ability to analyze every pixel of the entire food surface and quantify surface defects [6, 7].

Generally, food coloration is modified with natural and synthetic food additives permitted by food legislation. However, some risks are associated with their use concerning possible allergy reactions, risk of exceeding ADI, and ext. A perspective approach to avoid these possible side effects of food additives is the application of "coloring foods" referring to vegetable juices and microalgae [8, 9]. Microalgae represent a sustainable source of pigments and other valuable components. They can be cultivated ecologically, and they are renewable on an industrial scale without limitations of seasonal, climatic, and environmental conditions. They are characterized by a fast growth rate, the ability to tolerate stress conditions, and do not require arable land for cultivation. Regarding this, many authors emphasize them as one of the most promising and competitive sustainable sources of natural pigments [10, 11].

Spirulina platensis refers to cyanobacterium blue-green algae with high coloring potential due to phycocyanin, chlorophylls, and carotenoids in its composition [12, 13]. Moreover, these microalgae contain other valuable components such as polysaccharides, polyunsaturated fatty acids, antioxidants, etc. Besides its coloring

properties, Spirulina platensis exhibits distinct antioxidant and anti-inflammatory properties [14, 15]. The author's experience shows that spirulina is a suitable additive in ice creams, providing color and structural stability [16-19].
The current research paper presents an approach to studying color stability during the storage of *Spirulina platensis* ice cream samples by image processing.

2 Materials and methods

2.1 Ice cream production

Spirulina platensis powder, industrially produced by Magic Rose Ltd., Bulgaria, was used to supplement ice cream. The following ingredients were used to formulate the ice cream mixture: 1000 g fresh cow's milk (3,5% fat), 180 g/kg cream (35% fat), 220 g/kg sugar, 60 g/kg dextrose, 50 g/kg Panna base (MEC 3, Unigel® Ltd) and mint flavor. After pasteurization at 85 °C, the milk base was kept for maturation at 6 °C for 17 h. After the cold maturation process, spirulina powder was added at concentrations of 0,5% (S – 0,5), 1% (S – 1), and 1,5% (S – 1,5). Spirulina concentrations were chosen based on the desired color saturation of the ice cream mixture. Freezing of the ice cream mixture was for 40 min in an ice cream machine (Gelato Chef 2200, 150W, 1,5L). Spirulina platensis ice cream samples were stored at -18 °C for 30 days.

2.2 Color measurement

*2.2.1 CIE L a*b* system*

The color was measured with a Minolta Chroma meter (model CR 410, Osakka, Japan) in the CIE La*b* system. The evaluation was done using illuminant C and a standard 2° observation angle. All measurements were repeated four times in non-overlapping zones. The analysis of color characteristics in the CIE L a*b* system describes the following color parameters: L - lightness (0 – black; 100 – white), colors: a* - red (+ value) and green (-value), b* - yellow (+value) and blue (-value).

2.2.2 Digital images of ice cream samples

All ice cream samples are captured with a digital camera Canon EOS 2000D in daylight conditions using three modes for additional lightening: first without other lightening sources, using embedded (built-in) flash, and third in which an additional flash module connected to the camera used. In Table 1, there are presented some parameters of all used for capturing devices. The camera is positioned at a distance of 200mm from the work table, on which is placed the container with the examined sample, and autofocus mode is used for the ice cream surface capture.

Table 1. Technical parameters of camera and flash modules.

Device/Module	Description (main parameters)
Digital camera Canon EOS 2000D	Image sensor 22.3 mm x 14.9 mm CMOS with ≈ 24.1 megapixels (effective pixels); Rechargeable Li-ion Battery LP-E10 (battery life – ≈ 500 shots (at 23°C, AE 50%, FE 50%) and ≈ 410 shots (at 0°C, AE 50%, FE 50%)); File type – RAW and JPEG.
Built-in Flash GN	Recycle time – approximate 2 seconds; Coverage – up to 17mm focal length (35mm equivalent: 28mm).
External Flash GODOX V350C	Rechargeable Li-ion battery (7.2V/2000mAh); Recycle time – 0,1s ~ 1,7s and over 500 full power flashes; Coverage – 24mm to 105mm.

Ice cream samples with three different concentrations of colorant (Spirulina platensis) are presented in Figure 1; from left to right, the concentrations used are 0,5%, 1%, and 1,5%.

Fig. 1. Ice cream samples.

All captured images are cropped to select a region of interest (ROI) that contains only the surface of the examined sample, and images are stored in BMP format; thus, the algorithmic correction of a pixel color is avoided (which is typical for many formats such as popular JPEG), and all next processing steps are related to original data for the pixels. The size of ROIs varies because every region is defined close to the center of the image, and it excludes areas that contain a lot of sparkles and shine spots which is performed to reduce their influence on the process of representative color extraction.

2.3 Images processing

Measuring the color of every sample based on image processing is performed using IceColor software [4]. This software implements three different methods for representative color extraction that are based on mean and median values.

The process of extraction of the representative color is managed by two parameters: the size of the kernel, which is used for the selection of pixels that are involved in the process of final representative color definition about the processed image, and the number, size, and position of ROIs that are used for processing (the whole image also could be processed). All images of one sample are processed at once using batch mode, and their representative colors as well as the color distance between every couple of colors are calculated and presented in RGB and L a*b* color systems. As a preliminary step before batch processing of all images, an adjustment of IceColor settings has to be done using one easy image because when one image is processed, the selected settings for ROIs are visible directly on the application window – all ROIs are visualized on the selected image.

Data that are received using a chroma meter are expressed as mean values ± standard deviation (SD). One-way analysis of variance (ANOVA) was performed on the obtained results. A $p<0,05$ value indicated a statistically significant difference. All analyses were conducted using Statgraphics 19.0.

3 Results and discussion

3.1 Instrumental study of color stability

Table 2 illustrates obtained values for L, a*, and b* of Spirulina platensis ice cream mixture after freezing at t = -4°C and during storage at -18°C for 1, 15, and 30 days. Spirulina platensis is a source of coloring compounds such as phycocyanin (blue color), chlorophylls (green color), and carotenoids (orange color) which explained negative values of a* and b* for all ice cream samples. The obtained values give reason to claim that as the concentration of the added spirulina increases, the values of L* decrease, with the most significant changes being recorded between samples with 0,5% spirulina (71,53±0,24) and 1,5% spirulina (65,14±0,15).

Results show for all three samples the most significant changes ($p<0,05$) in the blue component (b*) and statistically indistinguishable values of the green component ($p>0,05$) when measuring the color immediately after freezing the ice cream mixture and the first day of storage of the ice cream.

Table 2. Change of color parameters L, a*, and b* during storage of ice cream with 0,5%, 1,0%, and 1,5% concentration of spirulina powder.

Ice cream sample	Storage period, days	L	a*	b*
S – 0,5%	After freezing	$71,53±0,24^{c}$	$-8,38±0,16^{b}$	$-4,45±0,01^{b}$
	1	$67,55±0,23^{b}$	$-8,38±0,32^{b}$	$-5,28±0,03^{c}$
	15	$60,33±0,59^{a}$	$-9,23±0,56^{a}$	$-6,41±0,16^{a}$
	30	$60,07±0,60^{a}$	$-9,25±0,24^{a}$	$-6,26±0,25^{a}$
S – 1,0%	After freezing	$69,81±0,07^{c}$	$-8,58±0,09^{b}$	$-5,09±0,04^{c}$
	1	$63,22±0,53^{b}$	$-8,76±0,25^{b}$	$-5,98±0,12^{b}$
	15	$60,70±0,54^{a}$	$-9,19±0,02^{a}$	$-6,28±0,02^{a}$
	30	$60,59±0,11^{a}$	$-9,04±0,08^{a}$	$-6,28±0,10^{a}$
S – 1,5%	After freezing	$65,14±0,15^{d}$	$-9,16±0,03^{a}$	$-6,04±0,04^{d}$
	1	$60,05±0,58^{c}$	$-8,95±0,31^{a}$	$-6,95±0,15^{c}$
	15	$53,09±0,45^{b}$	$-9,17±0,37^{a}$	$-7,79±0,14^{b}$
	30	$51,27±0,56^{a}$	$-8,23±0,25^{b}$	$-7,98±0,11^{a}$

*The values of the data are expressed as means ± standard deviation (SD). Mean values followed by different lowercase letters in the same column are statistically different ($p<0,05$).

A trend of a statistically significant decrease in the values of a* and b* and an increase in the intensity of the blue and green color for the three concentrations of imported spirulina between the 1^{-st} day and $15^{th\ days}$ of storage were reported. Biochemical transformations and color stability depend on various environmental parameters such as pH, temperature, and light intensity [1]. The colorimetric study showed an insignificant change in all three color parameters ($p<0,05$) between the 15^{-th} days and 30^{-th} days of storage.

3.2 Image analysis

For the current experimental evaluation of color stability, all images of ice cream samples are processed with IceColor software using settings as follows:

- method for color extraction: SCALAR, VECTOR and AVERAGE;
- mask size: 5x5, 7x7 9x9;
- ROIs settings: one area sized 500x500 pix.

It could be noticed that one area is chosen for ROI because previous experiments indicate that this setting is appropriate for sustainable color extraction regarding instrumental color measurement that is used as a referent method [5]. In Table 3, Table 4, and Table 5, there are presented values for the L component (La*b* color system) of the defined representative color for all samples during the storage period using respectively SCALAR, VECTOR, and AVERAGE methods for color extraction.

It is observed that representative colors that are extracted using lightening mode 1 are presented as quite different (differences among colors for samples colored with different colorant concentrations are significant) in comparison with those that are extracted using lightening mode 2 or 3. This observation could be explained by the stability of lightning, which is low when a source of light is used only in daylight rather than the flash (built-in or external).

Table 3. Representative color is defined using SCALAR method.

Lightening mode 1 (without flashlight)												
Mask size	**After freezing** *Spirulina platensis*			**1^{-st} day** *Spirulina platensis*			**15^{-th} day** *Spirulina platensis*			**30^{-th} day** *Spirulina platensis*		
	0,5%	**1%**	**1,5%**	**0,5%**	**1%**	**1,5%**	**0,5%**	**1%**	**1,5%**	**0,5%**	**1%**	**1,5%**
5x5	61,26	53,87	52,80	53,22	55,23	54,55	69,24	62,18	63,99	55,84	60,51	58,03
7x7	61,62	54,16	53,16	53,25	55,29	54,93	69,62	62,56	64,01	56,22	60,84	58,40
9x9	61,62	54,23	53,16	53,61	55,59	54,96	69,88	62,84	64,39	56,22	61,18	58,45
Lightening mode 2 (using built-in flash)												
Mask size	**After freezing** *Spirulina platensis*			**1^{-st} day** *Spirulina platensis*			**15^{-th} day** *Spirulina platensis*			**30^{-th} day** *Spirulina platensis*		
	0,5%	**1%**	**1,5%**	**0,5%**	**1%**	**1,5%**	**0,5%**	**1%**	**1,5%**	**0,5%**	**1%**	**1,5%**
5x5	73,64	68,27	69,96	69,36	71,59	66,80	72,85	72,56	71,74	71,52	74,04	73,19
7x7	73,67	68,27	70,24	69,64	71,95	66,85	73,22	72,87	72,11	71,57	74,07	73,26
9x9	73,73	68,27	70,30	69,73	71,95	67,14	73,28	73,21	72,11	71,88	74,12	73,55
Lightening mode 3 (using the external flash module)												
Mask size	**After freezing** *Spirulina platensis*			**1^{-st} day** *Spirulina platensis*			**15^{-th} day** *Spirulina platensis*			**30^{-th} day** *Spirulina platensis*		
	0,5%	**1%**	**1,5%**	**0,5%**	**1%**	**1,5%**	**0,5%**	**1%**	**1,5%**	**0,5%**	**1%**	**1,5%**
5x5	60,7	55,25	51,07	58,65	54,43	55,5	66,55	60,14	64,06	62,97	60,63	55,98
7x7	60,98	55,56	51,46	59,04	54,79	55,53	66,92	60,53	64,43	63,35	60,93	56,39
9x9	61,09	55,63	51,46	59,04	54,79	55,6	66,92	60,6	64,74	63,35	61,31	56,44

Table 4. Representative color is defined using VECTOR method.

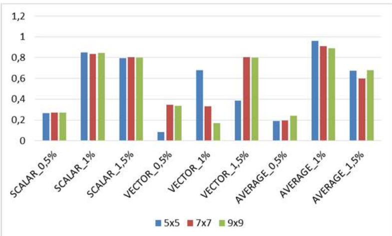
Lightening mode 1 (without flashlight)												
Mask size	**After freezing** *Spirulina platensis*			**1^{-st} day** *Spirulina platensis*			**15^{-th} day** *Spirulina platensis*			**30^{-th} day** *Spirulina platensis*		
	0,5%	**1%**	**1,5%**	**0,5%**	**1%**	**1,5%**	**0,5%**	**1%**	**1,5%**	**0,5%**	**1%**	**1,5%**
5x5	62,99	54,02	54,17	55,37	54,79	55,75	70,14	62,94	65,94	54,16	57,23	25,72
7x7	60,40	55,12	52,21	52,24	54,88	56,49	71,63	63,28	64,25	55,59	53,66	58,07
9x9	60,86	55,19	53,76	52,69	54,88	54,59	59,52	68,81	12,23	52,25	48,42	56,31
Lightening mode 2 (using built-in flash)												
Mask size	**After freezing** *Spirulina platensis*			**1^{-st} day** *Spirulina platensis*			**15^{-th} day** *Spirulina platensis*			**30^{-th} day** *Spirulina platensis*		
	0,5%	**1%**	**1,5%**	**0,5%**	**1%**	**1,5%**	**0,5%**	**1%**	**1,5%**	**0,5%**	**1%**	**1,5%**
5x5	73,82	68,43	70,27	69,62	72,66	63,42	72,00	72,34	71,14	74,48	61,21	72,49
7x7	73,82	68,27	70,81	69,36	72,66	68,25	83,66	72,71	73,15	68,69	73,97	76,71
9x9	73,4	69,77	63,14	67,93	73,02	68,44	65,09	72,53	73,54	70,89	79,7	72,35
Lightening mode 3 (using the external flash module)												
Mask size	**After freezing** *Spirulina platensis*			**1^{-st} day** *Spirulina platensis*			**15^{-th} day** *Spirulina platensis*			**30^{-th} day** *Spirulina platensis*		
	0,5%	**1%**	**1,5%**	**0,5%**	**1%**	**1,5%**	**0,5%**	**1%**	**1,5%**	**0,5%**	**1%**	**1,5%**
5x5	60,46	55,22	51,98	60,42	54,4	59,12	63,07	53,21	68,51	65,04	66,89	53,16
7x7	62,96	55,25	52,28	60,04	53,93	54,68	63,03	65,18	60,58	62,76	66,51	53,66
9x9	61,87	54,6	53,37	51,12	54,4	53,23	68,63	61,73	61,39	58,65	60,90	36,00

As a common, it is observed also that setting for mask size influence significantly on the value of extracted representative color when AVERAGE method is used for color extraction, in opposite the other two methods produce more stable results regarding the value of this parameter. This observation corresponds to the nature of implemented methods – AVERAGE method uses mean values which leads to the production of a new color that is not necessary to exist in the original image. The other two methods (SCALAR and VECTOR) use median values i.e. they extract real color from the image. There are also some exceptions of this assumption registered for the last two measurements in the storage period when VECTOR method is used. This could be explained by the trend of changing the color of ice cream during the storage period. The sensitivity of VECTOR method is expected because it extracts real three component colors from the image while the SCALAR method extracts separately every color component to combine them for final color extraction.

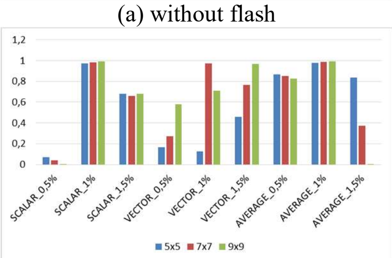
In Figure 2, there are presented calculated correlation coefficients for instrumentally measured color versus representative color defined by image processing.

Table 5. Representative color is defined using AVERAGE method.

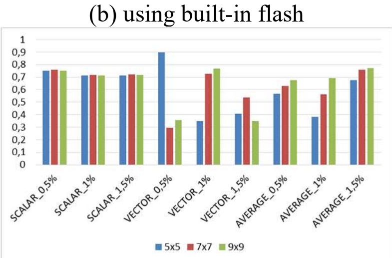
Lightening mode 1 (without flashlight)												
Mask size	**After freezing** *Spirulina platensis*			**1-st day** *Spirulina platensis*			**15-th day** *Spirulina platensis*			**30-th day** *Spirulina platensis*		
	0,5%	**1%**	**1,5%**	**0,5%**	**1%**	**1,5%**	**0,5%**	**1%**	**1,5%**	**0,5%**	**1%**	**1,5%**
5x5	45,15	46,48	50,21	41,35	50,35	51,21	52,08	50,98	49,71	40,08	50,18	49,15
7x7	50,35	50,36	51,69	45,21	52,3	52,84	57,01	55,26	54,53	45,08	53,62	52,45
9x9	53,11	51,9	52,84	47,86	53,83	53,92	59,96	57,87	57,54	48,43	55,87	54,33
Lightening mode 2 (using built-in flash)												
Mask size	**After freezing** *Spirulina platensis*			**1-st day** *Spirulina platensis*			**15-th day** *Spirulina platensis*			**30-th day** *Spirulina platensis*		
	0,5%	**1%**	**1,5%**	**0,5%**	**1%**	**1,5%**	**0,5%**	**1%**	**1,5%**	**0,5%**	**1%**	**1,5%**
5x5	68,07	64,48	65,64	58,66	70,17	63,39	50,72	70,73	60,4	57,51	70,54	62,68
7x7	70,36	66,01	67,13	62,02	70,99	64,96	57,02	71,88	65,1	61,69	71,67	66,39
9x9	71,50	67,10	68,31	63,94	71,69	66,08	60,7	72,61	66,96	64,27	72,74	68,27
Lightening mode 3 (using the external flash module)												
Mask size	**After freezing** *Spirulina platensis*			**1-st day** *Spirulina platensis*			**15-th day** *Spirulina platensis*			**30-th day** *Spirulina platensis*		
	0,5%	**1%**	**1,5%**	**0,5%**	**1%**	**1,5%**	**0,5%**	**1%**	**1,5%**	**0,5%**	**1%**	**1,5%**
5x5	43,17	49,55	46,31	55,84	52,52	43,68	60,94	47,97	51,75	48,96	58,11	48,63
7x7	48,34	51,93	48,27	57,39	54,01	47,62	63,23	52,54	55,95	53,26	59,58	51,73
9x9	51,88	53,42	49,76	58,27	54,87	50,03	64,74	55,48	58,58	56,02	60,42	53,67



(a) without flash



(b) using built-in flash



(c) using external flash

Fig. 2. Correlation coefficients.

All correlation coefficients are presented as absolute values. It is observed that mostly low values for correlation coefficients are calculated when there are used images that are captured in daylight without the usage of additional lightening sources (flash modules). This observation indicates that variations in daylight conditions influence significantly on the color registered by the camera. When the external flash module is used for image capturing (Fig. 2 (c)) the color extracted from images corresponds significantly with instrumentally measured color-calculated correlation coefficients that have high values. As a common, the relation between instrumentally measured color and representative color extracted from images is higher for samples with a higher concentration of colorant which could be explained by the lower contrast between ice cream matter and small particles of colorant that are not enough dissolved in ice cream samples. The highest correlation coefficient (≈0,9940) is calculated for ice cream colored with 1% Spirulina platensis using built-in flash for image capturing, AVERAGE method, and mask size 9x9 (as settings for IceColor software). Using the mentioned settings, the correlation coefficients for the samples with colorant concentrations 0,5% and 1,5% are ≈0,8239 and ≈0,0052, respectively which indicates that these settings could not be used for examination of all samples. Using built-in flash and AVERAGE method (mask size 5x5) for all samples calculated correlation coefficient is above 0,83 which indicates a strong correlation between examined variables [19] thus these settings could be used to produce values that could be replaced in a linear equation for prediction the color of examined samples. When the lightening mode 1 is used (only daylight is a source of light) moderate to strong correlation is achieved for AVERAGE method for all examined mask sizes (5x5, 7x7, and 9x9) only for samples with a high concentration of colorant (1% and 1,5%) and strong correlation is achieved for SCALAR method for all examined mask sizes (5x5, 7x7 and 9x9) again only for samples with high concentration of colorant. These results indicate that capturing images without an additional source of light could be used for monitoring the color changes only for samples that do not have high contrast between specific particles and the matter of the examined object.

4 Conclusion

Current research presented the results of the examination of the color stability of ice cream samples colored with Spirulina platensis in three different concentrations. The analysis of color stability was performed using data registered with a chroma meter and CVS (Computer Vision System) including a digital camera and special software for image processing, and the results could be summarized as follows:
- colorimetric study showed changes in the color characteristics expressed in an increase in the intensity of the green and blue components of the ice cream supplemented with spirulina powder;
- sustainable measurement of the color for monitoring the color stability of ice cream could be performed using image processing with IceColor software;
- lightening conditions influence significantly registered by digital camera information for pixels color;
- in the context of sustainable ICT trends (Information and Communications Technology) the results indicate that data for the color of ice cream samples could be precisely registered using only built-in flash without additional flash modules.

The future work will continue with an examination of other sources of color pigments for the development of ice cream mixtures with stable parameters.

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