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Development and application of a computer vision system for the measurement of the colour of Iranian sweet bread

M. Hashemi Shahraki[1], M. Mashkour[1] and A. Daraei Garmakhany[2]

[1]Gorgan University of Agricultural Science and Natural Resources, Department of Food Science and Technology, Beheshti Avenue, Gorgan 49138-15739, Iran; [2]Islamic Azad University, Department of Food Science and Technology, Azadshahr Branch, Azadshahr, Golestan 53119-53719, Iran; m.hashemi.sh@gmail.com

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Abstract

A combination of digital camera, computer and graphics software can provide a less expensive and more versatile technique to determine the surface colour of foods. The aim of this work is the development and application of a computer vision system for the measurement of the colour of Iranian sweet bread. In this study, imaging from samples was performed in an environment with 6,500 K illumination standard, and RGB colour space of captured images were transferred to L*a*b* indexes by computer software under illumination standard. This digital image processing was developed as a simple and efficient method for evaluating Iranian sweet bread colour. Also the effect of adding honey on qualitative and quantitative changes of colour values was evaluated as a function of the honey percentage (0, 2, 4, 6, 8, 10, 12, 14% honey powder). Results showed that the colour of the bread produced was improved by adding honey and the developed image processing system was suitable for the measurement of colour parameters. The developed image processing system can be used to measure the surface colour of food.

Keywords: colour measurement, computer vision system, honey powder, image J, Iranian sweet bread

1. Introduction

The colour of the food surface is the first quality parameter evaluated by consumers and is critical in the acceptance of the product, even before it enters the mouth. The observation of colour thus allows the detection of certain anomalies or defects that food items may present (Abdullah *et al.*, 2004; Du and Sun, 2004; Hatcher *et al.*, 2004; Pedreschi *et al.*, 2000).

Honey is a natural biological product that comprises simple sugars (glucose and fructose: 70-80%), water (10-20%), and other minor constituents such as organic acids, mineral salts, vitamins, proteins, phenolic compounds, and free amino acids (Ouchemoukh *et al.*, 2007). Ram (2011) demonstrated that spray-dried honey powder with retrograded starch could be used as a substitute for sucrose in bread-making (Ram, 2011).

The effects of honey powder on dough rheology and bread quality were studied (Tong *et al.*, 2010) The results showed that honey usage in the bread formulation supported an improvement in dough rheology, and better sensory and textural properties of bread as compared to the control formulation (Tong *et al.*, 2010).

Most commercial colour measurement instruments are not well suited for food engineering research, because they are designed mainly for quality control. Since those instruments can only provide average values, it would be rather difficult and time-consuming if they were used for point-by-point measurement at many locations to obtain colour distribution. Moreover, some of these instruments require the food sample to be homogenised using a blender or grinder to achieve uniform colour. The blending or grinding not only takes time, but also renders the food sample useless for other purposes. Commercial microscopy imaging systems with sophisticated image and colour analysis capabilities are also available, but they are not suitable for analysing the colour of larger food objects such as pizza and bread (Yam and Papadakis, 2004).

Computer vision (CV) is a technology for acquiring and analysing an image of a real scene by computers to obtain information or to control processes (Brosnan and Sun, 2004). CV analysis is a non-destructive method of objectively measuring colour patterns in non-uniformly coloured surfaces, and also determining other physical features such as image texture, morphological elements and defects (Mendoza and Aguilera, 2004; Pedreschi *et al.*, 2004). CV has been used in the food industry for quality evaluation, detection of defects, identification, grading and sorting of fruits and vegetables, meat and fish, bakery products (Gerrard *et al.*, 1996; Gunasekaram and Ding, 1994; Leemans *et al.*, 1998; Luzuriaga *et al.*, 1997; Shanin and Symons, 2001; Sun, 2000). In particular, CV has been used to measure objectively the colour of fried potatoes. The colour of potato chips was measured using computerised video image processing by mean of grey level values (Scanlon *et al.*, 1994). Hashemi Shahraki *et al.* (2013) evaluated the effect of active packaging with different humidity absorbers over time on mushroom colour using a computer vision system.

A computer-based video system was developed to quantify the colour of potato chips in the L*a*b* colour space that correlated well with the perception of the human eye (Segnini *et al.*, 1999). The video image analysis technique had some obvious advantages over a conventional colorimeter, namely, the possibility of analysing the whole surface of the chips, and quantifying several characteristics such as brown spots and other defects.

Basically, a computer vision system (CVS) consists of a digital or video camera for image acquisition, standard settings illuminants, and computer software for image analysis (Brosnan and Sun, 2004; Papadakis *et al.*, 2000). Image processing and image analysis are the core of CV with numerous algorithms and methods capable of objectively measuring and assessing the appearance quality of several agricultural products. In image analysis for food products, colour is an influential attribute and powerful descriptor that often implies object extraction and identification and that can be used to quantify the colour distribution of non-homogeneous samples (Brosnan and Sun, 2004).

The use of CV for colour quality assessment require an absolute colour calibration technique based on a common interchange format for colour data and a knowledge of which features from an image can be best correlated with product quality. Rapid advances in hardware and software for digital processing have motivated several studies on the development of CVS to evaluate the quality of diverse raw and processed foods (Brosnan and Sun, 2004). Colour imaging analysis not only offers a methodology for the specification of uneven colouration to the specification of other attributes of total appearance. CVS is also recognised as the integrated use of devices for non-contact optical sensing, and computing and decision processes to receive and interpret an image of a real scene. The technology aims to replace human vision by electronically perceiving and understanding an image (Brosnan and Sun, 2004).

In recent years, computer vision has been used to objectively measure the colour of different foods since they provide some obvious advantages over a conventional colorimeter, namely, the possibility of analysing each pixel of the entire surface of the food, and quantifying surface characteristics and defects (Brosnan and Sun, 2004; Du and Sun, 2004). The colour of many foods has been measured using computer vision techniques (Mendoza and Aguilera, 2004; Papadakis *et al.*, 2000; Pedreschi *et al.*, 2004; Scanlon *et al.*, 1994; Segnini *et al.*, 1999). A computational technique with a combination of a digital camera and image processing software has been used to provide a less expensive and more versatile way of measuring the colour of many foods than traditional colour-measuring instruments (Yam and Papadakis, 2004). With a digital camera it is possible to register the colour of any pixel of the image object using three colour sensors per pixel (Forsyth and Ponce, 2003). The most often used colour model is the RGB (red, green, and blue) model in which each sensor captures the intensity of the light in the red (R), green (G) or blue (B) spectrum, respectively. Today the tendency is to digitally analyse the images of food items in order to firstly carry out a point analysis, encompassing a small group of pixels with the purpose of detecting small characteristics of the object, and secondly to carry out a global analysis of the object under study such as a colour histogram in order to analyse the homogeneity of the object (Brosnan and Sun, 2004; Du and Sun, 2004). The use of colour considerably improves high-level image processing tasks (Mendoza and Aguilera, 2004; Pedreschi *et al.*, 2004; Segnini *et al.*, 1999). The published computational approaches that convert RGB into L*a*b* units use an absolute model with known parameters (Mendoza and Aguilera, 2004; Paschos, 2001; Segnini *et al.*, 1999). In these works, the parameters are not estimated in a calibration process. However, the parameters of the models vary from one case to another because RGB is a non-absolute colour space, i.e. the RGB colour measurement depends on external factors (sensitivity of the camera sensors, illumination, etc.). Ilie and Welch (2005) reported that most cameras (even of the same type) do not exhibit consistent responses. This means that the conversion from RGB to L*a*b* cannot be done directly using a standard formula, like a conversion from centimetres to inches.

2. Materials and methods

Colour models

Three colour models are used to define colour in this paper: the RGB model, the CMYK (cyan, magenta, yellow, black) model, and the L*a*b* model. Among them, the L*a*b* model has the largest gamut encompassing all colours in the RGB and CMYK gamuts (Adobe Systems, 2002). While those colour models are useful, their limitations should also be observed. For example, the spectrum of colours seen by the human eye is wider than the gamut (the range of colours that a colour system can display or print) available in any colour model.

The RGB model is an additive colour model that uses transmitted light to display colours. Various proportions and intensities of three primary colours (red, green, and blue) are used to create cyan, magenta, yellow, and white. The model is used for television and computer screens, in which coloured pixels are produced by firing red, green, and blue electron guns at phosphors on the screens. The model relates closely to the way humans perceive colour in the retina. The model is device-dependent, since its range of colours varies with the display device. The CMYK is a colour model based on the light absorbing quality of ink printed on paper (Adobe Systems, 2002). As white light strikes translucent inks, certain visible wavelengths are absorbed while others are reflected to the eyes. Three primary ink colours (cyan, magenta, and yellow) are used to create other colours. In theory, these three primary colours should combine to absorb all light and produce black; however, a muddy brown is produced instead because all printing inks contain some impurities. Thus, the fourth primary ink colour (black) is needed to produce a true black. The CMYK model is also device dependent and is used in four-colour process printing. The L*a*b* model is an international standard for colour measurement developed by the Commission Internationale Eclairage (CIE) in 1976 (Yam and Papadakis, 2004). The L*a*b* colour consists of a luminance or lightness component (L*value, ranging from 0 to 100), along with two chromatic components (ranging from -120 to +120): the a* component (from green to red) and the b* component (from blue to yellow). The L*a*b* colour is device independent, providing consistent colour regardless of the input or output device such as digital camera, scanner, monitor, and printer. The L*a*b* values are often used in food research studies.

It is important to reiterate that the RGB and CMYK models are device-dependent. For example, the food image appears darker on a Windows system than on a Mac OS computer, because the standard RGB colour space is darker in Windows than in Mac OS (Adobe Systems, 2002). Also, the RGB and CMYK gamuts are smaller than the L*a*b* gamut, and thus there are out-of gamut colours that cannot be display on-screen or printed.

Measuring colour

Food colour measurement is based on three parts: proper lighting, digital camera and software. A high-resolution digital camera (≥2 mega-pixels) is used to measure colour by capturing the colour image of the food sample under proper lighting. The captured image is a bitmap image consisting of many pixels; each pixel is assigned a specific location and colour value. The software converts the values from RGB to L*a*b* values. The three basic parts of measuring colour are defined below.

Proper lighting system

When capturing colour images, a proper light source is important since the colour of the food sample depends on the part of spectrum reflected from it (Francis and Clydesdale 1975). Hence, the spectral power distribution of the illumination must be standardised. The CIE has defined several standard illuminants, which are specified by their colour temperatures. The standard illuminants commonly used in food research are A (2,856 K), C (6,774 K), D65 (6,500 K), and D (7,500 K). The light sources C, D65, and D are designed to mimic variations of daylight (Lawless and Heymann, 1998).

The angle between the camera lens axis and the lighting source axis should be around 45°, because the diffuse reflection responsible for the colour occurs at 45° from the incident light (Francis and Clydesdale, 1975). Furthermore, the light intensity over the food sample should be uniform. This can be achieved by experimenting with various lighting arrangements (such as varying the distance between the light source and the food sample, taking the pictures in a dark room) and checking the results with a light meter.

Digital camera

Digital camera records images on an electric light sensor that is made up of millions of tiny points or pixels. There are two major factors that affect the quality of the image resolution and file compression. Resolution is related to the number of pixels on the light sensor: the more pixels, the higher the resolution, and the better the image quality. File compression reduces the amount of memory taken up by the image and allows more images to be stored. The trade-off for compressing the file is loss of image quality. For research purpose, non-compressed file (TIFF format) is preferred to compressed file (JPEG format). A digital camera with a minimum resolution of 1,600×1,200 pixels is recommended, which is equivalent to a 2.1 megapixels or higher camera. The camera should also have a macro and zoom feature.

It is important to regularly ensure that the lighting system and camera are working properly and consistently. Hence, at least two standard coloured chips should be used to calibrate or verify the experimental settings prior to actual measurements, and those coloured chips should cover the colour range of the specific food samples.

Standard coloured chips can be obtained from the Munsell book of colour (Munsell Book of Color: Matte Finish Chips; Munsell Color Company, New Windsor, NY, USA). A free software is also available on the company website (http://munsellstore.com/), which allows the conversion between the Munsell values and the L*, a*, b* values (Yam and Papadakis, 2004).

Software

Suitable software capable of changing the colour space of the obtained picture to standard space is one of the main components of image processing colorimeter methods. Different software was used for this purpose, for example Adobe®Photoshop® software was used for colour measurement of pizza samples (Yam and Papadakis, 2004); Image J software with powerful plugins for colour space conversion is one of the most suitable software packages for image processing study and the ability to convert colour space under desirable lightness is one of its special characteristics.

The aim of this study was to design and develop a colorimeter machine based on an image processing method and evaluate its performance for measurement of food colour and sweet bread colour change as a function of honey powder content as sweetener agent.

Qualitative analysis

Here the term 'qualitative' refers to those aspects that are not easily quantified. For example, there were scattered dark spots in the samples, and their appearance was not easily quantified with parameters such as L*, a*, b*. In qualitative analysis, subjective terms such as 'lighter', 'darker', and 'more appealing' were used to describe or compare the samples. Both qualitative and quantitative analyses were used to provide accurate descriptions of the colour of the samples. In many other research studies, only quantitative information (such as the average colour) was reported. While the average colour provided a simple description, some important details were not included. In some cases, the use of average colour alone (i.e. without visually inspecting the food sample) even resulted in misleading conclusions.

Quantitative analysis

In quantitative analysis, L*a*b* values were used because they are device-independent and cover a larger gamut than RGB. By using the Measure stack option in the plugins menu of software, results for maximum, minimum and mean of Lab values can be obtained.

Colorimeter development

The colour of the produced breads was measured using an image processing method; for this purpose a colorimeter machine was developed as follows:

A digital camera (SX40hs; Canon, Ota, Japan) with a resolution of 3,000×4,000 pixels, which is equivalent to 12 megapixels, was adjusted to 35 cm on top of the samples in a box (with 60×60 cm length and width) of which all of its inside walls were covered with dark cloth to prevent light scattering. For sample capturing, the illumination inside the box was adjusted to 6,500 K using 4 fluorescent lamps (18 W, 60 cm in length). The standard illuminant in capturing medium was adjusted by colour temperature meter (Kenko KCM-3100; Tokyo, Japan). The angle between the camera lens axis and the lighting sources was around 45°. The setting of the camera is given by Hashemi Sharahraki *et al.* (2013). The obtained pictures were directly transferred to a Pentium IV computer and saved in JPEG format without compression.

Image processing method

Image processing was performed similar to the method used for button mushrooms by Hashemi Sharahraki *et al.* (2013), using Image J (version 1.44; NIH, Bethseda, MD, USA) software as follows:

- The noise of captured pictures was reduced by the use of Noise Despeckle within the Process menu.
- The colour space of pictures was converted from RGB to CIEL*a*b* using Converter Space Colour of the Plugins menus under 6,500 K illumination.
- For each of the colour parameters (L*a*b*) the software gives separate pictures and by using Measure Stack from the Stacks menu the minimum, maximum and mean of each colour parameter of the samples can be obtained from the Results window. A schematic representation of the colorimeter machine is shown in Figure 1.
- Evaluation of colorimeter performance: for this purpose 24 colourful tiles (the values of colour standard tiles are shown in Table 1) with qualified specification was used and the value of colour parameters obtained from colourful tiles by the colorimeter machine was fitted against the standard colour value of colourful tiles.

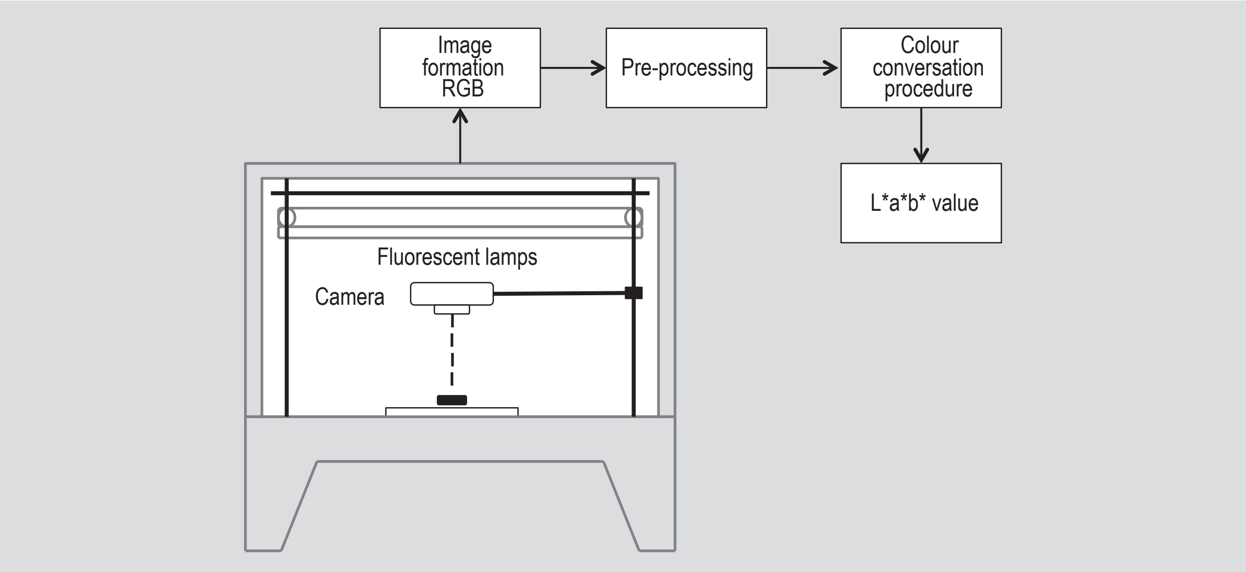

Figure 1. The general methodology for converting RGB images into L*a*b* units.

Table 1. Colour values of standard tiles used in the calibration process and values obtained by computer vision system (CVS). The correlation coefficients (R^2) are given.

L* values of tiles	L* values obtained by CVS	a* values of tiles	a* values obtained by CVS	b* values of tiles	b* values obtained by CVS
40	42.02	5	6.05	15	17.26
70	72.92	20	21.11	15	14.92
50	51.9	10	8.98	-30	-31.62
50	52.07	-20	-22.99	30	32.5
50	50.71	20	19.06	-30	-31.98
70	71.9	-30	-31.64	0	1.2
60	58.9	20	19.21	50	52.62
35	36.19	30	28.59	-55	-56.98
50	51.52	40	41.65	10	11.63
30	29.94	25	24.21	-20	-19.97
75	75.63	-40	-41.62	60	62.02
80	79.42	0	-0.72	75	76.99
20	19.35	40	42.29	-60	-58.77
60	58.08	-40	-39.16	30	32.22
40	37.19	45	46.56	25	24.64
90	88.06	-15	-16.14	80	78.9
50	52.02	55	53.06	-20	-22.23
50	48.99	0	1.97	-40	-41.63
100	99.02	0	-1.48	0	-1.03
80	82.64	0	2.04	0	1.9
70	68.78	0	1.9	0	-1.02
50	48.9	0	2.01	0	1.62
30	28.68	0	1.82	0	1.79
10	11.9	0	-1.24	0	-1.96
R^2=99.41		R^2=99.61		R^2=99.84	

Preparation of bread

Commercial wheat flour was provided by Golha Co. Ltd (Tehran, Iran). Honey powder was provided by Cactus (Decatur, IL, USA). Stevia extract with proportion 1:1 was provided by Giahessans Co. Ltd. (Gorgan, Iran). Dry baker's yeast was obtained from Fariman Yeast Co. Ltd (Mashhad, Iran). Butter was provided by Kalleh Co. Ltd (Amol, Iran). Milk powder was provided by biomil, Behdashtkar Co. Ltd (Rasht, Iran), sugar by Naghshe-Jahan (Esfahan, Iran), eggs, salt and food bag were purchased at a local market.

Bread samples were prepared using a traditional method. The compositions of the selected dough formulation used in the control bread are shown in Table 2. Flour, fine sugar, honey powder (0, 2, 4, 6, 8, 10, 12, 14%), milk powder were uniformly mixed in a spiral mixture, followed by the addition of yeast and bread improver. The dough was prepared in the stirrer for 2 min at 40 rpm, and 10 min at 70 rpm after egg and water were added. The dough was rested in bulk for 12 min, divided into pieces of 100 g, rounded by hand (ball shape), and submitted to an extra fermentation period of 10 min (intermediate proof). The dough was then kneaded, put in well-greased pans, proofed at 37 °C and 85% relative humidity for 2 h and baked in an electric oven set at temperature 180 °C for 20 min. The bread was removed from the pans and cooled at 25 °C for 1 h.

3. Results and discussion

Image processing machine evaluation

A comparison between the results obtained from machine and colourful tiles is shown in Figure 2. Results showed a suitable correlation between L*a*b* values of colour tiles and colour values obtained by the colorimeter machine (L*: R^2=99.41; a*: R^2=99.61; b*: R^2=99.84). The excellent correlation coefficient indicates high accuracy in colour index measurement.

Table 2. The composition of the selected dough formulation used in the control bread comprised 1000 g flour.

Constituent	Amount
water	500 g
honey powder	0-140 g
butter	100 g
milk powder	50 g
baker's yeast	15 g
bread improver	10 g
salt	8 g
egg	2 (nearly 120 g)

Breads colour variation

The images were examined and compared, and the effects of treatment (honey addition) on colour were observed. The values of colour for the crust and crumb of Iranian sweet bread with various amounts of honey were presented in Table 3. As can be seen by adding an amount of honey the crust colour was darker and the crumb colour was lighter. The colour of bread is related to the physicochemical characteristics of the raw dough and chemical reactions that take place during baking which are dependent on operating conditions, such as Maillard reactions and caramelisation which cause browning of baked products during baking (Michalska *et al.*, 2008; Purlis and Salvadori, 2009). The crust of the honey powder breads had significantly higher L* values and b* values, and lower a* values as compared with those of the control bread. The higher glucose and fructose levels in the honey powder caused a greater

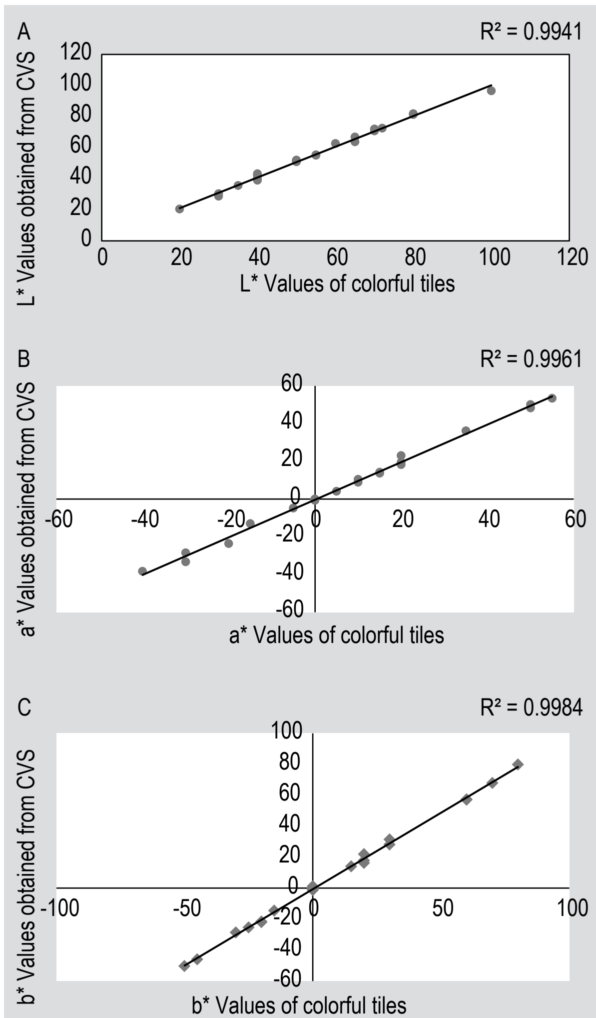

Figure 2. Colour indexes obtained from the computer vision system (CVS) vs. colour indexes of colourful tiles. (A) L* values; (B) a* values; (C) b* values.

Table 3. The colour parameters of crust and crumb of sweet bread containing honey powder.

Honey powder (%)	Crust			Crumb		
	L*	a*	b*	L*	a*	b*
0	59	18	32	82	-3	15
2	63	18	34	79	-2	16
4	64	17	34	77	-1	17
6	65	16	36	78	0	18
8	67	17	35	77	-1	17
10	68	16	36	76	1	19
12	66	15	37	76	2	20
14	69	13	38	75	4	22

degree of Maillard browning reaction in the crust, thereby intensifying the crust colour of honey breads.

The honeyed breads showed a yellower crumb than the control bread, again due to Maillard browning reaction of reducing sugars in honey with protein in the flour. Compared with the crust, the crumb of the honey bread gave much higher L* values, but much lower a* values, and b* values. This lighter colour was due to the lower levels of Maillard browning reactions that take place in the crumb than crust. Crumb L* value decreased while crumb a* and b* values were increased as the honey powder level increased. The obtained results are consistent with the findings of Tong *et al.* (2010). They showed that breads with a lighter crust colour and a more yellow crumb colour have higher colour sensory evaluation scores than the others. The trend of colour index values changes by the addition of honey similar to the results of Tong *et al.* (2010).

4. Conclusions

The implemented CVS allows measurements and analyses of the colour of Iranian sweet breads from RGB images into L*a*b* units in an easy, precise, representative, objective and inexpensive way. The CVS allows easy measurements of the colour over the entire surface of a sample or over a small specific surface region of interest. Honey powder could potentially be used as a dough improver. Honey powder usage in the bread formulation supported an improvement in the colour of the bread as compared to the control formulation.

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