Colour and appearance analysis of fruit and vegetable soup using a digital colour imaging system

Gerard van Dalen, Faisal Osman, Aat Don
Unilever Research & Development; P.O. Box 114, 3130 AC Vlaardingen, The Netherlands

Abstract

Within Food R&D scientists, chefs and engineers aim to develop natural fruit and vegetable based soups with optimal flavour, texture, appearance and health benefits whilst maintaining product safety. The colour and appearance has a major influence on the perceived quality (e.g. nutrition and freshness). This paper describes a method for the determination of the colour of soups containing vegetable particles. Digital images were made under controlled lighting using a DigiEye imaging system. It allows documenting the appearance by making colorimetrically accurate images which are suitable for the measurement of colour uniformity, size and shape. The uniformity of the light under diffuse and directional illumination was investigated using different targets and soup samples. For accurate colour analysis the images have to be corrected for non-uniform illumination and the colour has to be measured at a fixed location outside the centre of the lighting cabinet. Directional illumination (angled light with additional mirrors) was used to introduce gloss resulting in images matching the actual appearance of soups and vegetable particles very closely. Imaging glossy soups under diffuse illumination resulted in dull images with dark spots. No significant difference was found between the colours of soups analysed under diffuse or directional illumination. Under directional illumination a better repeatability was observed. Additionally, for 36 different soups, the measured results from the DigiEye system were compared to two different colorimeters ($0^o/45^o$ and diffuse/0^o geometry). Linear relations were found between the CIE Lab values measured by the DigiEye system and those measured by two different colorimeters. Best correlations were obtained between DigiEye and $0^o/45^o$ colorimeter (r^2=0.980-0.996). The short term precision of the DigiEye system is somewhat better than those of the colorimeter.

Introduction

Foods have to be visually appealing, tasteful and healthy. Colour is regarded as a key attribute of foods. The overall multi-sensorial appearance strongly affects the consumers' perception of food products and finally the consumption, enjoyment and purchasing behaviour. Consumers prefer bright coloured fruits and vegetables. The colour and appearance has a major influence on the perceived quality (e.g. freshness). Browning or yellowing of raw green vegetables such as broccoli is considered undesirable. Processing of green vegetables may turn them into a non attractive dark olive green colour (degradation of chlorophyll). The colour may be a measure for over processing (heat treatment) and the accompanying decomposition of the nutrients and the change in bioavailability. The consumer's perception of colour does not only effect the interpretation of product appearance, but also extends to how product flavour and overall quality is perceived. The colour of tomato soup may be associated to creaminess or to the strength of the tomato flavour [1]. The perception of colour-texture is finally linked to vitality.

Fruit and vegetable based soups are an important source of nutrition [2]. The colour can be linked to the presence of specific antioxidants and other phytochemicals that neutralise free radicals in the body (e.g. lycopene in tomatoes and beta carotene in carrots and pumpkin). There is a general agreement among the scientific and nutritional communities that to gain the maximum benefit and protection from antioxidants, our diets should be as colourful as possible. Food research aims to develop fruit and vegetable soups with optimal flavour, texture, appearance and health benefits whilst maintaining product safety.

Visual colour assessment is subjective and difficult to control (e.g. depends on observer and viewing conditions). Colour can easily be measured by instrumental methods such as colorimeters or spectrophotometers [1,3]. For homogeneous opaque materials with a smooth surface the measured colour will be close to the consumer perception of colour. However, only very few food products are really homogeneous. The surface texture, gloss, shape and form of food products has a dramatic influence on the human perception of colour.

Figure 1*. Influence of lighting conditions on the images of tomato / bell pepper soup [diffuse (left) and directional (right) illumination]. Image size = 10cm * 10cm.*

This paper describes the development of a method for capturing and analysing of colour images of soup products containing fruit and vegetable particles. These images have to be colorimetrically accurate and in agreement with the visual appearance of the product allowing direct and immediate comparison of products produced at different global locations to investigate the influence of processing parameters and colour stability during shelf life. They have to be used for colour (uniformity), size, shape and structure analysis, communication and archiving, on-screen panelling and artificial colour mapping. Accurate colour images can be made using flatbed scanners (FBS) or camera based systems. FBS is limited to relative thin samples like rice [4] or textiles [5]. For soups and vegetable particles the DigiEye colour imaging system from Verivide was used. This system has been developed for the textile industry [6,

7, 8] and is recently also used in the food industry. Normally for colour analysis an even diffuse illumination is needed avoiding bright specular reflections in the image. However under these conditions very dull images without surface texture were obtained by which these images are not suitable for appearance analysis (Figure 1). By using directional illumination (angled light and mirrors) gloss was introduced resulting in an image matching the actual appearance of the soup and vegetable particles very closely. In this study it was investigated if these images can be used for colour analysis.

Experimental

Digital images were made under controlled lighting using a DigiEye imaging system (VeriVide, UK) with Nikon D70 digital camera and Nikon 35 mm F/2 D lens. The lighting cabinet (illumination box) contains VeriVide D65 fluorescent tubes (artificial day light). With standard diffuse illumination the sample is illuminated by two lamps at 45° to the sample. For directional illumination the D65 light was directed to the lower mirrors by selecting the angled position. Additional mirrors were placed at the top of the lighting cabinet (Figure 2). The mirrors provide gloss on the sample surface. The visual appearance depends strongly on gloss.

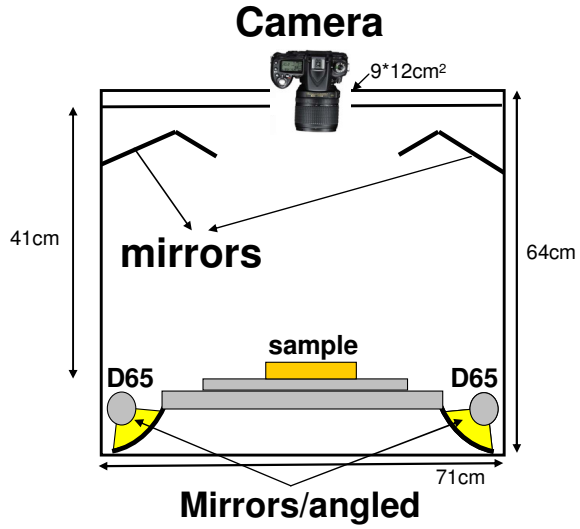

Figure 2. *Schematic overview of the set-up used for imaging soup (front view inside the lighting cabinet of the DigiEye system).*

For the camera, constant settings were used (angled: 1/13 sec – F/6.3; diffuse: 1/8 sec – F/6.3; ISO200). For each image, a 12-bits (per pixel) raw file (NEF lossless compressed) and a TIF file were stored. An Adobe RGB colour space (mode 2) was selected. The white balance (preset) was determined using a Gretagmacbeth white balance (WB) card. For uniformity correction a DigiEye grey aluminium plate (30 × 42 cm^2) and Epson inktjet S041328 white premium semi gloss photo paper (33 × 42 cm^2, 251 g/cm2, brightness (ISO): 93% and opacity 97%) were tested. The image resolution is 3008 x 2000 pixels corresponding to 34 x 22 cm^2. The camera was calibrated using a DigiTizer (DigiEye) colour target (the DigiEye software uses a 35 by 3 multivariate polynomial fit to correlate the RGB values to the known CIE XYZ values of the target). Samples were poured into specially made aluminium grey coated containers with an inner diameter of 9.5 cm. Containers with inner heights of 1 cm, 2 cm and 3 cm were tested. For homogeneous samples an area of 5cm x 5cm within the container was measured. The average CIE Lab colour of the corresponding region was measured using the DigiPix tool of the DigiEye software (version 3.4.2) and the average R, G and B values were measured using Leica Qwin Pro program (version 2.4).

Soup samples were sieved using a sieve with pores of 1.0mm * 1.0mm. The residue of vegetable particles was rinsed with tap water and distributed on a grey plate of 36cm*26cm (Figure 3). The total sample, sieved sample and residue were imaged using the DigiEye system at room temperature.

Figure 3. *Vegetable particles isolated from minestrone soup Image obtained using directional illumination.*

The method was tested using commercial soup samples containing fruit and vegetable pieces (can, pouch or pack). Most vegetable soups are based on puréed vegetable (thick to thin consistency) while a few are based on a type of bouillon (watery consistency). These soups may contain particles from very small, including herbs at low percentage, to chunky soups containing a high proportion (up to 50%) of vegetable pieces plus other ingredients such as noodles, grains and meat. Only very thick soup samples may be considered as opaque and will be seen wholly by reflected light. All other soups will be more or less translucent. Both transmitting and scattering light with the extreme case of clear soups which are not completely transparent because of the presence of very small scattering particles. The colour of translucent samples will change when the light path length through it, is changed. When the depth of the sample in the sample cup is not large enough, a portion of the light will reach the bottom of the cup and the measured colour will be influenced by the background. So either the depth of the sample has to be large enough to seem opaque or the depth must be fixed for consistent colour results. The influence of the depth of the sample was investigated by imaging creamy soups with thick and thin consistency and a clear soup in sample containers with different depths. The containers with samples were placed on a fixed position in the sample cabinet.

For comparison the colour of the samples was measured using a Hunterlab colorimeter (Labscan 6000) and Minolta colorimeter (Chroma Meter CR400). The Labscan 6000 was calibrated under CIE D65, 10°, 0/45 conditions using white and black standard reflective plates. An illumination distance of 44

mm (area view: 1.75´´) and a large opening (port size: 50 mm = 2.00´´) was selected. As reference, red and green tiles were used: red ceramic tomato reference tile BCR CRM no. 400 (D65/10°: L*=31.1, a*=43.5, b*=32.2, Institute of Reference Materials and Measurements, Belgium) and Hunterlab green diagnostic tile no 14161(D65/10°: L*=52.3, a*=-25.7, b*=13.9). The glass sample cup with an inner diameter of 58 mm and height of 37 mm was filled with the sample after gentle stirring (to prevent the introduction of air). The sample has to appear smooth and opaque through the bottom of the sample cup. The sample cup was placed on top of the instrument port and covered with a black opaque cover. The opaque cover prevents any ambient light from outside the instrument from leaking into the detector.

The Minolta CR400 colorimeter was calibrated under CIE D65, 2°, Diffuse illumination/0° (specular component included) conditions using a white standard reflective plates. The liquid measurement head (measuring area of 8 mm) of the colorimeter was placed in a glass sample cup with an inner diameter of 58 mm and height of 37 mm filled with a soup sample.

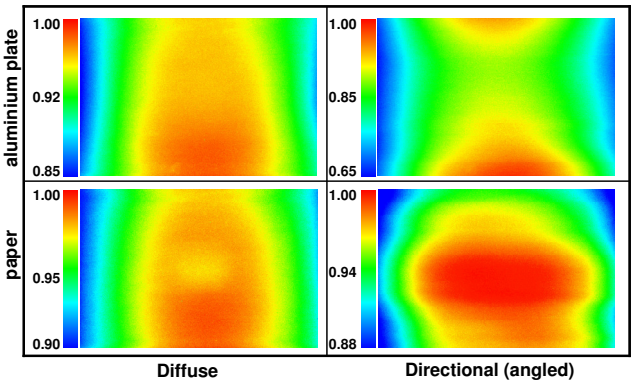

***Figure 4**. Spatial distribution of the intensity (average RGB value per pixel) of two different uniformity targets imaged within the DigiEye imaging system using diffuse and directional (angled/mirror) illumination.*

Results

In order to check the uniformity of the DigiEye imaging system a grey aluminium plate (standard supplied by DigiEye) and white semi gloss photo paper were imaged. These uniform reference targets cover the total imaged area. As can be seen from Figure 4, the non-uniformity of the aluminium target is much larger than for white paper (note the difference in scale of the LUT). This effect is less pronounced for diffuse illumination. Uniformity correction using the DigiTizer software on either the Al plate or white paper resulted in the uniform distribution of the used uniformity target but in a large difference between targets (Table 1). Correction using white paper resulted in a more accurate colour calibration (lower colour difference). The reflecting properties of the white paper are comparable to those of the calibration target. As uniformity target, different white photo papers can be used (no significant difference between gloss or semi gloss). The paper should be spatial uniform and thick enough (250 g/cm^2).

The spatial uniformity of soup was checked by placing the filled sample container with a depth of 2cm at 15 different locations in the sample cabinet so that the measured areas (5*5 cm^2) cover the imaged area. The results for two sieved thick creamy soups are shown in Figure 5. These soups can be considered as opaque. For the tomato soup imaged using diffuse illumination very low RGB values were measured at the centre, especially for the green and blue channel. At this location a dark spot is observed for glossy surfaces directly below the camera (Figure 11). The camera is located within a black opening at the top of the sample cabinet (a black square of 9*12 cm^2 within the grey interior of the cabinet, see Figure 2). For directional illumination only a very small effect is observed. A white soup (asparagus/cauliflower/celeriac/onion) resulted in a more homogeneous distribution of the RGB signal without a dark spot in the centre of the imaged area (Figure 5). The spatial distribution of the intensity depends on the reflection properties of the soup.

Table 1. Average RGB values of targets before and after uniformity correction (measured area = 34 x 22 cm^2 for the Al plate and paper and 26 x 17 cm^2 for the white balance card). For the DigiTizer colour calibration target, 15 white patches at the border were measured. Colour difference = difference between measured and predicted colour value.

targets	RGB value -diffuse					
	no uniformity correction		uniformity correction Al plate		uniformity correction paper (S041328)	
	average	st.dev.	average	st.dev.	average	st.dev.
Al plate	223	7.5	226	0.8	225	3.3
Paper (S041328)	238	4.8	240	3.6	239	0.9
WB card	215	2.9	233	1.7	233	1.2
DigiTizer White Patches	210	4.8	214	2.5	212	1.1
Calibration Colour difference	0.97		0.62		0.63	0.01

targets	RGB value -directional (angled/mirror)					
	no uniformity correction		uniformity correction Al plate		uniformity correction paper (S041328)	
	average	st.dev.	average	st.dev.	average	st.dev.
Al plate	201	16.8	205	1.8	202	13.0
Paper (S041328)	236	7.4	**	**	237	0.9
WB card	238	4.3	234	7.5	234	1.0
DigiTizer White Patches	210	5.7	218	14.9	212	1.2
Calibration Colour difference	1.34		1.60		0.86	0.02

** = saturated

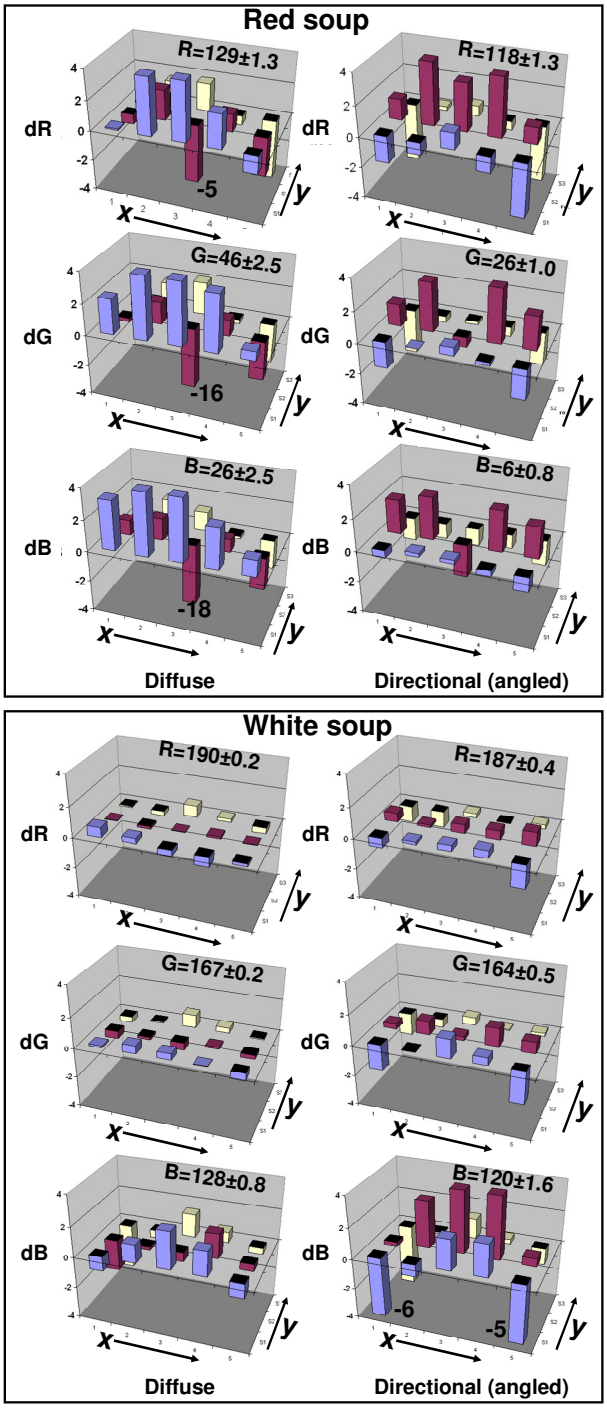

Figure 5. *Spatial distribution of the intensity of a sieved red tomato soup and white asparagus/cauliflower/celeriac/onion soup imaged within the DigiEye imaging system using diffuse (left) and directional (right) illumination after uniformity correction: absolute difference between RGB values at different locations and the average RGB®. Maximum difference® between measured L*a*b* colours (CIEDE2000) is 1.5 and 2.1 for tomato soup and 0.6 and 0.9 for white soup using diffuse and directional illumination, respectively. ® = excluding the centre.*

For accurate colour measurement the colour has to be measured at a fixed location. The distribution of the light within the sample cup was measured at 3 different locations in the lighting cabinet (Figure 6): on the edge of the image (x=6 cm), just outside the dark spot (x=10 cm) and within the centre (x=18 cm). The intensity at the edge of the sample holder is lower. At 6 cm the uniformity correction is insufficient to flatten the intensity profile and at 18cm the dark spot resulted in a lower intensity. A position of 10 cm resulted in the largest area with a constant intensity. In this case an area with a diameter of about 5 cm can be used for colour measurement.

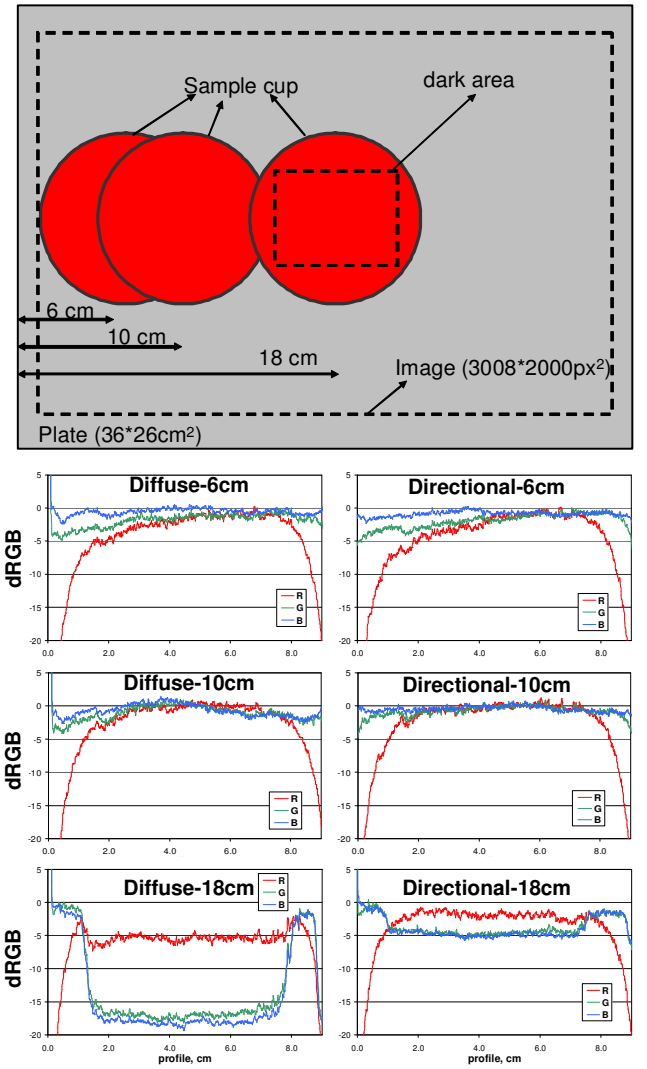

Figure 6. *Intensity profile (RGB) (average of 100 pixels) of tomato soup under diffuse and directional (angled/mirror) illumination after uniformity correction using white paper: absolute difference of RGB values between pixels along a central line (x) and the pixels in the centre (R=121, G=31, B=10 for angled and R=126, G=45, B=27 for diffuse) at 10cm. (inner diameter cup = 9.5 cm).*

The colour of different soups was measured using sample cups with depths of 1cm; 2cm and 3cm. Each cup was filled and measured 2 times using both diffuse and directional illumination. The total measurement run was repeated three times. For each run white balance, uniformity correction and calibration were performed (switching illumination conditions between each run). This method was applied to determine the influence of the depth of the sample cup, the influence of the illumination and the repeatability (r). Three creamy thick soups with a high opacity and two clear vegetable soups with a high translucency were analysed. The soups were sieved to remove the vegetable particles. The analysis of variance was used to calculate the precision parameters and to study the effects of the different influences. The average results with confidence intervals are presented in Figure 7. For clear soups a significant influence of the depth was observed (large F value), showing an increase in a* and b* values (more saturated). For thick creamy soups only a small effect of the depth was observed (significant for a* of red soup for both directional and diffuse). To obtain consistent colour results, sample cups with a depth of 2 cm were selected. Cups with a depth of 3cm may result in larger shadow effects of the walls when not completely filled. No significant difference was found between the average CIE lab values measured under directional and diffuse illumination. The precision parameters are presented in Table 2. Angled illumination resulted in a better precision than diffuse illumination (significant lower standard deviation for L* and b*).

Table 2. Precision parameters for the determination of the CIE colour of sieved soups (3 creamy thick soups and 2 bouillons) in sample cups with 3 different depths and a reference standard under angled and diffuse illumination (s1 = standard deviation of the short term repeatability (r1), s2 = standard deviation of the between runs repeatability (r2)).

Creamy thick soups						
	L*		a*		b*	
	directional	diffuse	directional	diffuse	directional	diffuse
s_1	0.17	0.18	0.20	0.29	0.27	0.35
s_2	0.34	0.46	0.36	0.40	0.47	0.92
r_1	0.39	0.52	0.58	0.81	0.77	0.99
r_2	0.97	1.29	1.02	1.12	1.32	2.60

Bouillons						
	L*		a*		b*	
	directional	diffuse	directional	diffuse	directional	diffuse
s_1	0.14	0.19	0.17	0.24	0.30	0.46
s_2	0.30	0.37	0.38	0.64	1.04	1.07
r_1	0.40	0.54	0.49	0.68	0.84	1.31
r_2	0.82	1.05	0.85	1.81	2.90	3.04

Green diagnostic tile						
	L*		a*		b*	
	directional	diffuse	directional	diffuse	directional	diffuse
s_1	0.15	0.01	0.26	0.06	0.08	0.23
s_2	0.15	0.20	0.40	0.28	0.31	0.23
r_1	0.42	0.02	0.73	0.16	0.23	0.65
r_2	0.42	0.57	1.12	0.80	0.86	0.65

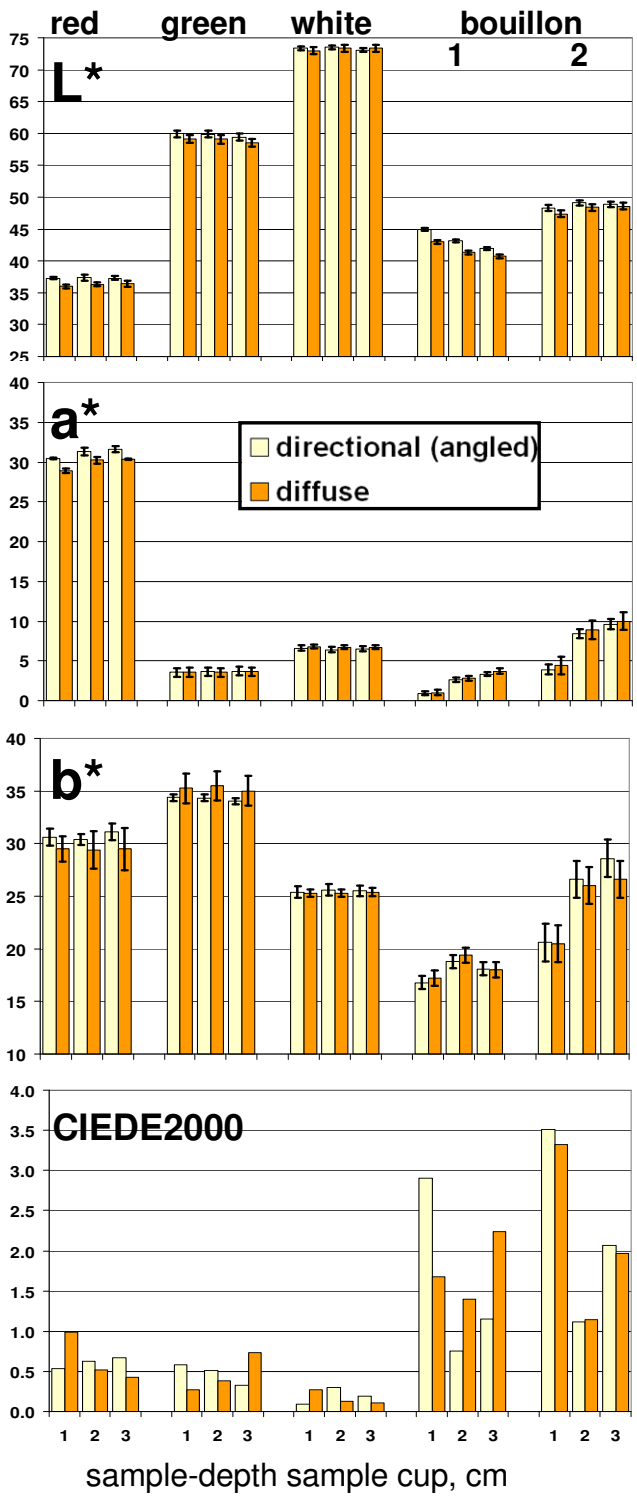

***Figure 7**. CIE colour parameters of sieved tomato soup (red), pea-soup (green), asparagus/cauliflower/celeriac/onion soup (white) and two vegetable soups (bouillon 1&2) under angled and diffuse illumination using sample cups with 3 different depths. CIEDE2000 colour difference [9, 10] between average colour per depth & sample (n=6) and average colour per sample (n= 18).*

For validation of the method 36 different creamy soups were analysed in duplicate using the DigiEye system under angled and diffuse illumination and two different colorimeters: Hunterlab Labscan 6000 and Minolta CR400. Representative images of the sieved soups are shown in Figure 10. The sieved soups may contain small pieces of herbs. The used colorimeters have different geometry ($0^o/45^o$ for Labscan and diffuse/0^o & specular included for the CR400). A $0^o/45^o$ geometry will better match the visual appearance of the product. For both visual assessment and colour analysis using a $0^o/45^o$ geometry, a glossy sample may appear darker and more saturated than a matte sample with comparable concentrations of colour compounds. Diffuse/0^o colorimeters, used in the specular included mode, minimize the effect of differences in gloss, texture and directionality. It will result in comparable results for samples with comparable concentrations of colour compounds but with a different gloss and therefore different visual appearance. The difference between the CIE standard observers used in the Labscan 6000 and CR400 (resp. 10^o and 2^o) will only have a small effect on the measured CIE Lab values.

Linear relations were found between the CIE Lab values measured by the DigiEye system and those measured by the Labscan 6000 and CR400. However much better correlations were found between the DigiEye and the Labscan 6000. An overview of the regression parameters is shown in Table 3. The DigiEye results are in close agreement with the Labscan 6000 (Figure 8). However results of the DigiEye and Labscan 6000 can not directly be interchanged for product specification. For direct comparison only instruments of the same geometry have to be used (preferably from the same brand and model). For inter-instrument agreement the DigiEye system can be calibrated using soup samples. A good correlation exists between XYZ values of the DigiEye and Labscan 6000 (r^2= 0.997, see Table 3). Colour measurements are mainly used to estimate differences between samples (e.g. after treatment or storage). The colour difference is based on the Euclidean distance between two colours in the 3D CIE colour space. The CIEDE2000 colour difference formula [9, 10] also takes into account the colour discriminating power of the human eye (including saturation and hue). A value of CIEDE2000 of about 1.0 is intended to represent a just noticeable difference between two colours regardless their location in colour space. The colour differences between adjacent colours of the soups shown in Figure 10 are presented in Figure 9. The discriminating power of the DigiEye is comparable to the Hunterlab Labscan 6000.

Direct comparison of directional with diffuse illumination showed only a small significant difference for the b* value and lower correlation coefficient for a* (Table 3). The correlation between a* values obtained by the DigiEye under diffuse illumination and the Labscan 6000 is lower than for directional illumination (r^2 = 0.94 and 0.98, respectively). For several dark glossy samples dark spots were observed under diffuse illumination resulting in lower CIE Lab values (Figure 12). For the validation study the colour was measured outside these areas.

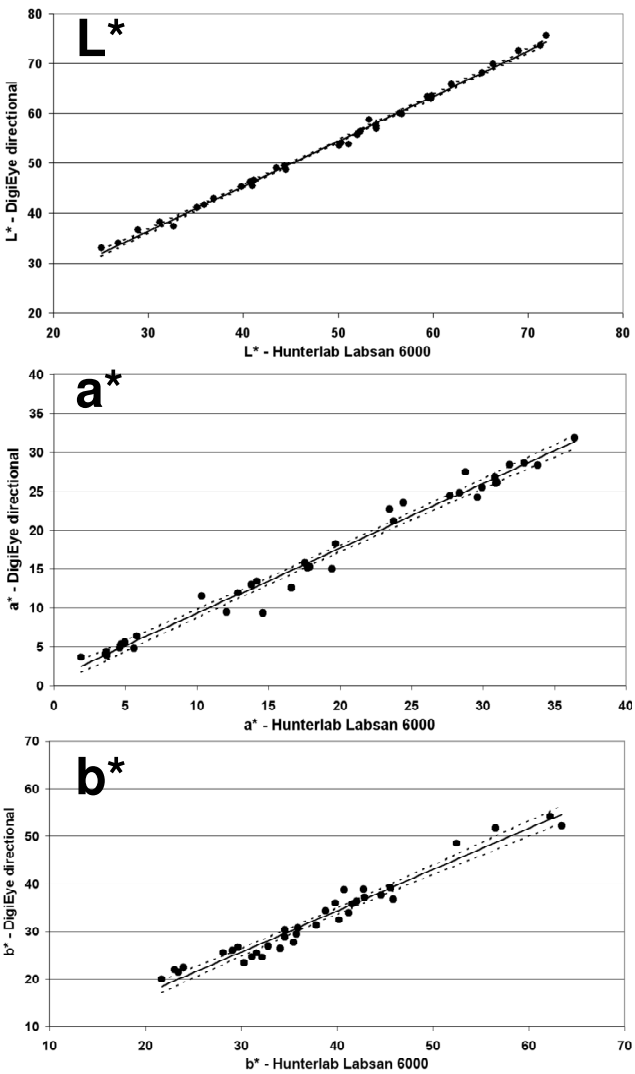

***Figure 8**. CIE Lab values of soup samples measured using the DigiEye system under directional illumination versus values obtained using the Hunterlab Labscan 6000 colorimeter (dotted line: 95% confidence interval).*

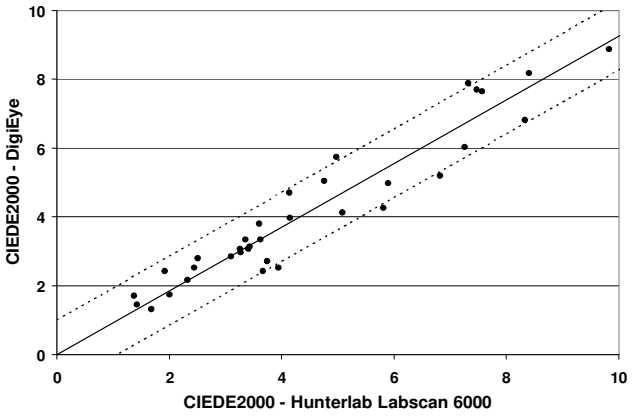

***Figure 9**. Colour differences between adjacent colours of soups used in the validation study (Figure 10) analysed using the DigiEye system under directional illumination versus the Hunterlab Labscan 6000 colorimeter (dotted line: y=x±1).*

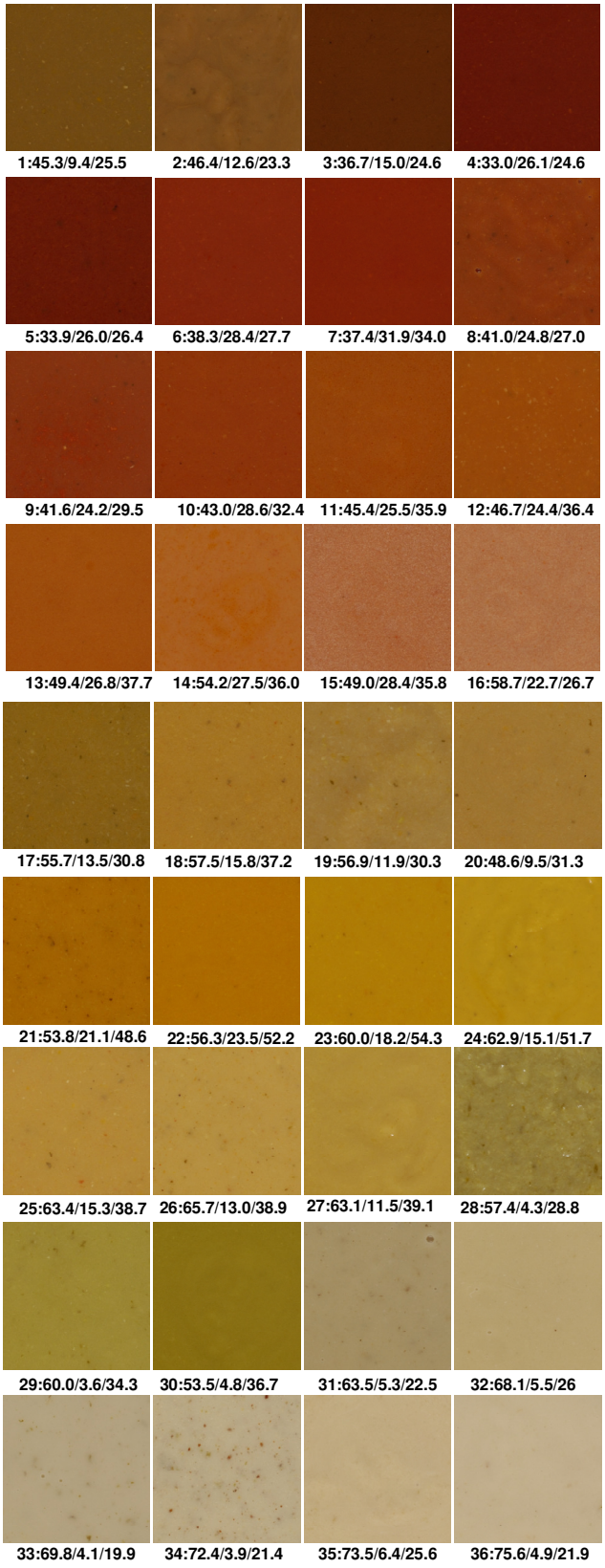

***Figure 10**. Images (5cm * 5cm) of soup samples used in validation study (sorted on colour). Images obtained under directional illumination with measured CIE Lab values (L*/a*/b*).*

Table 3. Regression parameters for the comparison of the CIE colour values obtained using the DigiEye system versus values obtained using the Hunterlab Labscan 6000 and the Minolta CR400 colorimeters.

DigiEye = α + β * Hunterlab Labscan 6000						
	L*		a*		b*	
	directional	diffuse	directional	diffuse	directional	diffuse
α	9.4±1.3	7.8±1.2	0.88±1.0	1.7±1.6	-0.1±3.0	-1.4±3.3
β	0.90±0.02	0.91±0.02	0.85±0.05	0.79±0.09	0.86±0.07	0.91±0.08
r^2	0.996	0.997	0.98	0.94	0.96	0.96

DigiEye = α + β * Minolta CR400						
	L*		a*		b*	
	directional	diffuse	directional	diffuse	directional	diffuse
α	4.7±5.2	2.6±4.9	7.5±2.0	7.9±2.1	13.1±3.9	12.6±4.0
β	1.04±0.10	1.06±0.10	1.10±0.21	1.03±0.22	0.86±0.15	0.90±0.16
r^2	0.95	0.95	0.85	0.81	0.87	0.87

DigiEye (directional) = α + β * colorimeter						
	X		Y		Z	
	Labscan6000	CR400	Labscan6000	CR400	Labscan6000	CR400
α	2.6±0.7	3.2±3.6	2.9±0.5	1.49±3.31	2.5±0.3	-1.6±0.7
β	1.04±0.03	1.25±0.17	1.04±0.02	1.25±0.16	1.09±0.03	1.23±0.05
r^2	0.997	0.91	0.998	0.93	0.997	0.991

DigiEye (directional) = α + β * DigiEye (diffuse)			
	L	a*	b*
α	2.1±1.0	0.5±1.0	1.1±1.1
β	0.98±0.18	1.04±0.06	0.95±0.03
r^2	0.998	0.983	0.995

The short term repeatabilities of the DigiEye system under directional and diffuse illumination are compared to those obtained by the Labscan 6000 and CR400 in Table 4. The repeatability of the DigiEye under directional illumination is somewhat better than that of the Labscan 6000. For the CR400 much higher repeatability values were obtained. This can be due to the small measuring area of 8mm.

Table 4 *Precision parameters of soup samples (Figure 10) used in the validation study (*s1 = standard deviation of the short term repeatability (r_1)).

	L*		a*		b*	
	s_1	r_1	s_1	r_1	s_1	r_1
DigiEye directional	**0.14**	**0.40**	**0.13**	**0.38**	**0.23**	**0.64**
DigiEye diffuse	**0.14**	**0.40**	**0.17**	**0.49**	**0.34**	**0.96**
Labscan 6000	**0.23**	**0.64**	**0.15**	**0.41**	**0.41**	**1.15**
CR400	**0.81**	**2.31**	**0.44**	**1.25**	**1.64**	**4.65**

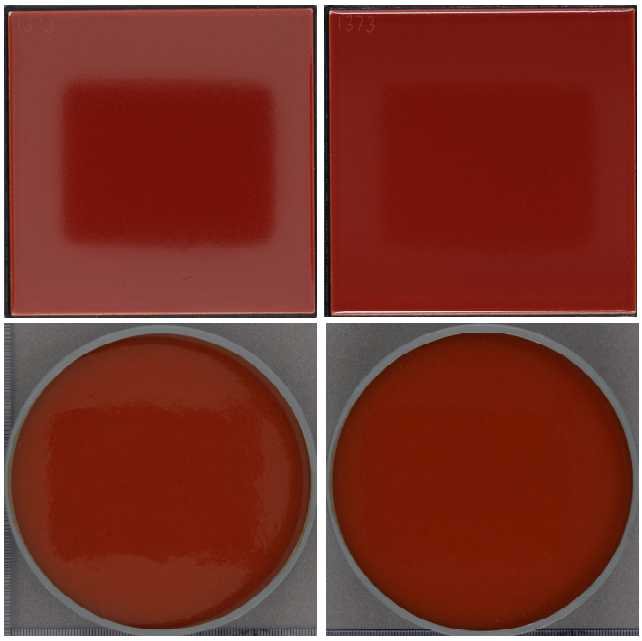

***Figure 11**. Images of a red ceramic tomato reference tile (top) and a sieved tomato soup (bottom) obtained at diffuse (left) and directional (right) illumination. Image size = 10cm * 10cm.*

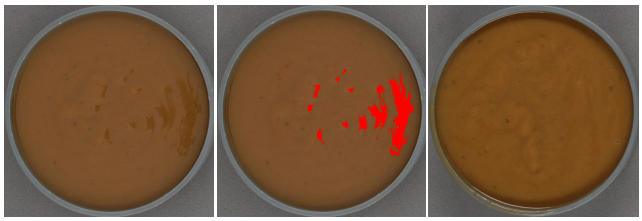

***Figure 12**. Influence of lighting conditions on the images of brown bean soup [diffuse (left and middle) and directional (right) illumination] with detected dark areas in red. L*=44.9, a*=12.7, b*=23.1 (outside) and L*=40.5, a*=11.5, b*=31.2 (inside red area).*

Conclusion

The DigiEye system can be used for colour and appearance analysis of soup containing fruit and vegetable particles. It allows documenting the appearance by making colorimetrically accurate images which are suitable for the measurement of colour uniformity, size and shape. For accurate colour analysis the images have to be corrected for non-uniform illumination and the colour has to be measured at a fixed location outside the centre of the lighting cabinet. To match the actual appearance of soups and vegetable particles, directional illumination (angled light with additional mirrors) was used to introduce gloss on the surface of the soup. Imaging glossy soups under diffuse illumination resulted in dull images with dark spots. No significant difference was found between the colours of soup analysed under diffuse or directional illumination. Under directional illumination a better repeatability was observed. Linear relations were found between the CIE Lab values of 36 different soup samples measured by the DigiEye system and those measured by two different colorimeters ($0^o/45^o$ and diffuse/0^o geometry). Best correlations were obtained between DigiEye and $0^o/45^o$ colorimeter (r^2=0.980-0.996). The short term precision of the DigiEye system is somewhat better than those of the colorimeter.

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Author Biography

Gerard van Dalen has been working in Unilever Research Vlaardingen for 30 years and was manager for 12 years of the Atomic and Vibrational Spectroscopy unit. He is currently involved as a research scientist in the application of IA techniques for advanced imaging techniques (2D, 3D and 4D) to obtain quantitative information of the micro and macro structure, composition, texture, size, shape, colour and appearance of foods, detergents and related products. He is author of 35 papers on Spectroscopy, Microscopy and Image Analysis.