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ORIGINAL PAPER

Color of Salmon Fillets By Computer Vision and Sensory Panel

R. A. Quevedo · J. M. Aguilera · F. Pedreschi

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Abstract A computer vision method was developed and used to assign color score in salmon fillet according to SalmonFan™ card. The methodology was based on the transformation of RGB to $L^*a^*b^*$ color space. In the algorithm, RGB values assigned directly to each pixel by the camera in the salmon fillet image, were transformed to $L^*a^*b^*$ values, and then matched with other $L^*a^*b^*$ values that represent a SalmonFan score (between 20 and 34). Colors were measured by a computer vision system (CVS) and a sensorial panel (eight panelists) under the same illumination conditions in ten independent sets of experiments. Errors from transformation of RGB to $L^*a^*b^*$ values by the CVS were 2.7%, 1%, and 1.7%, respectively, with a general error range of 1.83%. The coefficient of correlation between the SalmonFan score assigned by computer vision and the sensory panel was 0.95. Statistical analysis using t test was performed and showed that there were no differences in the measurements of the SalmonFan score between both methods (t_c=1.65 $\leq$ t=1.96 at α= 0.05%). The methodology presented in this paper is very versatile and can potentially be used by computer-based vision systems in order to qualify salmon fillets based on color according to the SalmonFan card.

Keywords Computer vision · Color · Salmon fillet · SamonFan™ card · Image analysis · Sensory panel

R. A. Quevedo (✉)
Department of Science and Food Technology,
Universidad de Los Lagos,
Av. Fushlocher 1305,
Osorno, Chile
e-mail: rquevedo@ulagos.cl

J. M. Aguilera
Department of Chemical Engineering and Bioprocesses,
Pontificia Universidad Católica de Chile,
P.O. Box 306, Santiago, Chile

F. Pedreschi
Department of Food Science and Technology,
Universidad de Santiago de Chile (USACH),
Av. Ecuador,
3769 Santiago, Chile

Introduction

Color is an important organoleptic characteristic used to establish the acceptance of various food products (Hutchings 1999). The aspect and color of the food surface is the first quality parameter evaluated by consumers, and it is critical to product acceptance. Furthermore, food appearance (determined mostly by surface color) is the first sensation that the consumer perceives and uses as a tool either to accept or reject food (Leon et al. 2006).

Consumers purchasing fish in supermarkets have few means of evaluating the flavor, tenderness, and juiciness of fillets placed behind a glass window. Therefore, consumers commonly base their selection on visual appearance (color) when purchasing various meat cuts (Barbut 2003). However, in the salmon industry, visual color assessment is aided by the use of color charts, such as SalmonFan™ card (Hoffmann-La Roche Basel, Switzerland). SalmonFan score is now the most frequently used tool to assess the visual fillet color in Atlantic salmon. SalmonFan card ranges over 14 red colors with varying red intensity. Each color is associated with a numerical value ranging from 20 (very pale red) to 34 (very intense red; Forsberg and Guttormsen 2006). Computer vision algorithms for both SalmoFan lineal and Roche color card scores have been proposed for salmon fillets (Marty-Mahé et al. 2004; Misimi et al. 2007; Stien et al. 2006).

In food, the color space used to describe color is the CIELab or $L^*a^*b^*$ space. This color space is device-independent, creating consistent colors regardless of the device being used to acquire the image. L^* is the luminance or lightness component, it ranges from 0 to 100, while a^* (green to red) and b^* (blue to yellow) are two chromatic components, with values varying from −120 to +120 (Papadakis et al. 2000). Recently, Leon et al. (2006) has suggested a computer vision system (CVS) to measure color in Lab from RGB space to be used in image analysis.

Computer vision could help the food industry meet new traceability regulations in place throughout Europe and North America, its manufacturer claims. The mandatory traceability requirement applies to all food, animal feed, food-producing animals, and all types of food chain operators from the farming sector to processing, transport, storage, distribution, and retail to the consumer (Smith and Furness 2006). Fishery chain traceability is the most important tool for fish food safety and for consumer protection. Innovative and safe technologies are therefore necessary to assess species identification and authenticity testing (Arvanitoyannis et al. 2005). Among the variety of methods that are able to identify commercially imported fish and seafood species, molecular biotechnologies are becoming more widely utilized and are attracting increased attention (Maldini et al. 2006). In fact, various means to discriminate between fish of dissimilar origins have been investigated in several previous studies. These have used a range of intrinsic parameters, notably the compositional analysis of fatty acids and the nature of the xanthin pigments present, among other properties (Rezzi et al. 2007; Thomas et al. 2008).

In this work, a novel computer algorithm based on Lab space to assign color is proposed. The objective of this study was to correlate a computer vision system with a sensory panel**,** apply a new algorithm based on Hunterlab color values**,** and assign color in salmon fillet.

Materials and Methods

Computer vision is an alternative technique for color evaluation and quantification (Yam and Papadakis 2004). Basically, a computer vision system generally consists of five basic components: the illumination system, a digital camera, an image capturing board (frame grabber or digitizer), computer hardware, and software to process the images. A standardized lighting system is crucial to reduce reflection, shadows, and some noise, thus enhancing the image quality and assuring repeatability. To ensure high quality, a high-resolution charge-coupled device camera is normally used in conjunction with a frame grabber to capture a color image of the food sample. Once an image is obtained, feature extraction and quantitative analysis may be performed (Sun 2000). With a digital camera, it is possible to register the color of any pixel of the object image by using three color sensors per pixel (Forsyth and Ponce 2003). The color model most often used is the RGB model in which an imaging sensor captures the light intensity of the red (R), green (G), and blue (B) components, respectively.

RGB, HSV (hue, saturation, and value), and CIELab are the most popular space color models used in food computer vision (Dana and Ivo 2008; Du and Sun 2005; Kang et al. 2008; Leemans et al. 1998; Leon et al. 2006; Magdic and Dobricevic 2007; Mendoza et al. 2006; Misimi et al. 2007; O'Sullivan et al. 2003; Sun 2004; Zhang et al. 2003; Zhou et al. 2004), among others. The RGB color model is used for computer color representation. However, RGB space is not quite perceptually uniform and does not represent the colors perceived naturally by humans very well. Perceptual uniformity is the property by which the perceptual similarity of two colors is measured based on the distance between the two color points in the color space (Anil 1989). CIELab and the HSV color space are preferred in foods because these color spaces effectively represent the colors naturally perceived by humans, and they are perceptually uniform. In this study, the CIELab color model space was selected because of its perceptual uniformity and because recently it has been recommended as the best space for color quantification in foods (Mendoza et al. 2006).

Computer Vision System

A computer vision system (CVS), described by Mendoza and Aguilera (2004), was used to capture the images (2,048 × 1,536 pixels). Samples were illuminated briefly, using four fluorescent lamps of TL-D deluxe, natural daylight, 18W/D65 (Philips, Santiago, Chile), with a color temperature of 6,500 K (D65, standard light source commonly used in food research) and a color-rendering index (Ra) close to 95%. The lamps (60 cm long) were arranged in the form of a square, 35 cm above the fillet samples, at an angle of 45° in relation to the sample. Additionally, light diffusers covering each fluorescent lamp and electronic ballasts were added. These measures were taken to provide, as uniform as possible, illumination (Briones and Aguilera 2005; Quevedo et al. 2002, 2008). The appearance of a food product is not only affected by its true color but also by the light source, observer's position, light intensity, etc. (Barbut 2003). The photographed images were stored in the JPEG (quality 90%) format.

Calibration

A methodology suggested by Leon et al. (2006) was used to calibrate the CVS in order to obtain $L^*a^*b^*$ estimated values from the RGB space (Fig. 1). Color charts (30 charts) and SalmonFan cards (20 cards) were used in the calibration of the computer vision. A HunterLab colorimeter (model 45/0–version 1.51) was used in the experiments.

In the charts and SalmonFan cards, ten different regions, corresponding to each area that represents a color level, were measured (ten repetitions were carried out). Averages ($10\times10=100$ measurements) were taken as the original $L^*a^*b^*$ for each color level, respectively. In the case of the SalmonFan card, each scanned area corresponded to a score (20 to 34). These original $L^*a^*b^*$ values were used by the CVS in the calculation of estimated $L^*a^*b^*$ values.

Images for the charts and for the SalmonFan card (20 images for each one with 20 repetitions for each image) were taken by the CVS to calculate estimated $L^*a^*b^*$ values. In order to transform RGB values to $L^*a^*b^*$ color values, the quadratic model suggested by Leon et al. (2006), was used:

$$\begin{bmatrix} L^* \\ a^* \\ b^* \end{bmatrix} = \begin{bmatrix} \theta_{11} & \theta_{12} & \theta_{13} & \theta_{14} & \theta_{15} & \theta_{16} & \theta_{17} & \theta_{18} & \theta_{19} & \theta_{1,10} \\ \theta_{21} & \theta_{22} & \theta_{23} & \theta_{24} & \theta_{25} & \theta_{26} & \theta_{27} & \theta_{28} & \theta_{29} & \theta_{2,10} \\ \theta_{31} & \theta_{32} & \theta_{33} & \theta_{34} & \theta_{35} & \theta_{36} & \theta_{37} & \theta_{38} & \theta_{39} & \theta_{3,10} \end{bmatrix} \cdot \begin{bmatrix} R \\ G \\ B \\ R\cdot G \\ R\cdot B \\ G\cdot B \\ R^2 \\ G^2 \\ B^2 \\ 1 \end{bmatrix} \quad (1)$$

Where $L^*a^*b^*$ values are the estimates of the original $L^*a^*b^*$ values of the charts and the SalmonFan™ card, and the θ's are the coefficients of the quadratic model. This model infers the $L^*a^*b^*$ values on the basis of the RGB measurements from the camera without having to use the colorimeter and considers the influence of the square of the variables (R, G, B). The mean normalized error (E), in the estimate of each of the L^*, a^*, and b^* variables, was obtained by comparing

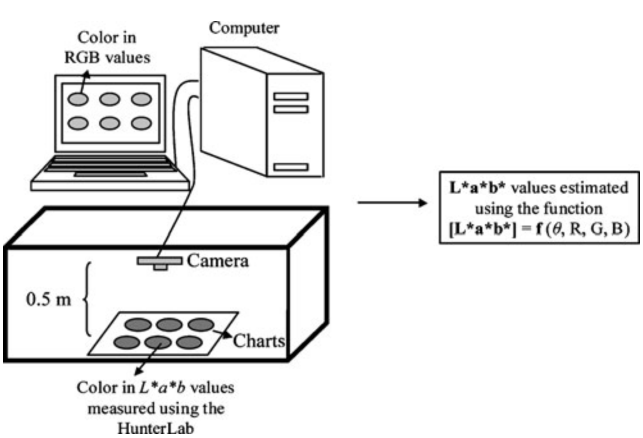

Fig. 1 Schedule showing the calibration of the CVS in order to estimate $L^*a^*b^*$ using original $L^*a^*b^*$ values from colors charts

colorimeter measurements ($L^*a^*b^*$) with model estimates L^*, a^* and b^*:

$$E_X = \frac{1}{N\cdot\Delta X}\cdot\sum\left|X_{o,i}-X_{e.i}\right| \quad (2)$$

Where N is the number of experimental data (i), X the corresponding variable (L^*, a^*, or b^*); subscripts o is the original variable; subscripts e is the estimate variable; and ΔX is the range for each variable, $\Delta L^*=100$; $\Delta a^*=240$, and $\Delta b^*=240$, respectively. The θ coefficients in Eq. 1 were established minimizing the error function (Eq. 2). Minimization was carried out using the solver macro from the Excel program (Microsoft office 2000).

SalmonFan Colors in $L^*a^*b^*$ Color Space

$L^*a^*b^*$ range values were calculated for each color level in the SalmonFan card. Twenty-five cards were used, and ten pictures for each one were captured by the CVS. Areas that represent each color level in the SalmonFan card were manually segmented, and $L^*a^*b^*$ values using CVS were calculated with Eq. 1. In other words, each area representing a color level in the SalmonFan card was represented by $L^*a^*b^*$ range values obtained by using the CVS.

Transformation Algorithm

A procedure was developed (an algorithm) in order to assign a SalmoFan score to salmon fillet images, in Matlab® R14 (MathWorks™). For each pixel in a segmented image of salmon fillet, RGB values were transformed to the $L^*a^*b^*$ values, using the Eq. 1. Then, $L^*a^*b^*$ values in each pixel were matched with the $L^*a^*b^*$ range values corresponding to each color level in the SalmonFan card. According to this matching, a color level (20 to 34) was assigned to each pixel in the original image (Fig. 2). Finally, the mean of these color level values was assigned to the salmon fillet.

Computer Vision System and Sensory SalmonFan Scores

Two hundred salmon fillets were evaluated by eight trained panelists in order to assign a color score according to the SalmoFan card. The evaluations were separated into ten different sessions, each one evaluated 20 fillets. During the experiments, a fillet was put inside the CVS (under the camera) and ten different images (ten repetitions) were taken. Subsequently, the camera was removed in order to allow to the panelists to assign a color score according to the SalmoFan card (Fig. 3). The SalmoFan card was placed near to the fillet in order to compare colors under the same illumination conditions. Each panelist had 2 min to observe and visually assign a color level from the SalmonFan card (same illumination conditions, fillet position, etc., as in the

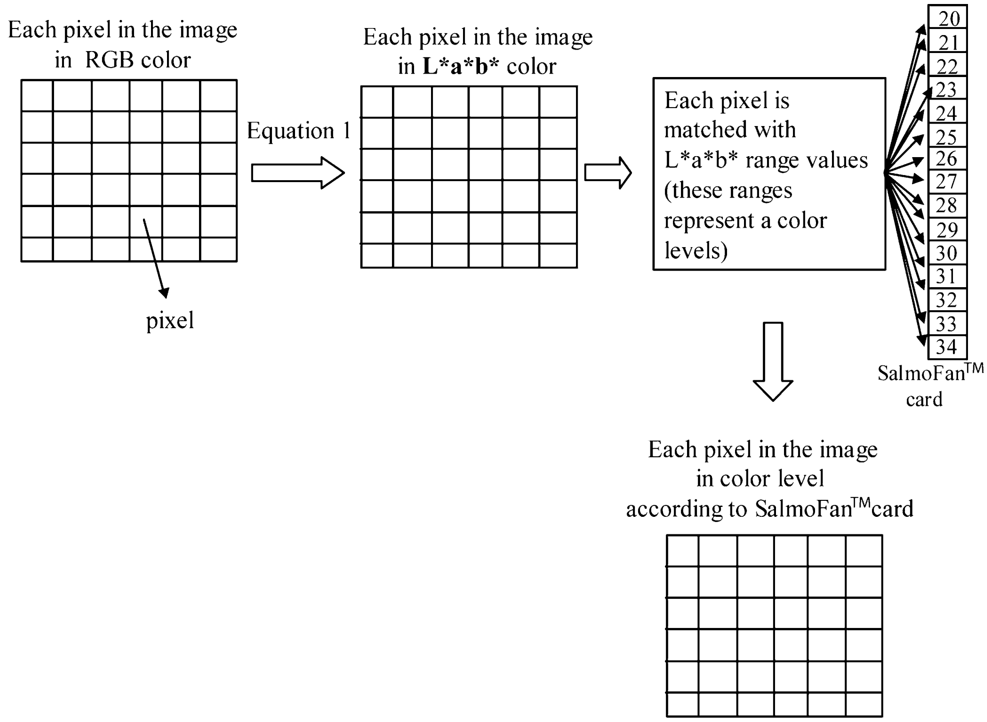

Fig. 2 Schedule showing the algorithm to assign color values to the salmon fillet image

CVS, were used). In the experiment, each panelist evaluated the fillet sample for around 1 min, comparing the fillet color with each area in the SalmonFan card**.** Ten images for each fillet were taken to be analyzed by the CVS. Comparison differences were established using a statistical correlation and *t* test at 95% confidence level in Statgraphics 5.1 (Rockville, MA, USA).

Results and Discussion

Calibration of the Computer Vision System

Table 1 shows the optimized transformation matrix based on Eq. 1. These values were used to estimate $L^*a^*b^*$ values from the *R*, *G*, and *B* in the segmented image. For this model, errors calculated (Eq. 2) for $L^*a^*b^*$ color values were 2.7%, 1%, and 1.7%, respectively; with a general error of 1.83%. Leon et al. (2006) obtained errors for the quadratic model equal to 1.23%. It is important to highlight that these parameters need to be recalculated if the CVS or the illumination is modified. Correlation between the $L^*a^*b^*$ values measured by CVS and the colorimeter HunterLab (correlation coefficient) was 0.99, 0.98 and 0.92 for L^*, a^*, and b^* values, respectively. Despite errors in the optimization, the quadratic model used in this paper was considered satisfactory, although other models that transform RGB space to Lab space with minor errors can be found in the literature available (Larraín et al. 2008; Leon et al. 2006; Pedreschi et al. 2006).

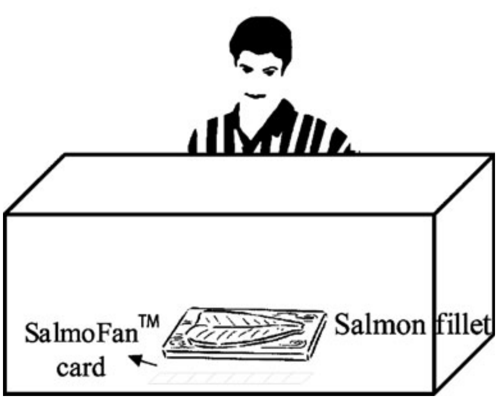

Fig. 3 Schedule showing the sensorial analysis to assign a color level to the salmon fillets

Table 1 Optimized transformation matrix based on Eq. 1

Parameters	L^*	a^*	b^*
θ_1	0.2186	0.335	0.093
θ_2	0.1316	−0.5012	0.435
θ_3	−0.0211	0.1551	−0.0538
θ_4	−0.0005	0.0001	−0.0001
θ_5	0.0012	0.0003	0.0005
θ_6	0.0002	0.001	−0.0007
θ_7	−0.0005	0.0011	0.0001
θ_8	0.0002	−0.001	0.0003
θ_9	−0.0007	−0.001	−0.0018
θ_{10}	15.527	−0.393	−4.4257

Table 2 $L^*a^*b^*$ values for each SalmoFan™ score calculated using the CVS (mean of 25 SalmoFan card)

SalmoFan score	L^*	a^*	b^*
20	72.73±0.55	23.50±0.90	16.35±1.25
21	68.80±0.70	27.80±0.90	21.20±1.40
22	65.95±0.45	30.00±0.50	26.35±1.45
23	63.30±0.40	32.15±0.45	29.15±1.05
24	60.80±0.70	33.70±1.10	32.45±1.35
25	58.60±0.50	34.05±1.05	33.60±1.50
26	57.70±0.90	32.80±2.30	32.10±2.30
27	56.50±0.50	39.05±0.95	38.10±1.50
28	54.20±0.60	41.70±1.10	40.10±1.80
29	52.35±0.45	44.45±0.75	41.50±1.00
30	50.35±0.45	46.00±1.10	41.00±1.50
31	48.35±0.75	45.70±4.00	40.40±2.30
32	47.05±0.45	50.25±1.15	42.10±1.60
33	45.10±0.40	50.00±1.00	38.80±1.60
34	44.20±0.50	46.20±1.40	33.00±2.00

Transformation of RGB to $L^*a^*b^*$

Table 2 shows L^*a^*b values estimated for each area in the SalmonFan card, measured using the CVS. A matching is established (and a SalmonFan score is assigned) if the L^*a^*b values in a pixel lie within any L^*a^*b range values in Table 2. For example, L^*a^*b values of a pixel equivalent to 61 for L^*, 33 for a^*, and 33 for b^* would match the SalmoFan score of 24 (Table 2). In this case, the SalmonFan score 24 is assigned to this pixel. Note in Table 2 that, for some SalmonFan score values, an overlap of the a^* and b^* values occurs, and in this case, the L^* value defines the matching. This novel procedure is very simple and could be applied quickly in computer vision, with minimum complexity, because it only requires the application of logical sentences to discriminate between color data.

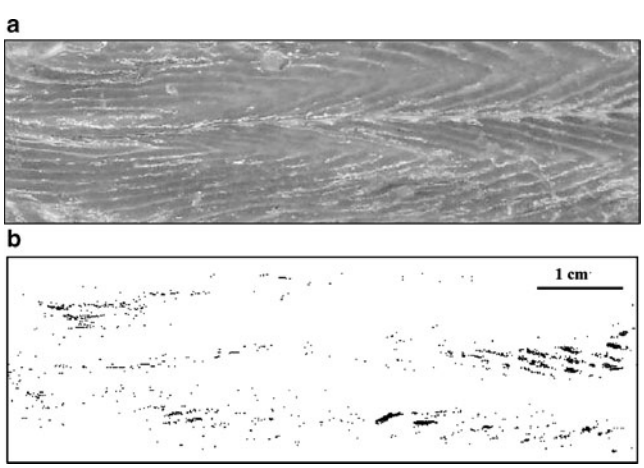

Fig. 4 A selected salmon fillet image (in *gray scale format*) submitted to evaluation by the proposed algorithm. **a** In gray levels. **b** *Black points* are pixels that were not matched by the algorithm

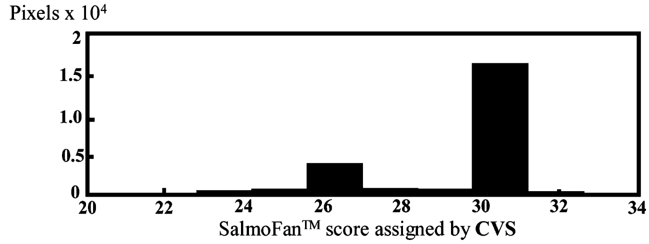

Fig 5 Histogram showing the distribution of the SalmonFan™ score values assigned by the algorithm to Fig. 4

Computational methods that are versatile and do not involve complex calculations are preferred in food computer vision (Parker 1997).

SalmoFan Score Assignment

One selected salmon fillet image (in gray scale format) submitted for evaluation by the proposed algorithm is shown in Fig. 4a. The image (86×299 pixels) corresponds to the tail section of the salmon fillet, and the pixel number in the image is 86×299=25,714. Initially, these pixels are potential candidates to be assigned a color score using the proposed algorithm. After the algorithm was applied to the image, a total of 22,986 pixels were assigned a SalmonFan score value (the average of these values represents the SalmoFan score value of the entire segmented image or region). In Fig. 4b, black points represent pixels that were not considered by the algorithm to assign a SalmonFan score value because those pixels do not match. Note that, in the proposed algorithm, a SalmonFan score value was assigned directly to each pixel in the original image, rather than an average of the $L^*a^*b^*$ values being calculated in the entire image and converted to SalmoFan score values. In other words, to assign a color to the salmon fillet, the algorithm proceeds, pixel by pixel, through the image of the selected region, as opposed to the algorithm proposed by Misimi et al. (2007), which used mean values from the selected region. This procedure makes it possible to

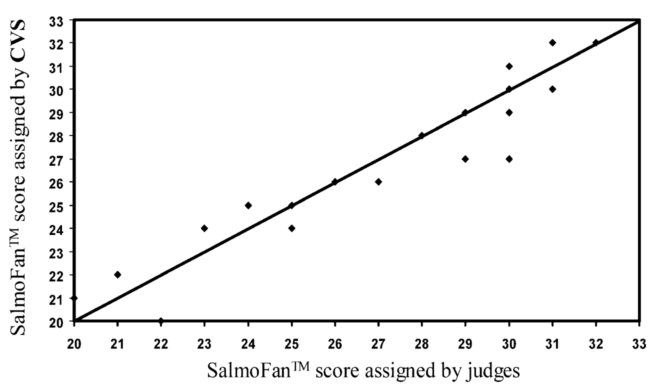

Fig. 6 Comparison among SalmonFan™ score obtained by CVS and SalmonFan™ score by using sensory analysis

discriminate pixels that, for some reason (blurred image, muscle defects, presence of lipids, among other defects), do not match with values in Table 2.

A histogram showing the distribution of the SalmonFan score values assigned to each pixel on the segmented image (Fig. 4) is presented in Fig. 5. The distribution shows that many points had values close to 31. This shows the variability of the salmon fillets regarding color (Barbut 2001).

Computer Vision System SalmonFan Score vs. Sensory SalmonFan Score

One set of scores corresponding to 20 different salmon fillet measurements, carried out by the CVS and by the sensory panel, is shown in Fig. 6. In total, ten sets of experiments, with 20 salmon fillets in each one, were carried out (200 fillets). In general, SalmonFan score values assigned to fillets (tail section) were very similar to those assigned by the sensory panels. Correlation analysis (r=0.95) indicated very strong relationships between CVS and the sensory panel methods. Statistical analysis was performed (t test), and it showed that there are no differences in the measurements of the SalmonFan score between the methods (t_c= 1.65 $\leq$ $t_{0.0025,\ 200}$=1.96, at α=0.05%). An immediate implication of this result is that the computer vision method assigned score values similarly to the traditional sensory evaluation of fillet color. As opposed to the traditional sensory evaluation, there is no eye fatigue or lack of color memory in computer vision, and illumination conditions are uniform (Irudayaraj and Gunasekaran 2001). Automation of this operation can reduce labor and production costs.

Conclusion

A novel algorithm to assign color in salmon fillet surfaces according to the SalmonFan™ score is presented. The quadratic model to transform RGB values to $L^*a^*b^*$ values was used with successful results (errors for $L^*a^*b^*$ color values were 2.7%, 1%, and 1.7%, respectively). Applying this algorithm, good correlation was observed between the color assigned by CVS and by the sensory panel (r=0.95), but the system needs to be recalibrated when CVS or illumination is modified.

The computer vision system methodology described in this paper could help the food industry meet new traceability regulations in place throughout Europe and North America, its manufacturer claims. Fishery chain traceability is a very important feature for ensuring fish food safety and for consumer protection. Innovative and safe technologies are therefore necessary to assess species identification and authenticity testing.

Despite the variability of the surface of salmon fillets, the algorithm, which uses the $L^*a^*b^*$ space and its transformed SalmonFan score to characterize the color, was very versatile and could be adapted easily and quickly in the quality control lines on salmon fillets with previous calibration. As opposed to traditional sensory evaluation, eye fatigue or lack of color memory do not affect computer vision, and illumination conditions are uniform. Automation of this operation can reduce labor and production costs. The subjectivity experienced by the sensory panels could be reduced using the CVS methods recommended in this study.

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