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Pros and cons of using a computer vision system for color evaluation of meat and meat products

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Abstract. The ability of a computer vision system to evaluate the color of meat and meat products was investigated by a comparison study with color measurements from a traditional colorimeter. Pros and cons of using a computer vision system for color evaluation of meat and meat products were evaluated. Statistical analysis revealed significant differences between the instrumental values in all three dimensions (L^*, a^*, b^*) between the computer vision system and the colorimeter. The computer vision system-generated colors were perceived as being more similar to the sample of the meat products visualized on the monitor, compared to colorimeter-generated colors in all (100%) individual trials performed. The use of the computer vision system is, therefore, considered a superior and less expensive alternative to the traditional method for measuring color of meat and meat products. The disadvantages of the computer vision system are its size, which makes it stationary, and the lack of official manufacturers that can provide ready-to-use systems. This type of computerized system still demands experts for its assembly and utilization.

1. Introduction

Color is primarily a personal experience. Without color, visual and emotional experiences we have while looking at the world around us, including our food, is imperfect. For most foods, visual appearance is the first thing to have a sensory impact on us. Color influences meat-purchasing decisions as well. For consumers, a major indicator of meat's freshness and wholesomeness is discoloration, making color a major meat quality factor [4]. This information is apparent to meat producers, retailers and researchers in meat science and technology. The importance of color is also reflected in the fact that improving color stability of meat and meat products will influence their shelf life by increasing the time that meat is still visually acceptable to consumers at retail [5]. To ensure food conformity to consumer expectations, it is critical for the food processing industry to develop effective color inspection systems to measure the color information of food products. Traditionally, instrumental meat color is assessed with a colorimeter [6]. However, all colorimeters have the disadvantage that the surface to be measured must be uniform and rather small (~2-5 cm^2) [7], which influences bias in measurements. Another problem is that optically non-homogeneous media such as poultry meat, refract, reflect, diffuse and absorb the light beam emitted by the colorimeter [8], causing deviations in all color dimensions evaluated. Therefore, to measure food color rapidly and non-invasively, new, objective and consistent methods are required. Among numerous new sensing technologies for the assessment of agricultural and food products, the computer vision system (CVS) is a novel technology for food color evaluation. The aim of this review is to present the application of a CVS for instrumental color evaluation of poultry and game meat and meat products with various physical properties and its advantages over the traditional color measuring method.

2. Materials and methods

2.1 Samples of meat and meat products

The research was carried out on *m. pectoralis major* samples of three animals for each of the four poultry species (chicken, turkey, duck and goose) and five game meat species (quail, wild boar, rabbit, deer and pheasant). We selected the samples in a retail setting. Before color analysis, freshly cut meat samples, about 3 cm thick, were individually placed on white polystyrene foam trays with a consistent color and overwrapped with a transparent PVC film permeable to oxygen. Then they were placed in a bench refrigerator at 4 °C for 30 min to obtain myoglobin oxygenation. The PVC film was removed before color measurement.

In addition, a group of meat products including the fresh processed, raw cured, cooked cured, raw cooked, and precooked-cooked categories and raw (dry) fermented sausages were investigated. Based on the treatment of raw materials and the individual processing steps and taking into account the processing technologies used, it is possible to classify processed meat products into these six broad groups of processed meat products [9]. In our research, within each product category, there were at least two and a maximum of four representative samples, so altogether, 18 different meat products were investigated.

2.2 Minolta CR-400 colorimeter

A Minolta CR-400 colorimeter with 8 mm aperture, 2° observer, illuminant D65 and pulsed xenon lamp was used as a default light source. A glass cover was applied over the aperture port while measurements were taken. The device was calibrated before each analysis with a standard white tile.

2.3 Computer vision system (CVS)

A Sony Alpha DSLR-A200 digital camera (10.2 Megapixel CCD sensor) was used. The camera was located vertically at a 30 cm distance from the sample. The camera setting was the following: shutter speed 1/6 s, manual operation mode, aperture Av F/11.0, ISO velocity 100, flash off, focal distance 30 mm, lens: DT-S18-70 mm f 3.5-5.6. Four Philips fluorescent lamps (Master Graphica TLD 965) with a color temperature of 6500 K were used for lighting. Each lamp was equipped with a designated light diffuser. In order to achieve uniform light intensity on the meat samples, the lamps (60 cm length) were located at a 45° angle and 50 cm above the samples. Both the lamps and the camera were fixed inside a cubic (a = 80 cm) wooden box with a removable top [2]. The box had an opening to the side for sample entry and another on the top for visual inspection before and after the measurements. The internal walls of the box were coated with black opaque photographic cloth to diminish background light.

After the camera and the monitor were calibrated, as explained in the investigation of Tomasevic *et al.* [2], the Adobe Photoshop CC (64 bit) software was used for image analysis. The colorimetric characteristics from RGB images were acquired using RAW photographs. They were measured on the digital image of the sample, using the Photoshop Average Color Sampler Tool (image area analyzed: 31 x 31 pixels).

2.4 Color changes

Total color difference (ΔE) was determined by using the standard equation:

$$\Delta \mathrm{E} = \sqrt{({a_C}^* - a_M^*)^2 + (b_C - b_M^*)^2 + ({L_C}^* - L_M^*)^2} \quad (1)$$

Values for a_C, b_C, L_C were obtained from the meat products using CVS, and for a_M, b_M, L_M using the Minolta colorimeter.

The degree of difference of hue as the quantitative attribute of colorfulness chroma (C*ab) was calculated according to Fernández-Vázquez *et al.* [10]:

$$\mathrm{C}^* = \sqrt{a^2 + b^2} \quad (2)$$

The difference in Chroma ΔC and lightness ΔL values were calculated using standard formulas:

$$\Delta \mathrm{C} = {C_C}^* - C_M^* \quad (3a)$$

$$\Delta \mathrm{L} = {L_C}^* - L_M^* \quad (3b)$$

Hue difference ΔH was calculated according to Mokrzycki and Tatol [13]:

$$\Delta \mathrm{H} = \sqrt{\Delta E^2 - \Delta L^2 + \Delta C^2} \quad (4)$$

2.5 Similarity tests

The tests used were adopted from the investigation of [8] with slight modifications. For all the tests performed, 14 panelists were individually seated at a distance of approximately 60 cm from the calibrated monitor, equipped with a shade that reduces glare (Compushade Universal Monitor Hood, DulCO, USA). Similarity tests were: test A – respondents compared photographs and real meat samples; test B – matching test: which chip is more close to the photo of the meat; test C – degree of difference of the color chips.

For test A, panelists were asked to compare the color of a digital image displayed on the monitor and a meat sample presented on polystyrene trays. They had up to 30s to rate the similarity by answering “yes” or “no”. If yes, the panelists had the opportunity to indicate the level of similarity according to a five-point Likert scale from 1 “very low”, 2 “low”, 3 “moderate”, 4 “high” to 5 “very high”.

Test B involved displaying colors generated by Adobe Photoshop CC (2015) using the L^*, a^* and b^* values obtained from both the CVS and Colorimeter (Minolta) data together on the monitor and panelists were asked to evaluate which of the two generated color chips was more similar to the sample of the product visualized on the monitor.

During test C, the panelists were asked to evaluate the level of difference between the two color chips (colorimeter and CVS) displayed on the monitor and rank the difference according to a five-point Likert scale from 1 “very low”, 2 “low”, 3 “moderate”, 4 “high” to 5 “very high”.

3. Results and discussion

3.1 Poultry meat

Consumers often select chicken meat based on its color, as it has significant influence on how they perceive quality characteristics of chicken meat products [11]. Because for the meat producers improving quality and customer satisfaction is a major objective [12], they also pay special attention to its color. The *L**, *a**, *b**, chroma and hue angle values of poultry meat, measured with CVS and colorimeter in our experiment, were significantly different [1]. The magnitude of color difference between the two pieces of equipment used is best represented by the total color difference value (ΔE). A clear threshold for human ability to detect meat-color difference has not been established, but a possible value could be around 2-6 [14]. ΔE in the range from 2 to 10 indicate the difference in color is perceptible at a glance and when ΔE is larger than 10, we can conclude that colors are more opposite then similar [15]. Therefore, with the ΔE=18.5 for chicken meat and ΔE= 22.04 for turkey meat observed in this study, we can conclude that the two systems measured the color of chicken meat significantly differently, and even contrasting [1]. Positive ΔL values indicate that the color measured with the CVS was lighter than the color obtained with colorimeter (Figure 1). However, the total color differences (ΔE) between the two methods were, for duck and goose, half the values calculated for chicken and turkey. Yet, with ΔE values above 10 [1], these differences in color should be perceptible at a glance or considered more opposite then similar. Negative ΔL values for duck and goose breasts indicate that the color measured with the CVS was darker than the color obtained with the colorimeter (Figure 1).

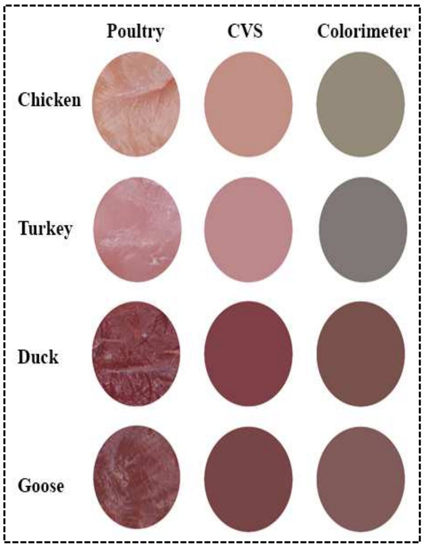

Figure 1. Color of poultry meat as measured by the two methods [1]

Figure 2. Color of game meat as measured by the two methods [3]

3.2 Game meat

Color of game meat plays a crucial role for many of its European consumers [16]. Game meat is a darker red in appearance than meat from domestic animals, and is characterized by low *L** values below 40, high *a** values and low *b** values which are indicative of the dark red color [17]. However, the *L**, *a** and chroma values measured with CVS and colorimeter in our study were significantly different [3]. Negative ΔL values for wild boar and deer meat indicate that the color measured with the CVS was darker than the color obtained with the colorimeter. All the *a** values were higher when measured with the CVS compared to the colorimeter, meaning that the color obtained with the CVS was more "red" (or less "green") (Figure 2). No statistically significant differences between the two applied methods were observed for b* and hue angle values. It is evident that differences in meat color and color stability between species can largely be attributed to differences in their muscle activity, which influences the muscle fiber type, myoglobin concentration and intramuscular fat content of the meat, which in turn influence the muscle color. Therefore, not all game meat is darker in color than meat from domestic animals [18].

The instrumental color values (L^*, a^*, b^*, chroma and hue angle) obtained with the CVS for lighter colored game meat samples (quail, pheasant and rabbit) were statistically different from the same values obtained with the colorimeter [3]. Positive ΔL values indicate that the color measured with the CVS was lighter than the color obtained with the colorimeter. All the a* values were much higher when measured with the CVS compared to the colorimeter, meaning that the color obtained with the CVS was more "red" (or less "green") (Figure 2). The positive difference in chroma (ΔC) meant that the CVS-generated color of quail and rabbit had greater intensity (were more saturated) then colorimeter-generated colors [3]. The CVS-generated colors were in a clockwise direction from colorimeter-generated colors, representing a shift in the red direction (Figure 2), since all the hue angle values were significantly higher when measured with the colorimeter compared to the CVS. The ΔE values ranged from 9.67 to 19.01, indicating that for lighter colored game meat samples, the two systems measured their color significantly differently [3] and in the case of rabbit meat, even contrastingly.

3.3 Meat products

When the color of uniformly-colored meat products was evaluated, the total color difference value (ΔE) ranged from 6.7 for saveloy sausage up to 26.0 for pork prosciutto. For the majority of meat products with homogenous surfaces, ΔE was around 10 [2]. Positive ΔL values for uniformly-colored meat products indicate that the color measured with the CVS was lighter than the color obtained with the colorimeter. All the a^* values were higher when measured with the CVS compared to the colorimeter, meaning the colors obtained with the CVS were more "red" (Figure 3), and with the exception of pork prosciutto and raw sausage, all the b* measured with the colorimeter were significantly higher than the values obtained with the CVS [2], meaning the colors of uniformly-colored meat products acquired with the CVS were more "blue" (or less "yellow") compared to colorimeter-acquired colors (Figure 3). The positive difference in chroma (ΔC) meant that the CVS colors of cooked ham, pork and beef prosciutto and raw sausage had greater intensity or were more saturated than colorimeter-generated colors [2]. The opposite was observed for the beef, chicken and liver pate, smoked-cooked pork, frankfurter and saveloy sausage. Our investigation is in concurrence

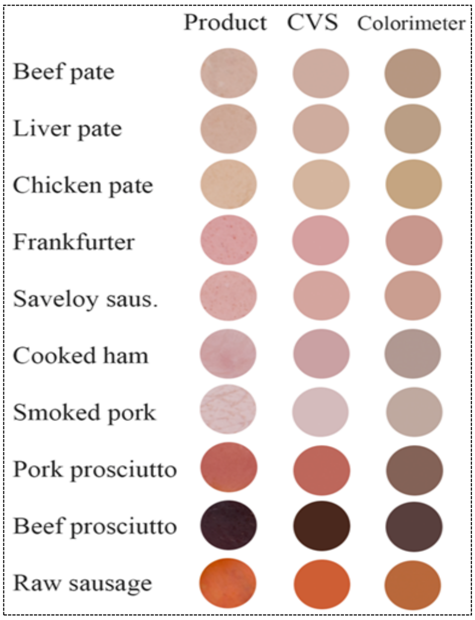

Figure 3. Color of uniformly colored meat products as measured by the two methods [2]

Figure 4. Color of bi and non-uniformly colored meat products as measured by the two methods [2]

with the conclusions of Valous *et al.* [19], who found CVS to be a tool that can objectively specify color of cooked-hams.

Bi-colored meat products, like mortadella, bacon, dry pork neck or pancetta, consisted of meat and fat segments that were larger than the Minolta aperture size (8 mm) used in our study, allowing the colorimeter to measure their color independently. The total color differences between the two methods for the meat segments ranged from 7.3 to 14.6 and for the fat parts ranged from 7.7 to 12.9 [2]. Meat segments were assessed as having darker and fat segments as having lighter colors when measured with the CVS compared to the colorimeter (Figure 4a). Non-uniformly colored meat product was any product that had meat and fat parts that were too small (less than 8 mm) for the colorimeter to independently assess their color. Therefore, when the color of beef and pork fermented sausage, and hamburger was measured, the L^*, a^*, b^* colorimeter-generated values for both meat and fat parts were the same. Because the CVS used 31 x 31 pixels for the average color sampler tool, it was capable of measuring the color of meat and fat parts independently in these non-uniformly colored meat products. This resulted with the highest total meat-parts color difference ($\Delta E = 20.3$), measured for beef fermented sausage, and maximum total fat-parts color difference ($\Delta E = 35.3$), measured for pork fermented sausage [2]. These extraordinarily high values for total color differences [20] indicated the colors assessed by the two methods were almost exact opposites [15]. The color of meat parts measured with the CVS were significantly darker, had greater intensity and were more saturated, compared to colorimeter-measured equivalents (Figure 4b). The opposite was observed for CVS-generated fat color. Due to the high variability and complex color distribution in non-uniformly colored meat products, the colorimeter was unable to accurately assess the color of the meat parts and the color of the fat parts. Instead, the colorimeter produced L^*, a^*, b^* values that were somewhere in between the values for these two tissue segments. Our investigation is in concurrence with the conclusions of [21], who concluded that CVS is a tool that can objectively evaluate color of fermented sausages.

Table 1. Similarity tests results

	Frequency of similarity (test A)	Level of similarity (test A)	CVS vs. Colorimeter (test B)	Level of difference (test C)
Beef pate	100%	$3.4 \pm 1.4^{a,b}$	CVS (100%)	$3.0 \pm 1.1^{a,b,c}$
Liver pate	100%	$3.6 \pm 1.1^{a,b}$	CVS (100%)	$2.4 \pm 1.1^{a,b,c}$
Chicken pate	92.9%	$3.5 \pm 1.0^{a,b}$	CVS (100%)	$2.1 \pm 1.0^{a,b,c}$
Beef fermented sausage	92.9%	$3.6 \pm 1.0^{a,b}$	CVS (100%)	$3.2 \pm 0.4^{a,b,c}$
Pork fermented sausage	100%	$4.0 \pm 0.8^{a,b}$	CVS (100%)	$2.3 \pm 0.5^{a,b,c}$
Frankfurter	100%	$4.0 \pm 1.1^{a,b}$	CVS (100%)	$1.7 \pm 0.5^{a,b}$
Saveloy sausage	100%	$3.8 \pm 0.9^{a,b}$	CVS (100%)	1.2 ± 0.5^{a}
Mortadella	100%	2.9 ± 1.2^{a}	CVS (100%)	$2.1 \pm 1.1^{a,b,c}$
Cooked ham	100%	$3.0 \pm 1.2^{a,b}$	CVS (100%)	$3.6 \pm 0.3^{b,c}$
Smoked cooked bacon	92.9%	$3.1 \pm 1.3^{a,b}$	CVS (100%)	$2.2 \pm 0.4^{a,b,c}$
Smoked cooked pork	100%	$3.5 \pm 1.0^{a,b}$	CVS (100%)	$2.8 \pm 1.2^{a,b,c}$
Pork prosciutto	100%	$4.1 \pm 0.8^{a,b}$	CVS (100%)	4.2 ± 1.0^{c}
Beef prosciutto	100%	$3.6 \pm 0.9^{a,b}$	CVS (100%)	$3.1 \pm 1.8^{a,b,c}$
Dry pork neck	92.9%	$3.5 \pm 1.3^{a,b}$	CVS (100%)	$3.0 \pm 0.7^{a,b,c}$
Pancetta	92.9%	2.8 ± 1.5^{a}	CVS (100%)	$2.7 \pm 1.5^{a,b,c}$
Pork hamburger	100%	2.8 ± 1.0^{a}	CVS (100%)	$2.0 \pm 1.0^{a,b,c}$
Beef hamburger	100%	$3.4 \pm 1.3^{a,b}$	CVS (100%)	$2.7 \pm 1.0^{a,b,c}$
Raw sausage	100%	4.4 ± 0.8^{b}	CVS (100%)	$3.2 \pm 1.5^{a,b,c}$
Chicken breast	100%	1.7 ± 0.8^{a}	CVS (100%)	3.8 ± 1.4^{a}

Duck breast	100%	$2.4 \pm 1.0^{a,b}$	CVS (100%)	1.8 ± 0.4^{b}
Goose breast	100%	3.1 ± 0.8^{b}	CVS (100%)	1.4 ± 0.5^{a}
Turkey breast	100%	2.9 ± 1.03^{b}	CVS (100%)	4.7 ± 0.7^{b}
Quail	100%	2.7 ± 1.3^{a}	CVS (100%)	3.6 ± 1.4^{a}
Wild boar	100%	3.4 ± 1.3^{b}	CVS (100%)	$1.9 \pm 0.9^{b,c}$
Rabbit	85.7%	2.7 ± 1.2^{a}	CVS (100%)	4.2 ± 1.2^{a}
Deer	100%	4.1 ± 0.8^{b}	CVS (100%)	1.0 ± 0.0^{c}
Pheasant	100%	$3.2 \pm 1.2^{a,b}$	CVS (100%)	$3.4 \pm 1.3^{a,b}$

Means in the same column with different small letters are significantly different ($P < 0.05$); Five-point Likert scale ranks from 1 "very low", 2 "low", 3 "moderate", 4 "high" to 5 "very high"

3.4 Similarity tests

The results of the first similarity test (test A) between the color of the actual sample of meat products and the CVS-generated color of the image displayed on the monitor showed that the panelists found the digital images similar to the actual samples (P<0.001). The frequency of similarity assessed by the panelists was 100% for all poultry meat and game meat samples (Table 1). This means that 14 out of 14 panelists found that the actual color of all samples was similar to the chip color generated by the CVS. The frequency of similarity for meat products was also very high and ranged from 92.9% for chicken pate, beef sausage, smoked bacon, dry pork neck and pancetta, to 100% for all the other meat product samples. For poultry meat samples, the level of similarity ranged from "low" to "moderate" and for game meat and meat products samples from "moderate" to "high".

Test B showed the CVS-generated color chips were more similar to the samples of poultry meat, game meat and meat products visualized on the monitor than to colorimeter-generated color chips in all (100%) individual trials performed (Table 1).

Test C, regarding meat products, revealed that, as assessed by the panelists, the magnitude of differences between the color chips generated by the CVS and the colorimeter and displayed on the monitor ranged from 1.2 ("very low") for saveloy sausage to 4.2 ("high") for pork prosciutto. The highest level of difference between colors for poultry meat was observed in the case of turkey meat (4.7 – "very high") and for game meat samples with rabbit (4.2 – "high").

4. Conclusion

We presume that one parameter influencing the difference between the two methods employed to measure the color of meat and meat products could be the penetration depth of the illumination source. In our investigation, the light employed in both devices had the same color temperature (6500 K), but the light interaction with the samples was obviously device-dependent. For the same reasons as were reported in an earlier meat color study [8], we deem the colorimeter not suitable for the color analysis of meat products. The reason is the translucent and optically non-homogenous matrix of the meat products due to the presence of different ingredients scattered inside these foods. The colorimeter is placed on the sample surface and the light penetration through the meat product matrix is required to be higher than for CVS. This, therefore, causes multiple reflections and refractions where optical discontinuities are present, resulting in a diffusion of light (scattering) from the illumination source [22], making the colorimeter measurements unsuitably inaccurate.

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