Accepted Manuscript

Comparison of a computer vision system vs. traditional colorimeter for color evaluation of meat products with various physical properties

Igor Tomasevic, Vladimir Tomovic, Bojana Milovanovic, Jose Lorenzo, Vesna Đorđević, Nedjeljko Karabasil, Ilija Djekic

PII: S0309-1740(18)30422-4
DOI: doi:10.1016/j.meatsci.2018.09.015
Reference: MESC 7692

To appear in: *Meat Science*

Received date: 24 April 2018
Revised date: 18 September 2018
Accepted date: 20 September 2018

Please cite this article as: Igor Tomasevic, Vladimir Tomovic, Bojana Milovanovic, Jose Lorenzo, Vesna Đorđević, Nedjeljko Karabasil, Ilija Djekic , Comparison of a computer vision system vs. traditional colorimeter for color evaluation of meat products with various physical properties. Mesc (2018), doi:10.1016/j.meatsci.2018.09.015

Comparison of a computer vision system vs. traditional colorimeter for color evaluation of meat products with various physical properties

Igor Tomasevic[a] *, Vladimir Tomovic[b], Bojana Milovanovic[a], Jose Lorenzo[c], Vesna Đorđević[d], Nedjeljko Karabasil[e], Ilija Djekic[f]

[a] Department of Animal Source Food Technology, University of Belgrade, Faculty of Agriculture, Nemanjina 6, 11080 Belgrade, Serbia.

[b] Faculty of Technology, University of Novi Sad, Bulevar cara Lazara 1, Novi Sad, Serbia

[c] Centro Tecnológico de la Carne de Galicia, Parque Tecnológico de Galicia, Rua Galicia No. 4, San Cibrao das Viñas, Ourense, Spain

[d] Institute of Meat Hygiene and Technology, Kaćanskog 13, Belgrade, Serbia

[e] University of Belgrade, Faculty of Veterinary Medicine, Department of Food Hygiene and Technology, Bulevar oslobodjenja 18, Belgrade, Serbia

[f] Food Safety and Quality Management Department, University of Belgrade, Faculty of Agriculture, Nemanjina 6, 11080 Belgrade, Serbia

Corresponding author:

Name: Igor Tomasevic

Address: Department of Animal Source Food Technology
Faculty of Agriculture, University of Belgrade
Nemanjina 6
11080 Belgrade
Republic of Serbia

Email: tbigor@agrif.bg.ac.rs

1.Introduction

While visual determinations are the benchmark for evaluating color of meat and meat products and assessing consumer perception (Mancini & Hunt, 2005), trained visual panels are not always possible. Thus, instrumental color analyses based on spectrophotometric and colorimetric principles have been used extensively for meat and meat products. Several options for instrumental color analysis are also available: (i) Minolta chroma meter; (ii) Hunter Lab colorimeter and (iii) Dr. Lange colorimeters. Until recently, Minolta colorimeters were the most widely used brand of instruments for measuring meat color (59.7%) as recognized in the review of Tapp, Yancey, and Apple (2011). However, for all colorimeters the surface to be measured must be uniform and rather small (~2-5 cm2) (Kang, East, & Trujillo, 2008) which influence bias in measurements. We also know that in instrumental color determination the increase of number of readings per sample (technical replicates) improves the precision of color evaluation. The issue is that the guideline which defines optimal number of technical replicates for colorimeter is still unavailable (Holman, Collins, Kilgannon, & Hopkins, 2018).

Another problem is that optically non-homogeneous medium such as meat or meat products, refract, reflect, diffuse and absorb the light beam emitted by the colorimeter (Girolami, Napolitano, Faraone, & Braghieri, 2013). Therefore, slight deviations in color readings (L*- lightness; a*- redness; b*-yellowness) using the same colorimeter on the same spot of meat or meat product, during replicates in not uncommon.

On the other hand, for computer vision system (CVS) meat color analysis only a single digital measurement is needed for a valid evaluation of color, digital images explain surface variation in color, and data retrieved from digital images can be transformed to numerous color measurement systems (O'Sullivan et al., 2003). This have already been explored and explained when the color of pork (Chmiel & Słowiński, 2016; Chmiel, Słowiński, & Dasiewicz, 2011; O'Sullivan et al., 2003), beef (Chen, Sun, Qin, & Tang, 2010; Zheng, Sun, & Zheng, 2006) or chicken meat (Girolami et al., 2013) was investigated.

However, processed meat products represent complex systems that can be considered as a 'matrix' of interacting components. Properties of the product on the macro-scale are determined by processes and forces operating at the micro-scale (Tobin, O'Sullivan, Hamill, & Kerry, 2012). The properties of meat and meat products as a medium for instrumental measurements of color are significantly different. They also vary between different types of meat products.

In this study, fresh processed, raw cured, cooked cured, raw-cooked, precooked-cooked meat products and raw (dry) fermented sausages were exposed to color measurements by the standard colorimeter and CVS. The goal of this study was to compare and contrast two color evaluation methodologies (CVS vs. traditional colorimeter) using the color assessments of 18 different processed meat products that varied in surface texture and structural uniformity. We also wanted to investigate whether the type of meat product influences its color evaluation in this matter.

2. Materials and methods

2.1. Meat product samples and experimental design

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 in six broad groups of processed meat products (Heinz & Hautzinger, 2007). In our research, within each product category, there were at least two and maximum four representative samples adding together 18 different meat products investigated (Table 1). Three products of every selected commercial brand were randomly purchased at the supermarket.

The colorimetric characteristics, lightness (L*), redness (a*) and yellowness (b*) values were measured using the Minolta CR-400 colorimeter and a Computer vision system (CVS). Hue angle [tan−1 (b*/a*)] and chroma = [(a*2+b*2)1/2] were computed for every sample. Since it was not possible, using the two devices, to evaluate color on the entire surface of the sample, seven readings per sample (technical replicates) were randomly chosen for the measurements, both for the colorimeter and CVS. For the following statistical analysis, average values were used. One picture of every sample was taken for CVS. All measurements were performed in three replicates using three different commercial products that were randomly purchased at the supermarket. Before color analysis all samples were refrigerated, then either freshly cut (about 2.00 cm thick), or taken from freshly opened vacuum packs of pre-sliced meat products (about 2.00 mm thick) and then placed on white trays. Pate color was measured on a flat surface of a freshly opened can. Color of the same sample was firstly measured with Minolta CR-400 colorimeter and immediately after with computer vision system. Total duration of the color measurement per sample did not exceed 20 seconds, successfully preventing color deterioration during measurements.

2.2.1. Minolta CR-400 colorimeter

Minolta CR-400 colorimeter was used with 8 mm aperture, 2° observer, illuminant D65 and pulsed xenon lamp as a default light source. Glass cover, light protection tube (CR-A33a, Konica Minolta, Japan), was applied over the aperture port while measuring. The convex protection glass plate prevents specimen from entering the instrument and facilitate cleaning between measurements. A calibration of a device with white tile standard was performed before each analysis.

2.2.2. Computer vision system (CVS)

A Sony Alpha DSLR-A200 digital camera (10.2 Megapixel CCD sensor with the size of 23.7mm x 15.6mm and approximate pixel pitch of 6.12 microns) was used. The camera was located vertically at a 30 cm distance from the sample (Fig. 1). 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 the CVS. The illumination of the lamps was 2100 lm with negligible deterioration in performance since they were used only for 5h before the investigation and manufacturer guidelines for full lamp performance is 6.000 h. Each lamp was equipped with a designated light diffuser. In order to achieve the uniform light intensity without shadows on the sample, 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 cubical (a = 80 cm) wooden box with a removable top (Fig. 1). The box had an opening to the side for sample entry and the other 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.

The standard rendition chart X-Rite Colorchecker Passport (Michigan, USA) was used for camera calibration. Colorchecker is a checkerboard array of scientifically prepared colored squares (4×4 cm2) in a range of 24 colors, which help calibrate a camera. The calibration is performed by photographing the checkerboard as a target, than opening it into a designated software (ColorChecker Passport 1.0.1, X-Rite Inc.) installed on the computer,that will automatically evaluate the color values and create a custom camera Digital Negative (DNG) profile based on that image. All cameras see colors differently and creating a custom profile for the specific device permit color management capable software to make allowances for any/all variances. Once the profile is made, it can be used for all other photos taken under the same lighting conditions.

The camera was connected to a Toshiba Portege R830 PC equipped with a 22″EA53 LG InPlaneSwitching LED external monitor, designed to improve color reproduction. The monitor with a sRGB gamut (Standard RGB) was calibrated with X-Rite i1 Display Pro device by selecting white chromaticity at 6500 K (illuminant D65), gamma at 2.2 and white luminance at 140 cd/m2. The i1Profiler 1.5.6 software was used to create the ICC monitor profile. 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 a Photoshop (31 x 31 pixels) Average Color Sampler Tool.

2.2.3. 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 Minolta.

Degree of difference of hue as the quantitative attribute of colorfulness chroma (C^*_{ab}) was calculated according to Fernández-Vázquez, Stinco, Hernanz, Heredia, and Vicario (2013):

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

The difference in Chroma and lightness value 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 (2011):

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

2.3. Similarity tests

A trained panel of 14 people was used to carry out three similarity tests. The selection of the panel members was conducted using the Ishihara 38 plates test (Clark, 1924) to identify possible color blindness. The minimum passing score was 18/21.

Panelists' training was performed using Blendoku (blendoku.com) software. Finally, they were subjected to IQ color test (X-Rite, Prato, Italy, *xritephoto.com/coloriq*) with a maximum passing score of 20, making them color assessors with almost perfect color acuity.

The tests used were adopted from the investigation of Girolami, Napolitano, Faraone, & Braghieri (2013) with slight modifications. For all the tests performed, 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), and from the meat samples presented inside the CVS wooden box. For the test A, panelists were asked to individually analyze the color similarity between a digital image displayed on the monitor and a meat sample presented on polystyrene trays. They had up to 30s to evaluate each sample by answering “yes” or “no”. If yes, the panelists had the opportunity to rank 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 included 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 the test C, the panelists were asked to evaluate the level of difference between the two color chips (colorimeter and CVS) displayed on the monitor ranking it according to a five-point Likert scale from 1 “very low”, 2 “low”, 3 “moderate”, 4 “high” to 5 “very high”.

2.4. Statistical analysis

The data gathered from the similarity tests (A, B) were analyzed to determine statistical significance based on the frequency of each response ($\chi 2$ One sample test), where the expected frequency was 50%. In order to analyze data in respect to level of similarity (test A) and level of difference (Test C), one-way ANOVA was used. To distinguish statistical differences between the data, Tukey's post hoc tests were performed.

3. Results and discussion

3.1.Uniformly-colored meat products

When a color of uniformly-colored meat products was evaluated, the L*, a*, b*, chroma and hue angle values measured with CVS and colorimeter were significantly different (Table 2). The magnitude of color difference between the two methods used is best represented by the total color difference value (ΔE). These values ranged from 6.7 for Saveloy sausage up to 26.0 calculated for Pork prosciutto. For the majority of meat products with homogenous surfaces ΔE was around 10 (Table 2). The clear threshold for human meat-color difference detection has not been established but a possible value could be around 2–6 (Larraín, Schaefer, & Reed, 2008). The values of ΔE in a range from 2-10 indicate that the difference in color is perceptible at a glance and when they are larger than 10, we can conclude that colors are more opposite than similar (Brainard, 2003). According to Ramirez-Navas and Rodriguez de Stouvenel (2012), all the color differences with ΔE values larger than 6 are considerable. Therefore, even though the color of the meat products was uniform, the two systems measured it significantly different. The color difference was even more noticeable because it was not concentrated in only one dimension but instead significantly different values between CVS and colorimeter were observed for all 3 dimensions (L*, a*, b*).

Positive ΔL values for uniformly-colored meat products indicate that the color measured with CVS was lighter than the color obtained with colorimeter (Table 2). All the a* values were higher when measured with CVS compared to colorimeter meaning that the color obtained with CVS was more "red" (Fig. 2). With the exception of pork prosciutto and raw sausage, all the b* measured with colorimeter were significantly higher than the values obtained with CVS (Table 2), meaning that the colors of uniformly-colored meat products acquired with CVS were more "blue" (or less "yellow") compared to colorimeter-acquired color (Fig. 2). The positive difference in chroma (ΔC) meant that the CVS color of cooked ham, pork and beef prosciutto and raw sausage, had greater intensity or were more saturated than colorimeter generated colors (Table 2). The opposite was observed for the beef, chicken and liver pate, smoked-cooked pork, frankfurter and Saveloy sausage (Table 2). The CVS-generated colors were in a clockwise direction from colorimeter-generated colors in CIE L*a*b* colorspace, representing a shift in the red direction (Fig. 2), since all the Hue angle values were significantly higher when measured with colorimeter compared to CVS (Table 2). Our investigation is in concurrence with the conclusions of Valous, Mendoza, Sun, and Allen (2009) that CVS is a tool that can objectively specify color of cooked-hams.

3.2. Bi-colored meat products

Bi-colored meat products, like mortadella, bacon, dry pork neck or pancetta, consisted of meat and fat segments that were larger than Minolta aperture size (8 mm) used in our experiment, allowing colorimeter to measure their color independently. The total color differences between the two methods of the meat segments were in a range from 7.3 up to 14.6 and for the fat parts in a range from 7.7 up to 12.9 (Table 3). Meat segments were assessed in darker and fat segments in lighter colors when measured with CVS compared to colorimeter (Fig. 3a). The CVS-generated colors of meat segments were more intense,saturated (positive ΔC values) while the CVS-generated fat color was less saturated (negative ΔC values) compared to colorimeter-generated colors (Table 3). Like with the meat products with homogenous surface, all the Hue angle values (both meat and fat parts) were significantly larger when measured with colorimeter compared to CVS but the magnitude of differences was even higher for bi-colored meat products. CVS-generated meat and fat parts color was in a clockwise direction from colorimeter-generated colors (Table 3), representing once again a shift in the red direction.

We presume that one parameter influencing the difference among the meat-products color measurements, between the two methods employed, could be the penetration depth of the illumination source. In our investigation, light employed in both devices had the same color temperature (6500 K) but the light interaction with a meat product samples was obviously device dependent. For the same reasons observed in meat color experiment (Girolami et al., 2013), we believe that the colorimeter could not be 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 it. The colorimeter is placed on the sample surface and the light penetration through meat product matrix must 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 illuminations source (Oleari, 1998) making the colorimeter measurements less accurate.

3.3. Non-uniformly colored meat products

Non-uniformly colored meat product was any product that has meat and fat parts that are too small (less than 8 mm) for 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 CVS used 13 x 13 pixels Average Color Sampler Tool, it was capable of measuring the color of meat and fat parts independently. This resulted with the highest total meat-parts color difference ($\Delta E = 20.3$) observed for beef fermented sausage, and maximum total fat-parts color difference ($\Delta E = 35.3$) observed for pork fermented sausage (Table 4). These extraordinary high values for total color differences (Ramirez-Navas & Rodriguez de Stouvenel, 2012) indicated that the colors assessed by the two methods were almost exact opposites (Brainard, 2003). The color of meat parts measured with CVS was significantly darker, had greater intensity and were more saturated, compared to colorimeter-measured equivalents (Fig. 3b). The opposite was observed for CVS-generated fat color (Table 4). Due to the high variability and complex color distribution in non-uniformly colored meat products, the colorimeter was unable to assess accurately neither the color of meat nor the color of fat parts. Instead, colorimeter reproduced L*, a*, b* values that were somewhere "in between" the two segments. Our investigation is in concurrence with the conclusions of Girolami, Napolitano, Faraone, Di Bello, and Braghieri (2014) that CVS is a tool that can objectively evaluate color of fermented sausages.

3.4. Similarity tests

The results of the similarity test (test A) between the color of the actual sample of meat products and the CVS obtained color of the image displayed on the monitor, showed that the panelists found the digital images similar to the actual samples ($p<0.001$). Frequency of similarity assessed by the panelists was 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 products samples. This means that at least 13 out of 14 panelist found that the actual color of all samples was similar to the chip color generated with CVS. The level of similarity ranged from "moderate" to "high" (Table 5).

Test B showed that the CVS-generated color chips were more similar to the sample of the meat product visualized on the monitor, compared to colorimeter-generated color chips (Fig. 2 & Fig. 3) in all (100%) individual trials performed (Table 5).

Test C revealed that, as assessed by the panelists, the magnitude of differences between the color chips generated by CVS and colorimeter and displayed on the monitor, ranged from 1.2 ("very low") for Saveloy sausage to 4.2 ("high") for Pork prosciutto.

4. Summary

With CVS analysis of a meat product color, it is possible to segment the sample image into exclusively meat and fat segments, no matter of their size or complexity of their distribution. As a result, meat color can be measured solely over a surface of a meat product of interest without the influence of fat, spices or other visible ingredients. Likewise, color of fat segments over the surface of a meat product can be evaluated without the influence of meat parts or other ingredients. Together, this information yield an objective tool for evaluating color of meat product. This type of information is not feasible by colorimeter. Its sampling strategy, based on an average of number of spot measurements (with a surface of about 2 -5 cm^2), does not reflect the color of the full meat product sample nor its differently colored segments, when their size is smaller than the aperture of the colorimeter used.

5. Conclusions

Traditional colorimeter and CVS are both color measuring devices, yet they use completely different principles for this objective. This study has demonstrated significant differences between L*, a*, b* color values of the meat products measured with CVS and traditional colorimeter. CVS-generated colors were found moderately to highly similar to the color of all (18) actual meat product samples. They have better represented the actual color of meat product samples as perceived by trained/experienced panelists. Our data clearly show that the CVS methodology is more accurate and precise for measuring color not only of uniformly colored samples, but especially better for bi-colored and non-uniformly colored meat. Using colorimeter for color evaluation of all meat products evaluated was reliable, but less accurate. Therefore, the use of a computer vision system should be considered a more desirable alternative to the traditional method for measuring color of meat products.

Conflict of interest

The authors declare that there is no conflict of interest.

Acknowledgement

The authors would like to thank Mr. Srdjan Miloradović (senior 3D artist) for the virtual representation of the computer vision (image acquisition) system.

References

Brainard, D. H. (2003). Color appearance and color difference specification. *The science of color, 2*, 191-216.

Chen, K., Sun, X., Qin, C., & Tang, X. (2010). Color grading of beef fat by using computer vision and support vector machine. *Computers and Electronics in Agriculture, 70*(1), 27-32.

Chmiel, M., & Słowiński, M. (2016). The use of computer vision system to detect pork defects. *LWT - Food Science and Technology, 73*, 473-480.

Chmiel, M., Słowiński, M., & Dasiewicz, K. (2011). Lightness of the color measured by computer image analysis as a factor for assessing the quality of pork meat. *Meat Science, 88*(3), 566-570.

Clark, J. (1924). The Ishihara test for color blindness. *American Journal of Physiological Optics, 5*, 269-276.

Fernández-Vázquez, R., Stinco, C. M., Hernanz, D., Heredia, F. J., & Vicario, I. M. (2013). Colour training and colour differences thresholds in orange juice. *Food Quality and Preference, 30*(2), 320-327.

Girolami, A., Napolitano, F., Faraone, D., & Braghieri, A. (2013). Measurement of meat color using a computer vision system. *Meat Science, 93*(1), 111-118.

Girolami, A., Napolitano, F., Faraone, D., Di Bello, G., & Braghieri, A. (2014). Image analysis with the computer vision system and the consumer test in evaluating the appearance of Lucanian dry sausage. *Meat science, 96*(1), 610-616.

Heinz, G., & Hautzinger, P. (2007). *Meat processing technology for small-to medium-scale producers* (RAP publication 2007/20 ed.). Bangkok: Food and Agriculture Organization of the United Nations (FAO).

Holman, B. W. B., Collins, D., Kilgannon, A. K., & Hopkins, D. L. (2018). The effect of technical replicate (repeats) on Nix Pro Color Sensor™ measurement precision for meat: A case-study on aged beef colour stability. *Meat Science*, *135*, 42-45.

Kang, S., East, A., & Trujillo, F. (2008). Colour vision system evaluation of bicolour fruit: A case study with 'B74'mango. *Postharvest Biology and Technology, 49*(1), 77-85.

Larraín, R., Schaefer, D., & Reed, J. (2008). Use of digital images to estimate CIE color coordinates of beef. *Food Research International, 41*(4), 380-385.

Mancini, R. A., & Hunt, M. C. (2005). Current research in meat color. *Meat Science, 71*(1), 100-121.

Mokrzycki, W. S., & Tatol, M. (2011). Color difference ΔE - a survey. *Machine Graphics and Vision, 20*(4), 383-411.

O'Sullivan, M. G., Byrne, D. V., Martens, H., Gidskehaug, L. H., Andersen, H. J., & Martens, M. (2003). Evaluation of pork colour: prediction of visual sensory quality of meat from instrumental and computer vision methods of colour analysis. *Meat Science, 65*(2), 909-918.

Oleari, C. (1998). *Misurare il colore: spettrofotometria, fotometria e colorimetria: fisiologia e percezione*: Hoepli.

Ramirez-Navas, J. S., & Rodriguez de Stouvenel, A. (2012). Characterization of Colombian quesillo cheese by spectrocolorimetry. *Vitae, 19*(2), 178-185.

Tapp, W. N., Yancey, J. W. S., & Apple, J. K. (2011). How is the instrumental color of meat measured? *Meat Science, 89*(1), 1-5.

Tobin, B. D., O'Sullivan, M. G., Hamill, R. M., & Kerry, J. P. (2012). Effect of varying salt and fat levels on the sensory and physiochemical quality of frankfurters. *Meat Science*, *92*(4), 659-666.

Valous, N. A., Mendoza, F., Sun, D.-W., & Allen, P. (2009). Colour calibration of a laboratory computer vision system for quality evaluation of pre-sliced hams. *Meat science, 81*(1), 132-141.

Zheng, C., Sun, D.-W., & Zheng, L. (2006). Correlating colour to moisture content of large cooked beef joints by computer vision. *Journal of Food Engineering, 77*(4), 858-863.

Table 1 Groups of meat products assessed and their representative samples

Meat products group	Representative samples	Surface measured
Fresh processed meat products	Raw sausage	Fresh cut of sausage
	Pork hamburger	Flat surface of a burger
	Beef hamburger	
Raw Cured meat products	Pork prosciutto	Freshly opened vacuum pack of pre-sliced sausages
	Beef prosciutto	
	Dry pork neck	
	Pancetta	
Cooked cured meat products	Cooked ham	Fresh cut fo ham
	Smoked cooked bacon	Freshly opened vacuum pack of pre-sliced products
	Smoked cooked pork	
Raw cooked meat products	Frankfurter	Fresh cut of sausage
	Mortadella	
	Saveloy sausage	
Precooked-cooked meat products	Beef pate	Flat upper surface of freshly opened pate can
	Liver pate	
	Chicken pate	
Raw (dry) fermented sausages	Beef fermented sausage	Freshly opened vacuum pack of pre-sliced sausages
	Pork fermented sausage	

Table 2 Instrumental color values (mean ± s.e.; n=3) of uniformly colored meat products using computer vision system and traditional colorimeter.

Parameter	CVS	Colorimeter	Significance *P*	CVS	Colorimeter	Significance *P*
	Beef pate			Cooked ham		
L*	73.6 ± 0.3	65.9 ± 0.5	***	70.9 ± 1.2	65.4 ± 0.6	**
a*	11.0 ± 0.2	9.0 ± 0.1	***	16.1 ± 1.0	8.5 ± 0.5	***
b*	11.1 ± 0.4	16.6 ± 0.1	***	5.0 ± 0.31	7.8 ± 0.1	***
Chroma	15.7 ± 0.4	18.9 ± 0.1	***	16.9 ± 1.0	11.5 ± 0.4	**
Hue angle	45.3 ± 0.7	61.4 ± 0.2	***	17.4 ± 1.0	42.9 ± 1.6	***
ΔE*	9.7 ± 0.5		ΔE*	10.7 ± 0.5		
ΔL*	7.6 ± 0.5		ΔL*	5.4 ± 1.5		
ΔC*	-3.2 ± 0.4		ΔC*	5.4 ± 1.0		
ΔH*	4.8 ± 0.2		ΔH*	6.1 ± 0.4		
	Liver pate			Smoked cooked pork		
L*	73.6 ± 0.2	67.3 ± 0.1	***	78.3 ± 0.6	71.7 ± 0.4	***
a*	11.0 ± 0.0	8.8 ± 0.1	***	9.7 ± 0.4	7.4 ± 0.7	*
b*	12.7 ± 0.2	17.8 ± 0.1	***	3.3 ± 0.4	8.4 ± 0.3	***
Chroma	16.8 ± 0.1	19.8 ± 0.1	***	10.3 ± 0.4	11.2 ± 0.7	
Hue angle	49.1 ± 0.4	63.7 ± 0.2	***	18.4 ± 1.3	49.0 ± 1.4	***
ΔE*	8.3 ± 0.2		ΔE*	9.1 ± 0.7		
ΔL*	6.2 ± 0.2		ΔL*	6.6 ± 0.8		
ΔC*	-3.0 ± 0.2		ΔC*	-1.0 ± 0.9		
ΔH*	4.6 ± 0.1		ΔH*	5.6 ± 0.2		
	Chicken pate			Pork prosciutto		
L*	76.9 ± 0.3	70.8 ± 0.5	***	54.6 ± 0.48	45.7 ± 0.7	***
a*	9.6 ± 0.2	8.2 ± 0.2	***	34.3 ± 0.42	12.7 ± 0.3	***
b*	16.4 ± 0.2	23.9 ± 0.2	***	23.1 ± 0.77	12.3 ± 0.2	***
Chroma	19.0 ± 0.2	25.2 ± 0.2	***	41.4 ± 0.39	17.7 ± 0.3	***
Hue angle	59.8 ± 0.6	71.11 ± 0.3	***	34.0 ± 1.08	44.13 ± 0.9	***
ΔE*	9.8 ± 0.4		ΔE*	26.0 ± 0.3		
ΔL*	6.0 ± 0.6		ΔL*	8.9 ± 1.0		
ΔC*	-6.2 ± 0.3		ΔC*	23.7 ± 0.5		
ΔH*	4.3 ± 0.2		ΔH*	4.7 ± 0.7		
	Frankfurter			Beef prosciutto		
L*	71.6 ± 0.3	67.2 ± 0.2	***	20.7 ± 0.9	30.5 ± 1.1	***
a*	20.9 ± 0.3	18.3 ± 0.1	***	14.9 ± 1.4	11.9 ± 0.7	
b*	8.6 ± 0.2	14.0 ± 0.1	***	3.9 ± 1.2	6.4 ± 0.7	
Chroma	22.5 ± 0.3	23.0 ± 0.1	***	15.5 ± 1.6	13.6 ± 0.8	
Hue angle	22.3 ± 0.3	37.4 ± 0.1	***	12.7 ± 4.0	27.9 ± 2.6	**
ΔE*	7.5 ± 0.3		ΔE*	11.0 ± 1.2		
ΔL*	4.4 ± 0.5		ΔL*	-9.8 ± 1.3		
ΔC*	-0.5 ± 0.3		ΔC*	1.9 ± 1.1		
ΔH*	6.0 ± 0.1		ΔH*	3.6 ± 0.4		
	Saveloy sausage			Raw sausage		
L*	72.6 ± 0.2	69.35 ± 0.17	***	54.7 ± 0.7	53.5 ± 0.2	
a*	17.9 ± 0.1	15.8 ± 0.05	***	43.4 ± 1.0	30.3 ± 0.6	***
b*	10.3 ± 1.5	14.33 ± 0.06	*	45.6 ± 1.5	39.2 ± 0.4	**
Chroma	20.8 ± 0.9	21.33 ± 0.06		63.0 ± 1.7	49.6 ± 0.6	***
Hue angle	29.2 ± 2.9	42.21 ± 0.09	**	46.3 ± 0.5	52.3 ± 0.4	***
ΔE*	6.7 ± 0.1		ΔE*	15.0 ± 1.6		
ΔL*	3.2 ± 0.3		ΔL*	1.2 ± 0.7		

ΔC*	-0.5 ± 0.9	ΔC*	13.4 ± 1.9
ΔH*	5.1 ± 0.6	ΔH*	5.7 ± 0.6

Level of significance: * = $P < 0.05$; ** = $P < 0.01$; *** = $P < 0.001$

Table 3 Instrumental color values (mean ± s.e.; n=3) of bi-colored meat products using computer vision system and traditional colorimeter.

Parameter	Meat parts		Significance *P*	Fat parts		Significance *P*
	CVS	Colorimeter		CVS	Colorimeter	
Mortadella						
L*	70.7 ± 0.4	65.6 ± 0.7	***	82.1 ± 0.6	78.2 ± 0.8	**
a*	17.4 ± 0.2	14.3 ± 0.1	***	7.3 ± 0.2	6.0 ± 0.4	*
b*	9.0 ± 0.0	12.9 ± 0.2	***	1.7 ± 0.3	8.0 ± 0.2	***
Chroma	19.6 ± 0.2	19.3 ± 0.2		7.5 ± 0.2	10.0 ± 0.3	***
Hue angle	27.3 ± 0.3	41.9 ± 0.4	***	13.0 ± 1.9	53.46 ± 1.6	***
ΔE*	7.3 ± 0.5		ΔE*	8.2 ± 0.7		
ΔL*	5.1 ± 0.8		ΔL*	3.9 ± 1.3		
ΔC*	0.3 ± 0.2		ΔC*	-2.4 ± 0.5		
ΔH*	4.9 ± 0.2		ΔH*	5.9 ± 0.3		
Smoked cooked bacon						
L*	60.1 ± 2.0	64.9 ± 3.1		81.3 ± 0.2	76.9 ± 0.2	***
a*	22.3 ± 0.7	12.2 ± 1.3	***	7.7 ± 0.3	6.6 ± 0.2	**
b*	7.6 ± 0.2	9.1 ± 0.1	***	2.6 ± 0.2	8.3 ± 0.1	***
Chroma	23.5 ± 0.8	15.3 ± 1.0	***	8.1 ± 0.3	10.6 ± 0.2	***
Hue angle	18.8 ± 0.4	38.0 ± 3.1	**	18.4 ± 1.2	51.7 ± 0.3	***
ΔE*	12.7 ± 2.3		ΔE*	7.4 ± 0.2		
ΔL*	-4.8 ± 3.0		ΔL*	4.4 ± 0.1		
ΔC*	8.2 ± 1.0		ΔC*	-2.5 ± 0.4		
ΔH*	6.1 ± 0.7		ΔH*	5.3 ± 0.2		
Dry pork neck						
L*	35.7 ± 0.7	38.3 ± 0.7	*	73.0 ± 0.8	73.0 ± 0.3	
a*	30.1 ± 0.3	17.4 ± 0.4	***	8.6 ± 0.5	4.8 ± 0.1	***
b*	13.3 ± 0.4	10.0 ± 0.3	***	4.7 ± 0.4	16.8 ± 0.1	***
Chroma	33.0 ± 0.3	20.1 ± 0.4	***	9.8 ± 0.5	17.5 ± 0.1	***
Hue angle	23.8 ± 0.7	29.9 ± 0.9	***	28.9 ± 2.0	73.9 ± 0.3	***
ΔE*	13.6 ± 0.4		ΔE*	12.9 ± 0.4		
ΔL*	-2.6 ± 0.5		ΔL*	0.0 ± 0.9		
ΔC*	12.9 ± 0.4		ΔC*	-7.7 ± 0.5		
ΔH*	2.7 ± 0.6		ΔH*	10.0 ± 0.5		
Pancetta						
L*	29.1 ± 1.5	35.9 ± 0.9	**	79.9 ± 0.6	74.5 ± 0.1	***
a*	22.6 ± 2.0	11.9 ± 1.3	**	7.3 ± 0.5	3.7 ± 0.1	***
b*	5.7 ± 1.1	5.6 ± 0.6		1.7 ± 0.5	5.4 ± 0.1	***
Chroma	23.3 ± 2.2	13.1 ± 1.5	**	7.6 ± 0.4	6.6 ± 0.1	
Hue angle	13.5 ± 1.8	25.0 ± 0.3	**	13.6 ± 3.8	56.1 ± 0.4	***
ΔE*	14.8 ± 1.2		ΔE*	7.7 ± 0.3		
ΔL*	-6.8 ± 2.1		ΔL*	5.3 ± 0.6		
ΔC*	10.2 ± 2.5		ΔC*	1.0 ± 0.5		
ΔH*	3.4 ± 0.6		ΔH*	5.0 ± 0.5		

Level of significance: * = $P < 0.05$; ** = $P < 0.01$; *** = $P < 0.001$

Table 4 Instrumental color values (mean ± s.e.; n=3) of non-uniformly colored meat products using computer vision system and traditional colorimeter.

Parameter	Meat parts		Significance *P*	Fat parts		Significance *P*
	CVS	Colorimeter		CVS	Colorimeter	
Beef fermented sausage						
L*	33.1 ± 0.3	48.0 ± 0. 8	***	64.4 ± 1.6	48.0 ± 0.7	***
a*	35.6 ± 0.6	21.9 ± 1.1	***	16.6 ± 0.8	21.9 ± 1.1	**
b*	11.9 ± 0.7	12.4 ± 0.5		5.1 ± 2.0	12.4 ± 0.5	**
Chroma	37.5 ± 0.8	25.2 ± 1.1	***	17.9 ± 1.3	25.2 ± 1.1	**
Hue angle	18.3 ± 0.8	29.7 ± 0.8	***	15.2 ± 5.4	29.7 ± 0.8	*
ΔE*	20.3 ± 1.1		ΔE*	19.5 ± 2.7		
ΔL*	-14.9 ± 0.9		ΔL*	16.4 ± 2.0		
ΔC*	12.3 ± 0.6		ΔC*	-7.3 ± 2.3		
ΔH*	6.0 ± 0.6		ΔH*	6.3 ± 0.9		
Pork fermented sausage						
L*	34.7 ± 0.8	41.9 ± 2.5	**	75.0 ± 0.8	41.9 ± 2.5	***
a*	34.9 ± 1.0	19.9 ± 1.1	***	8.7 ± 0.5	19.9 ± 1.1	***
b*	11.4 ± 1.0	8.7 ± 0.5	*	-1.1 ± 0.6	8.7 ± 0.5	***
Chroma	36.7 ± 1.2	21.1 ± 1.2	***	8.9 ± 0.5	21.01 ± 1.2	***
Hue angle	17.9 ± 1.2	23.7 ± 0.7	**	-7.1 ± 4.3	23.7 ± 0.7	***
ΔE*	18.9 ± 1.9		ΔE*	35.3 ± 2.8		
ΔL*	-8.1 ± 3.0		ΔL*	32.2 ± 2.6		
ΔC*	15.6 ± 1.0		ΔC*	-12.2 ± 1.3		
ΔH*	2.7 ± 0.7		ΔH*	7.3 ± 1.0		
Pork hamburger						
L*	41.1 ± 0.7	47.6 ± 1.9	*	75.3 ± 1.4	47.6 ± 1.9	***
a*	30.9 ± 0.8	15.1 ± 1.0	***	8.7 ± 0.5	15.1 ± 1.0	**
b*	10.9 ± 0.5	9.9 ± 0.7		2.9 ± 0.7	9.9 ± 0.7	***
Chroma	32.7 ± 1.0	17.7 ± 1.1	***	9.3 ± 0.5	17.7 ± 1.1	***
Hue angle	19.3 ± 0.5	33.2 ± 1.8	***	17.4 ± 4.1	33.22 ± 1.8	**
ΔE*	17.9 ± 2.3		ΔE*	29.4 ± 3.0		
ΔL*	-6.5 ± 1.9		ΔL*	27.7 ± 2.9		
ΔC*	15.0 ± 2.0		ΔC*	-8.4 ± 1.3		
ΔH*	5.8 ± 0.7		ΔH*	3.7 ± 0.8		
Beef hamburger						
L*	32.0 ± 1.2	41.7 ± 1.3	***	70.6 ± 1.2	41.7 ± 1.3	***
a*	29.7 ± 0.7	19.8 ± 0.5	***	14.1 ± 1.1	19.8 ± 0.5	**
b*	10.3 ± 0.9	11.7 ± 0.3		7.6 ± 0.4	11.7 ± 0.3	***
Chroma	31.5 ± 0.9	22.5 ± 0.6	***	16.1 ± 1.1	22.5 ± 0.6	***
Hue angle	18.9 ± 1.3	30.2 ± 0.7	***	28.6 ± 1.5	30.2 ± 0.7	
ΔE*	14.7 ± 1.0		ΔE*	30.0 ± 2.2		
ΔL*	-9.5 ± 1.5		ΔL*	29.1 ± 2.1		
ΔC*	9.0 ± 1.2		ΔC*	-6.4 ± 1.3		
ΔH*	5.2 ± 0.4		ΔH*	1.6 ± 0.2		

Level of significance: * = $P < 0.05$; ** = $P < 0.01$; *** = $P < 0.001$

Colorimeter values are the same for both meat and fat parts.

Table 5. 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	100.0%	3.4 ± 1.4[a,b]	CVS (100%)	3.0 ± 1.1[a,b,c]
Liver pate	100.0%	3.6 ± 1.1[a,b]	CVS (100%)	2.4 ± 1.1[a,b,c]
Chicken pate	92.9%	3.5 ± 1.0[a,b]	CVS (100%)	2.1 ± 1.0[a,b,c]
Beef fermented sausage	92.9%	3.6 ± 1.0[a,b]	CVS (100%)	3.2 ± 0.4[a,b,c]
Pork fermented sausage	100.0%	4.0 ± 0.8[a,b]	CVS (100%)	2.3 ± 0.5[a,b,c]
Frankfurter	100.0%	4.0 ± 1.1[a,b]	CVS (100%)	1.7 ± 0.5[a,b]
Saveloy sausage	100.0%	3.8 ± 0.9[a,b]	CVS (100%)	1.2 ± 0.5[a]
Mortadella	100.0%	2.9 ± 1.2[a]	CVS (100%)	2.1 ± 1.1[a,b,c]
Cooked ham	100.0%	3.0 ± 1.2[a,b]	CVS (100%)	3.6 ± 0.3[b,c]
Smoked cooked bacon	92.9%	3.1 ± 1.3[a,b]	CVS (100%)	2.2 ± 0.4[a,b,c]
Smoked cooked pork	100.0%	3.5 ± 1.0[a,b]	CVS (100%)	2.8 ± 1.2[a,b,c]
Pork prosciutto	100.0%	4.1 ± 0.8[a,b]	CVS (100%)	4.2 ± 1.0[c]
Beef prosciutto	100.0%	3.6 ± 0.9[a,b]	CVS (100%)	3.1 ± 1.8[a,b,c]
Dry pork neck	92.9%	3.5 ± 1.3[a,b]	CVS (100%)	3.0 ± 0.7[a,b,c]
Pancetta	92.9%	2.8 ± 1.5[a]	CVS (100%)	2.7 ± 1.5[a,b,c]
Pork hamburger	100.0%	2.8 ± 1.0[a]	CVS (100%)	2.0 ± 1.0[a,b,c]
Beef hamburger	100.0%	3.4 ± 1.3[a,b]	CVS (100%)	2.7 ± 1.0[a,b,c]
Raw sausage	100.0%	4.4 ± 0.8[b]	CVS (100%)	3.2 ± 1.5[a,b,c]

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”

Fig. 1. Computer vision (image acquisition) system

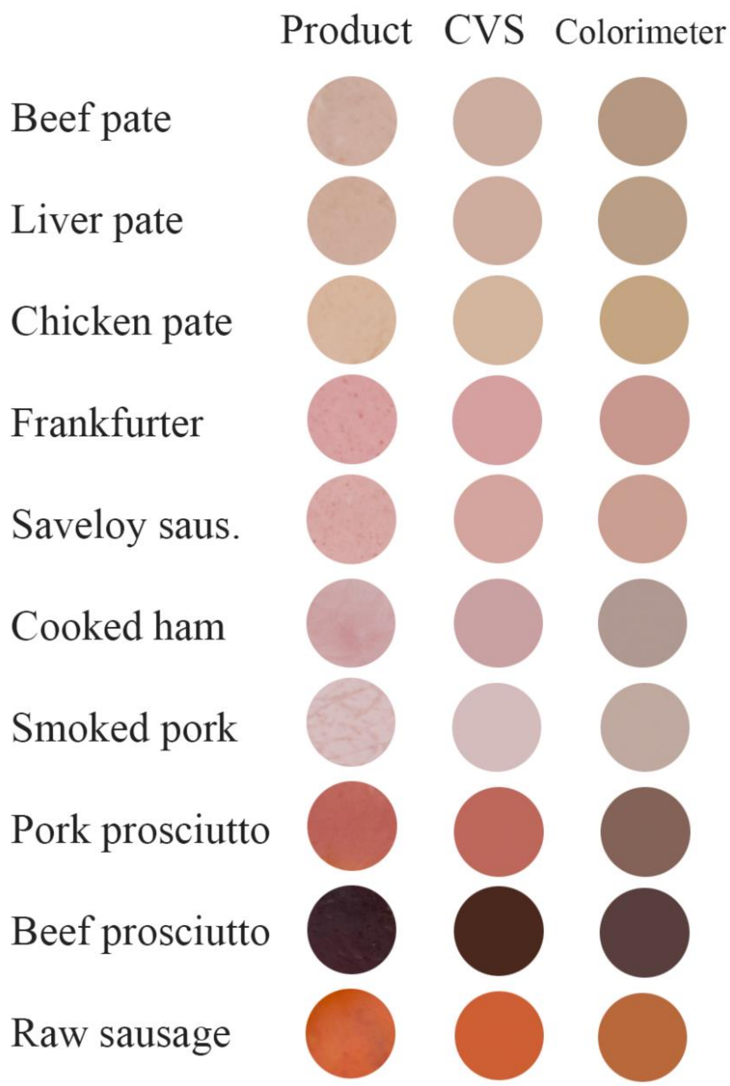

Fig. 2. Color of uniformly colored meat products as measured by the by the computer vision system and traditional colorimeter

Fig. 3. Color of bi and non-uniformly colored meat products as measured by the computer vision system and traditional colorimeter

(for non-uniformly colored products colors for meat and fat parts assessed by traditional colorimeter are the same)

Highlights

- Two methods of color measurement were compared, a computer vision system (CVS) vs a traditional colorimeter
- Some color parameters differed significantly between the two color-assessment methods.
- CVS color was more laborious to obtain, but was more accurate and representative, especially for non-uniformly colored samples.
- CVS-generated color chips were more similar to the actual sample color in all trials.
- CVS color was more accurate and precise for color traits compared with traditional colorimeter.

Figure 1

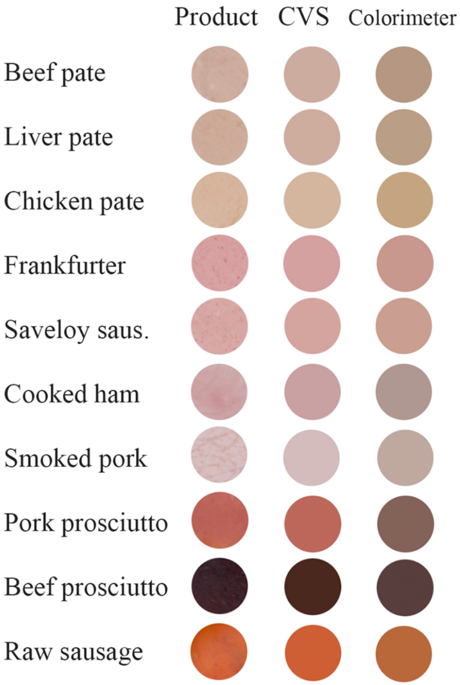
Product
CVS
Colorimeter
Beef pate
Liver pate
Chicken pate
Frankfurter
Saveloy saus.
Cooked ham
Smoked pork
Pork prosciutto
Beef prosciutto
Raw sausage

Figure 2


Product
Meat part
Fat part
CVS
Colorimeter
CVS
Colorimeter
a) bi-colored
Mortadella
Smoked bacon
Dry porck neck
Pancetta
b) non-uniformly colored
Beef fermented sausage
Pork fermented sausage
Pork hamburger
Beef hamburger

Figure 3