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Computer Vision System: A better tool for assessing pork and beef colour than a standard colourimeter

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*A b s t r a c t: The aim of this paper was to evaluate the use of computer vision system (CVS) to calculate CIE colour coordinates of beef and pork, as compared to a traditional Minolta colourimeter. Statistical analysis revealed significant differences of the colour parameters (L*a*b*, hue angle and chroma) using these two different techniques for colour detection. The CVS methodology produced colours highly similar to the visual assessment tests, but the Minolta colourimeter did not. The CVS-obtained colours were similar to the colours of both pork and beef samples visualized by trained panellists on the monitor, but colourimeter-obtained colours differed. The frequency of similarity for CVS-obtained colours and the actual meat colours as seen by the trained panellists was 100%. These results indicate that the CVS could be a superior alternative over the conventional Minolta colourimeter by offering improved representativeness and accuracy. In addition to providing objective colour measurement, it offers other possibilities that can be of benefit in further quality control or research within the meat industry.*

Keywords: *colour, pork, beef, computer vision system, colourimeter.*

Introduction

These days, people usually select products based on colour (*Akcay et al.,* 2012), especially in the case of meat (*Mancini and Hunt,* 2005). In general, it is well known that colour is one of the main aspects in sensory acceptance (*Fernández-Vázquez et al.,* 2011). Consumers associate colour with freshness, ripeness, desirability and flavour. Regarding fresh meat, a bright red colour is related to freshness, whereas a brownish colour denotes undesirability and unacceptability. At the present time, all food goods need to be monitored, in order to guarantee a satisfactory level of quality and safety.

For reliable and objective colour detection, colour measuring devices are used. So far, two types of commercial colourimeters have been most commonly used: the Minolta chromameter and the Hunter Lab colourimeter. Currently, the Minolta colourimeter is frequently used for meat colour assessment (*Tapp et al.,* 2011). Both devices offer simple and fast food colour analysis, moreover, they are easy to handle and calibrate. However, each colourimetric instrument has various settings such as (1) colour system i.e. CIE, Hunter, tristimulus, (2) illuminants (A, C, D_{65}), (3) observers (0, 2, 10) and (4) aperture size (0.64–3.2 cm).

The colourimeters are the handheld instruments that provide simple, rapid and easy to apply routine analysis of meat colour. However, there are some limitations related to the colourimeters; the measurements could be subjective and hard to reproduce (*Larraín et al.,* 2008). Moreover, these devices only provide average values of a small portion of the entire surface area (only a few cm^2) and therefore, many sampling locations and the number of readings must be measured to obtain a representative colour data (*Mendoza et al.,* 2006). Additionally, the food should have a uniform surface and colour (*Goñi and Salvadori,* 201). As a main reason for deviations in measurements many researchers quoted light reflection (*Trinderup et al.,* 2014) especially in the case of meat (*Girolami et al.,* 2013).

To overcome some of the limitations of the colourimeter we suggest using a computer vision system (CVS). Unlike the traditional colourimeter, the CVS measures colour readings across the entire sample. CVS has the advantage of determining L*, a*, b* values for each pixel of a sample's images, providing rapidness, precision, objectiveness, efficiency and

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non-destruction. Furthermore, many studies used CVS to detect PSE or DFD pork meat (*Chmiel et al.,* 2012; *Chmiel and Slowinski*, 2016a*; Chmiel et al.,* 2016b), or to predict pork and beef colour and marbling (*Jackman et al.,* 2008; *Sun et al.,* 2016; *Sun et al.,* 2018).

Hence, the purpose of this study was to evaluate the performance of using CVS and its possible advantages over Minolta colourimeter. Comparisons between CVS and colourimeter for meat colour measurement have already been investigated (*Tomasevic et al.,* 2019a; *Tomasevic et al.,* 2019b; *Tomasevic et al.,* 2019c). Nevertheless, to the best of our knowledge, there are no studies evaluating the suitability of CVS for evaluating pork and beef colour parameters. Thus, the aim of this study was to apply CVS to pork and beef in order to investigate whether it could be a superior tool over a conventional colourimeter for colour assessment of these meats.

Materials and Methods

Sample preparation

The research was conducted on *m. longissimus dorsi* pork and beef (three of each species), which we purchased in a retail setting. The meats were individually placed on white polystyrene plates with a consistent colour and overwrapped with a transparent PVC film permeable to oxygen. The PVC film was removed before colour measurement. Measurements were taken at room temperature on a freshly cut surfaces of slices about 3 cm thick of loin and after 30 min bloom time at 4°C.

Colour assessment

Two different colourimetric instruments were used to assess pork and beef colour. Colour of pork and beef samples was estimated using following the methods as reported in our previous study (*Tomasevic et al.,* 2019a). Colour readings (L*a*b*) were read by a traditional Minolta colourimeter and a computer vision system (CVS). Seven replicate measurements on different parts of the freshly cut loin surfaces were taken for all six loins (3 pork and 3 beef) and results were expressed as means.

Minolta colourimeter

We used a Minolta CR-400 colourimeter (Konica Minolta, Osaka, Japan). Each of the meat samples was measured at seven circular sites, each with a diameter of 8 mm. The measurements were performed under D65 standard illumination and pulsed xenon lamp as a default light source, 2° standard observer. Before the colour assessment, the device was calibrated with its white reference tile supplied by the manufacturer (Y=88.6, x=0.3175 and y=0.3350). Furthermore, this device was equipped with a CR-A33a accessory in order to measure the colour of solid samples.

Computer Vision system (CVS)

A CVS was used in this work for image acquisition (*Tomasevic et al.,* 2019a). It basically consists of the following elements: a cubical box, an illumination source, a high-resolution digital camera and a PC with image processing software. The computer vision system is shown in Figure 1.

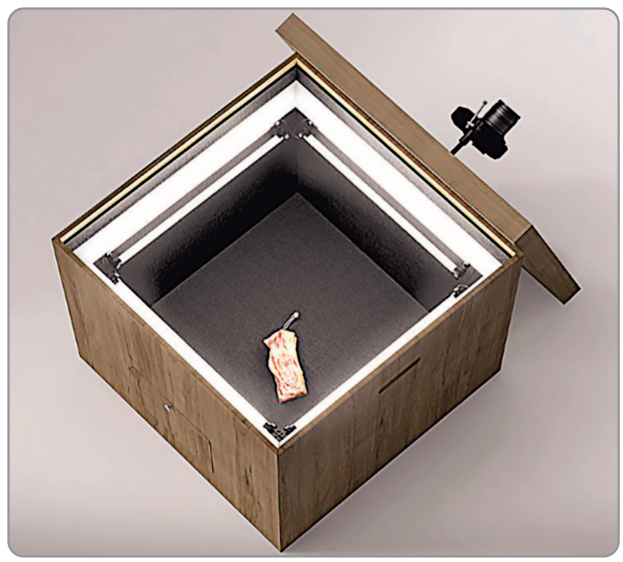

Figure 1. Computer vision system (*Tomasevic et al.*, 2019a)

Cubical (light) box: Black box (a=80 cm) with a removable top designed for the colour measurement was constructed from the wood. All internal walls were covered with matt black material in order to reduce any kind of light reflection. The entry for samples is located in the foreground of the box.

Light source: The samples were illuminated using 4 lamps (60-cm long), each a fluorescent tube (Master Graphica TL-D 90) with a colour temperature of 6500 K (D65; the standard light source widely used in food research) and a colour-rendering index (Ra) approaching 98%. Each lamp is located at a 45° angle and 50 cm above the samples in order to produce as uniform and diffuse illumination as possible.

Digital camera: A colour digital camera Sony Alpha DSLR-A200 was placed over the sample holder inside the imaging-acquisition apparatus. The settings of the digital camera used in the colour measurements are summarised in Table 1. The high-resolution pictures were stored in RAW format. The digital camera was placed at distance of 30 cm from the samples. Before taking digital images, the camera was calibrated using a 24-tile patter colour sheets with different hues (X-Rite Colourchecker Passpord, Michigan, USA) represented by coloured quadrates (4×4 cm^2). This procedure was done by photographing the card and putting it into specific software (ColourChecker Passport 1.0.1, X-Rite Inc.). The calibrated card inside the CVS apparatus was photographed and analysed in order to obtain the L*c, a*c and b*c values for each colour sheet, which were then compared with the measured colours (L*m, a*m and b*m).

Table 1. Digital camera settings

Parameters	Values
Size of the image	3872×2592
Image file format	RAW
Iso velocity	100
Aperture Av	F/11.0
Exposure Tv	1/6s
Image sensor	CCD
Focal distance	30mm
Lens	DT-S18-70mm f 3.5-5.6
Flash	Off
Modes	Manual (M)

Software: The computer hardware and software, arranged to simulate the human brain, is another key component of the CVS. The hardware consists of a personal computer and monitor. The PC provides disk storage for images and specific application programs. A high-resolution colour monitor provides the visualisation of captured images and the effects of various image analyses. The external monitor with sRGB was previously separate hardware calibrated using X-rite i1 display pro device. Colour management includes creating ICC profile with i1Profiler 1.5.6. software by selecting settings of brightness (white point) adjusted at 6500 K (D65), luminance (140 cd/m^2) and contrast (gamma) at 2.2. Adobe Photoshop was used to scrutinise images, due to its many advantages such as low cost, availability and many image editing features (*Yam and Papadakis*, 2004). The colour parameters were measured with RAW image format using the special average colour sampler tool (31×31 pixels).

Quantification of colour

The colour parameters measured were L*a*b*, hue angle, chroma, ΔL, ΔH, ΔC and total colour difference.

The L* value defines the lightness and can vary from 0 (black) to 100 (white). The a* value (+/) signifies the redness (red to green), and the b* value (+/) characterises the yellowness (yellow to blue).

Hue angle (h°) refers to the degree of the dominant spectral component, such as red, green, and blue, and ranges from 0° to 360°. An angle of 0º or 360º represents red hue, while angles 90º, 180º and 270º define yellow, green and blue hues, respectively. Combining a* and b* provides a better indication than their individual values; it is calculated based on the formula (*Salueña et al.,* 2019):

$$h_{ab} = \arctan\left(\frac{b^*}{a^*}\right)$$

Chroma (C*) is defined according to the following mathematical function:

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

and it defines the vividness or saturation of a colour (*Salueña et al.,* 2019).

The difference between chroma and lightness values was calculated using following equations:

$$\Delta C^* = C^*_c - C^*_M$$

$$\Delta L = L^*_c - L^*_M$$

Values for $C_c{}^*$ and $L_c{}^*$ were obtained from the meat samples using CVS and for and using the Minolta colourimeter.

Hue difference (H^*) was measured using the following formula according to (*Mokrzycki and Tatol,* 2011):

$$\Delta H^* = \sqrt{\Delta E^2 - \Delta L^2 - \Delta C^2}$$

Colour changes can be measured as total colour difference (ΔE). ΔE indicates the magnitude of colour difference between any two samples using the following equation:

$$\Delta E^* = \left[(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2\right]^{1/2}$$

$$\Delta L^* = L_1 - L_2$$

$$\Delta a^* = a_1 - a_2$$

$$\Delta b^* = b_1 - b_2$$

Values for a_1, b_1, L_1 were acquired using the CVS, whereas a_2, b_2, L_2 were acquired using the Minolta colourimeter.

Visual assessment

A trained panel of 12 assessors was recruited to carry out three sensory tests according to their normal colour vision. The Ishihara test (The Colblinder online Ishihara 38 plate) is used to diagnose possible colour blindness due to the fact that it is a valid screening test for colour vision deficiency (*Van Staden et al*., 2018). The minimum passing result was 18/21. Panellists' training was performed using Blendoku (blendoku.com) software. To access the ability of their eye colour perception, they completed the hue test (IQ colour test; X-Rite, Prato, Italy) with a maximum passing result of 20, which means almost perfect colour eyesight.

For all the sensory tests, panellists were kept 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 wooden light box. For the first test (test A), panellists were requested to compare a digital photograph on the monitor and a meat sample presented inside the light box. They assessed if there was similarity between them by answering "yes" or "no". If yes, the panelists recorded the level of similarity according to a 5-point scale from 1 – very low, 2 – low, 3 – moderate, 4 – high to 5 – very high. For test B, they were asked to estimate which of the two generated colours was more similar to the product colour visualised on the monitor. During the final test (test C), the panellists were asked to complete the triangle test. In this test, three colours were presented on the monitor, one of which was odd. Additionally, the assessors graded the extent of dissimilarity from 1 – very low level of dissimilarity to 5 – very high level of dissimilarity.

Statistical analysis

All statistical analyses were conducted with SPSS software (SPSS 23.0, Chicago, IL, USA). Instrumental colour measurement differences were measured with the t-test, whereas the data obtained from visual assessment tests (A, B) were analysed to determine based on the frequency of each response ($\chi 2$ one-sample test), where the expected frequency was 50%.

Results and Discussion

Pork colour assessment

Emphasize that this refers to meat part of pork muscle (the meat part of pork muscle), the colour traits measured with CVS and colourimeter were significantly different with the exception of b* (Table 3). Higher lightness (L*), lower redness (a*), and relatively higher yellowness (b*) indexes of pork meat were read by the colourimeter compared to the CVS. The magnitude of colour difference between the two methods used is best represented by the . For meat and fat parts of the muscle, was 16.7

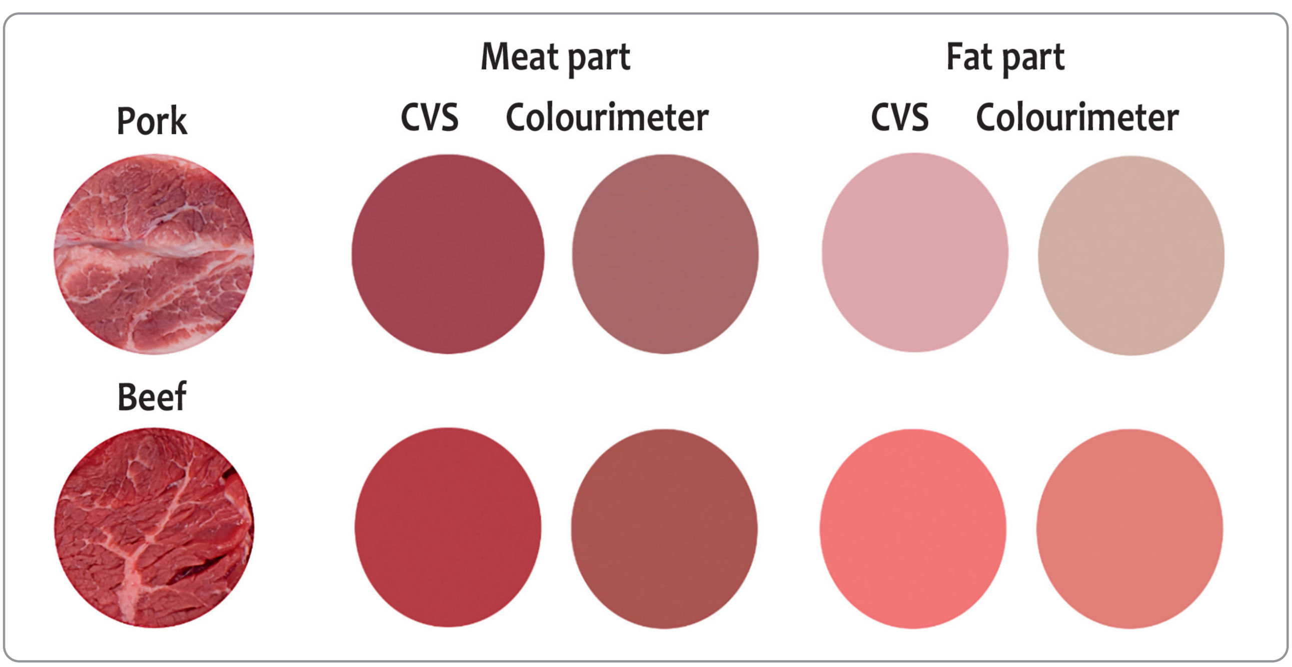

Figure 2. Colour of meat samples (pork and beef) measured by the computer vision system (CVS) and colourimeter

and 10.8, respectively, indicating that for meat parts, the colour difference between the two methods was even contrasting. Meat and fat parts were assessed as having darker colours when measured with the CVS than when measured with the colourimeter (Figure 2). The CVS-obtained colours of meat and fat parts were more saturated (positive values) than colourimeter values. All hue angle values of pork (both meat and fat parts) were significantly larger when measured with the colourimeter compared to CVS measurements. The CVS-generated colours of meat and fat parts were shifted in a clockwise direction from colourimeter-generated colours, representing, once again, a shift in the red direction.

The surface roughness and texture, the amount of surface gloss, the geometry of the measuring instrument and various other factors can affect colour analyses. In the case of fresh pork, as a bi-coloured meat that consists of meat and fat parts, its shininess can lead to specular reflectance, which results in chromatic components having smaller measurements. In addition, the colourimeter is dependent on both absorption and scattering properties of the test material. In our investigation, light employed in both instruments had the same colour conditions (6,500 K), but the light interface with the meat was obviously device dependent. Therefore, our results revealed that the colourimeter could not be suitable for the colour analysis of meat due to the fact that meat is a translucent and optically non-homogenous medium. This causes deviations in meat colour measurement resulting from the diffusion of light from illumination, making the colourimeter less accurate than the CVS. This study demonstrated the fact that CVS depicted more realistic meat colours than the colourimeter. Our observations are in good agreement with *Girolami et al.* (2013), who confirmed CVS was more precise and results were closer to the exact colour values than those of the colourimeter. This aspect was also reported by *Yagiz et al.* (2009), who stated that the reflectance properties of fresh meat can affect the colourimeter measurements and that diffuse illumination of the sample can be a way of overcoming this problem. In addition, *O'Sullivan*

Table 2. Colour values obtained using computer vision system (CVS) and colourimeter (mean±standard deviation; n=3)

Parameter	CVS	Colourimeter	Significance	CVS	Colourimeter	Significance
	Pork (meat part)			Pork (fat part)		
L*	39.3±2.3	49.8±2.8	***	73.3±4.5	73.9±2.2	
a*	33.1±1.6	20.4±2.4	***	15.0±4.1	7.9±1.6	**
b*	10.9±1.3	11.3±1.3		5.1±3.1	9.6±2.0	*
Chroma	34.9±1.4	23.4±2.4	***	15.9±4.9	12.5±2.4	
Hue angle	18.2±2.5	29.1±3.0	***	17.3±6.9	50.6±5.2	***
ΔE*	16.7±3.1		ΔE*	10.8±2.8		
ΔL*	−10.3±4.0		ΔL*	−0.6±5.1		
ΔC*	11.5±1.3		ΔC*	3.4±5.5		
ΔH*	5.5±2.0		ΔH*	7.8±1.7		
	Beef (meat part)			Beef (fat part)		
L*	39.3±2.6	44.1±2.1	*	60.2±2.2	59.6±3.4	
a*	42.6±1.4	29.4±2.8	***	42.2±1.1	30.4±2.6	***
b*	19.6±1.7	16.6±2.3	*	19.2±1.9	17.3±2.4	
Chroma	46.9±1.9	33.8±3.6	***	46.4±1.8	35.0±3.4	**
Hue angle	24.7±1.4	29.4±1.2	***	24.4±1.6	29.6±1.4	**
ΔE*	15.1±3.9		ΔE*	13.0±2.4		
ΔL*	−4.8±4.5		ΔL*	0.6±4.8		
ΔC*	13.1±4.3		ΔC*	11.4±3.3		
ΔH*	3.3±1.3		ΔH*	3.6±1.5		

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

et al. (2003) also postulated that CVS is more representative of real colour than the colourimeter, when pork colour was evaluated.

Beef colour assessment

Considering beef meat, the colour results returned by the two methods showed statistically significant differences. The values of the L*, a*, b*, hue angle and chroma obtained with the CVS and the colourimeter are shown in Table 2. Lightness (L*) for the meat part of beef muscle measured with the colourimeter was higher than that obtained using the CVS. In contrast, the other colour attributes of a*, b* and chroma values, gathered through the CVS, were always higher in both meat and fat parts than measurements obtained using the colourimeter. Hue angle values were higher with the colourimeter than with CVS, resulting in the non-real appearance of beef sample. We emphasized that total colour difference refers to meat part of beef muscle () for the meat part of beef muscle was 15.1, indicating the colours assessed by the two methods were opposite (*Brainard,* 2003). The colour obtained by the colourimeter has a non-real appearance, and that could be related to the penetration distance of the light into the samples. In beef samples*, Girolami et al.* (2013) assessed that the light from a colourimeter illuminates about 15–20 mm deep, but light from the CVS penetrates about 5 mm. Similarly, *Trinderup et al.* (2015) found that light penetrates about 20 mm from a colourimeter, and a few mm from the CVS. With regard to our results, they are in good agreement with findings from previous investigations (*Goni et al.,* 2016; *Girolami et al.,* 2013) that the colour predicted with the CVS is closer to the sample than the colour read by the colourimeter, making CVS more representative for beef colour evaluation.

Visual assessment tests

The results of the first visual test (test A) between the colour of the sample inside the light box and the CVS-produced colour on the display screen showed the panellists found the same colour of meats inside the box as the samples presented on the display. The frequency of similarity was 100.0% for both pork and beef meats (Table 3). This means that 12 out of 12 panelists found the sample colour was similar to the colour produced using CVS. The level of similarity recorded by the panellists ranged from moderate to high (Table 3).

The second test (test B) exposed that fact that CVS-observed colours were more similar to the actual meat sample when displayed on the PC, than were the colourimeter-observed colours, with panellists finding 100% similarity for pork and beef samples (Table 3).

The triangle test (test C) revealed there is a large difference between CVS and Minolta colour results, and this is a good agreement with our instrumental results (Table 3). The colour difference between these two methods ranged from 4.0 to 4.2 (high) for pork and beef, respectively.

According to the visual assessment tests, we found the CVS-produced colours more resembled the actual colours of the meat than did the colourimeter-produced colours. In conclusion, colours read by CVS are more realistic and representative of the true colours of both pork and beef muscle than those produced by the Minolta colourimeter.

Conclusion

Overall, our research on colour assessment proved that despite similar measurement conditions for the two studied methods, significant differences were observed. Our results show that employing a CVS is a valid alternative to the standard colourimeter. In fact, the CVS-obtained colours better represent the actual colour of meat samples as perceived by trained assessors (visual assessment tests) than the colourimeter-obtained colours. Taken together, our data clearly demonstrate the CVS methodology is more accurate and precise than the colourimeter for measuring colour of beef and pork. Although using a colourimeter for meat colour evaluation is

Table 3. Visual assessment tests (mean±standard deviation; n=3)

	Frequency of similarity (test A)	Level of similarity (test A)	CVS vs. Colourimeter (test B)	Level of difference test (test C)
Pork meat	100.0%	2.6±0.8^{a}	CVS (100.0%)	4.2±0.7^{a}
Beef meat	100.0%	4.1±0.5^{b}	CVS (100.0%)	4.0±0.7^{a}

CVS: computer vision system. Means in the same column with different small letters are significantly different ($p<0.05$). 5-point scale ranks from 1 – very low, 2 – low, 3 – moderate, 4 – high, 5 – very high.

regarded as reliable, it proved to be less accurate than CVS. Therefore, the CVS should be seriously taken into account as a more suitable alternative to the conventional method for measuring the colour of meat samples. Besides offering better objective measurement, it provides other possibilities that can be of benefit in quality control and research in meat science.

Kompjuterski vizuelni sistem kao alternativno sredstvo za procenu boje svinjskog i goveđeg mesa

Bojana Milovanović, Ilija Đekić, Bartosz Sołowiej, Saša Novaković, Vesna Đorđević, Igor Tomašević

*A p s t r a k t: Cilj ovog rada bio je da se proceni upotreba kompjuterskog vizuelnog sistema za izračunavanje CIE koordinata boje govedine i svinjetine u poređenju sa tradicionalnim Minolta kolorimetrom. Statistička analiza otkrila je značajne razlike u parametrima boje (L *, a *, b *, nijansa i hroma) koristeći ove dve različite tehnike za detekciju boje. CVS metod je bio vrlo sličan testovima vizuelne procene u poređenju sa Minolta kolorimetrom. Boja dobijena pomoću uređaja CVS bila je sličnija uzorcima svinjetine i govedine u odnosu na boju dobijenu kolorimetrom. Učestalost sličnosti bila je 100%. Ovi rezultati pokazuju da bi CVS mogao biti superiorna alternativa u odnosu na klasični Minolta kolorimetar nudeći poboljšanu reprezentativnost i tačnost. Osim što pruža objektivno merenje boje, nudi i druge mogućnosti koje mogu biti od koristi u daljoj kontroli kvaliteta ili istraživanju u industriji mesa.*

Ključne reči: *boja, svinjetina, govedina, kompjutre vision sistem, kolormetar.*

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References

Akcay, O., Sable, P., & Dalgin, M. H. (2012). The importance of colour in product choice among young Hispanic, Caucasian, and African-American Groups in the USA. *International Journal of Business and Social Science,* 3(6), 1−6.

Brainard, D. H. (2003). Colour Appearance and Colour Difference Specification. *The Science and of Colour*, 2, 191–216. doi:https://doi.org/10.1016/B978-044451251-2/50006-4

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

Chmiel, M., Słowiński, M., Dasiewicz, K. & Florowski, T. (2012). Application of a computer vision system to classify beef as normal or dark, firm, and dry. *Journal of Animal Science*, 90(11), 4126–4130. doi:https://doi.org/10.2527/jas.2011-5022

Chmiel, M., Słowiński, M., Dasiewicz, K., & Florowski, T. (2016b). Use of computer vision system (CVS) for detection of PSE pork meat obtained from *m. semimembranosus*. *LWT — Food Science and Technology*, 65, 532–536. doi:https://doi.org/10.1016/j.lwt.2015.08.021

Fernández-Vázquez, R., Stinco, C. M., Meléndez-Martínez, A. J., Heredia, F. J., & Vicario, I. M. (2011). Visual And Instrumental Evaluation Of Orange Juice Colour: A Consumers' Preference Study. *Journal Of Sensory Studies*, 26(6), 436−444.

Girolami, A., Napolitano, F., Faraone, D. & Braghieri, A. (2012). Measurement of meat colour using a computer vision system. *Meat science*, 93(1)*,* 111−118.

Goñi, S. M., & Salvadori, V. O. (2016). Colour measurement: comparison of colourimeter vs. computer vision system. *Journal of Food Measurement and Characterization*, 11(2)*,* 538−547.

Jackman, P., Sun, D. W., Du, C. J., Allen, P., & Downey, G. **(2008).** Prediction of beef eating quality from colour, marbling and wavelet texture features. *Meat Science*, 80(4), 1273−1281.

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

Mancini, R. A., & Hunt, M. C. (2005). Current research in meat colour. *Meat Science*, 71(1)*,* 100−121. doi:https://doi.org/10.1016/j.meatsci.2005.03.003

Mendoza, F. A., Dejmek, P., & Aguilera, J. M. (2006). Calibrated colour measurements of agricultural foods using image analysis. *Postharvest Biology and Technology*, 41(3)*,* 285−295. doi:https://doi.org/10.1016/j.postharvbio.2006.04.004

Mokrzycki, W. S., & Tatol, M. (2011). Colour 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. doi:https://doi.org/10.1016/S0309-1740(02)00298-X

Salueña, B. H., Gamasa, C. S., Rubial, J. M. D., & Odriozola, C. A. (2019). CIELAB colour paths during meat shelf life. *Meat Science*, 157. doi:https://doi.org/10.1016/j.meatsci.2019.107889.

Sun, X., Young, J., Liu, J. H., & Newman, D. (2018). Prediction of pork loin quality using online computer vision system and artificial intelligence model. *Meat Science*, 140, 72−77. doi:https://doi.org/10.1016/j.meatsci.2018.03.005

Sun, X., Young, J., Liu, J. H., Bachmeier, L., Somers, R. M., Chen, K. J., & Newman, D. (2016). Prediction of pork colour attributes using computer vision system. *Meat Science*, 113, 62−64. doi:https://doi.org/10.1016/j.meatsci.2015.11.009

Tapp, W. N., Yancey, J. W., & Apple, J. K. (2011). How is the instrumental colour of meat measured? *Meat Science*, 89(1)*,* 1−5. doi:https://doi.org/10.1016/j.meatsci.2010.11.021

Tomasevic, I., Tomovic, V., Barba, F., Vasilev, D., Jokanović, M., Šojić, B., & Djekic, I. (2019b). How the colour of game meat should be measured: Computer vision system vs. colourimeter. *Fleischwirtschaft – Frankfurt*, 1, 85−89.

Tomasevic, I., Tomovic, V., Ikonić, P., Barba, F., Djekic, I., Nastasijevic, I., Stajić, S., & Zivkovic, D. (2019c). Evaluation of poultry meat colour using computer vision system and colourimeter: Is there a difference? *British Food Journal*, 121(5), 1078−1087.

Tomasevic, I., Tomovic, V., Milovanović, B., Đorđević, V., Karabasil, N. & Djekic, I. (2019a). Comparison of a computer vision system vs. traditional colourimeter for colour evaluation of meat products with various physical properties. *Meat Science*, 148, 5−12, doi:https://doi.org/10.1016/j.meatsci.2018.09.015

Trinderup, C. H., Dahl, A. B., Jensen, K., Carstensen, J. M., & Conradsen, K. (2015). Comparison of a multispectral vision system and a colourimeter for the assessment of meat colour. *Meat Science*, 102, 1−7. doi:https://doi.org/10.1016/j.meatsci.2014.11.012

Van Staden, D., Noor Mahomed, F., Govender, S., Lengisi, L., Singh, B. & Aboobaker, O. (2018). Comparing the validity of an online Ishihara colour vision test to the traditional Ishihara handbook in a South African university population. *African Vis. Eye Health*, 77(1). doi: https://doi.org/10.4102/aveh.v77i1.370

Yagiz, Y., Murat, B., Hordur, K., Bruce, W., & Maurice, M. (2009). Comparison of Minolta colourimeter and machine vision system in measuring colour of irradiated Atlantic salmon. *Journal of the Science of Food and Agriculture*, 89(4*)*, 728−730. doi:https://doi.org/10.1002/jsfa.3467

Yam, K. L., & Papadakis, S. E. (2004). A simple digital imaging method for measuring and analyzing colour of food surfaces. *Journal of Food Engineering*, 61(1), 137−142. doi:https://doi.org/10.1016/S0260-8774(03)00195-X

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