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IDENTIFICATION OF REPRESENTATIVE SEGMENT OF ROOT FOR COLOUR DETERMINATION OF CARROT

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A b s t r a c t

The aim of the work was to verify hypothesis that colour of longitudinal section of carrot root may be represented by a selected segment of root or a cross-section. An image analysis was based on image data obtained for longitudinal sections of carrot roots using flatbed scanner and graphics editing software. Colour images were acquired into sRGB colour space and converted to CIE Lab. Sixteen segments of equal height were separated over whole length of root image. The colour difference metric was determined to present how colour of each segment differs from the mean colour of whole root. The root section was considered to be representative for whole root if colour difference metric was the least. The analysis of results confirmed a research hypothesis and allowed for finding representative section which was located at $^{10}/_{16}$ of total root length measuring from the carrot root head.

Introduction

Colour is one of inseparable and fundamental parameters used for the assessment of food products and materials. It affects the consumer reception of the product and may provide information about its chemical composition as well as suitability for processing, storage and transportation (GIEMZA 2004, ZAPOTOCZNY, ZIELIŃSKA 2005, KOLEK 2008, RÓJ, PRZYBYŁOWSKI 2012).

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Colour may be measured by instrumental or sensory methods. Sensory methods involve human vision but the values obtained in this way are subjective and imprecise. Measurements performed by means of spectrophotometers are precise and repeatable for a very small area. Colour assessment of large area object is usually the average of numerous random samples, which causes it may be not necessarily representative for this object (TRAJER, JAROS 2005, ZAPOTOCZNY, ZIELIŃSKA 2005, AGUILÓ-AGUAYO et al. 2017). More representative average colour may be determined based on the scanner or camera image of whole object or of a powdered sample using computer image analysis-related methodology (GONG et al. 2015).

It was proved that there is a correlation between carrot root colour and the content of carotenoids, sugars and vitamin C. Thus, colour measurement of carrot root may be extremely applicable for carrot quality assessment, since it may replace expensive and time-consuming chemical analyses (TRAJER, JAROS 2005, JANASZEK, TRAJER 2011, SHARMA et al. 2012, KOWALSKI et al. 2013, GONG et al. 2015, LIU et al. 2016).

In food processing the uniform colour of carrot roots is desirable. Thus, carrot roots with core and cortex having similar colour, i.e. without distinct line between them, are considered of the best quality. Nonetheless, different carrot varieties are characterised by different internal colour of root. The average values of colour discriminants of transverse sections (cross sections) or longitudinal sections images may be different than of size-reduced carrot. The lack of standard method for capturing images of plant objects complicates their utilization in production or food processing practice, and it also does not allow for comparing results of different imaging analyses, obtained by different researchers (BILLER et al. 2005, TRAJER, JAROS 2005, ZAPOTOCZNY, ZIELIŃSKA 2005). Therefore, the method of colour-related measurements of carrot roots must be precisely specified every time, due to the heterogeneity of roots' structure.

Generally, the analysis of changes in core and cortex colour, depending on the distance from the end of the root, as well as instrumental comparative assessment of the difference between the colour of the cortex and the core are based on the image of the longitudinal section of the root. Obtaining an appropriate research sample requires longitudinal cutting of root, which is both inconvenient and imprecise, because the root may crumble and even break due to stresses arising during cutting. Thus, transverse cutting of root is much more easier, since cutting out a cylinder segment, followed by obtaining its longitudinal section is fast and precise. This approach was applied to develop a simple and fast methodology to obtain an image of a sample representative for the whole carrot root. Logical analysis, supported by observations, allowed for making an assumption that changes of colour along whole carrot root are smooth. For the purpose of this work the following hypothesis was therefore assumed, that in the continuous material characterised by uniform variability, there must be an area with the

colour representing the average colour of the whole object. This assumption required empirical confirmation.

In preliminary tests, it was verified that the mean values of colour discriminants, determined for a certain transverse section of carrot root, may be the same as for the whole longitudinal section (BERNER 2010). The research was performed using spectrophotometer, and it was determined that transverse section with colour corresponding to the colour of longitudinal section of carrot root was located at ¾ of root length, measuring from root head. The deviation of colour discriminants of transverse section from the average colour of longitudinal section amounted to 10%. In order to confirm the existence of representative section, the research was repeated using more precise computer-based techniques.

Therefore, the aim of this study was to indicate a segment of carrot root longitudinal section, with the colour representative for whole root. The segment corresponded to the fragment of image of carrot root longitudinal section limited by two straight lines perpendicular to root longitudinal axis. Thus, it was necessary to determine length and place of cutting out the cylinder to obtain a research sample for colour reliable assessment of whole carrot root.

Material and methods

The study was carried out in two stages: image acquisition and colour analysis of images. Carrot roots of three varieties: 'Amsterdam 3', 'Flakke 2' and 'Daucus Carota' from own cultivation were used as a research material. Each cultivar was represented by roots of possibly the most uniform shape, mass and size: cultivar 'Amsterdam 3' – length 180±5 mm and head diameter 40±3 mm; cultivar 'Flakke' – length 170±3 mm and head diameter 353 mm; cultivar 'Daucus Carota' – length 200±5 mm and head diameter 45±3 mm. Research sample of each carrot cultivar consisted of six root longitudinal cross-sections for which smooth cutting surfaces were obtained (without cracks and patterns left by the cutting blade). Obtaining such sections required an immobilizing the root in a special matrix, followed by marking a straight line on root surface and cutting it cross with a sharp blade. The root was discarded from the research sample if any crack occurred during cutting or uneven cross-sectional area was obtained. Both halves of each selected, longitudinally cut root were scanned using Cannon 5600F flatbed scanner. Images were acquired using sRGB standard (IEC 61966-2-1) and were saved as bitmaps with resolution of 300 dpi. Each image has undergone pre-processing tasks leading to replacing original image background with a transparent layer. Subsequently, each image was divided in half perpendicular to the longitudinal root axis and the procedure was repeated four times, which allowed for obtaining image of root segments of the same length in each step. Colour components for two, four, eight and

sixteen obtained segments were determined for each segment independently. Segmentation of the carrot root image is presented in Figure 1. A simple algorithm searched for coloured pixels in the image and extracted their RGB values. Then RGB colour components were made linear using inverse sRGB companding. From chromaticity coordinates of sRGB components and its reference white 3×3 RGB to XYZ conversion matrix was calculated and finally CIE Lab colour coordinates were obtained using reference white corresponding to 2° standard observer and standard illuminant D65. No chromatic adaptation was used since sRGB is also relative to D65 reference white (CIE 15 2004, SCHANDA 2007).

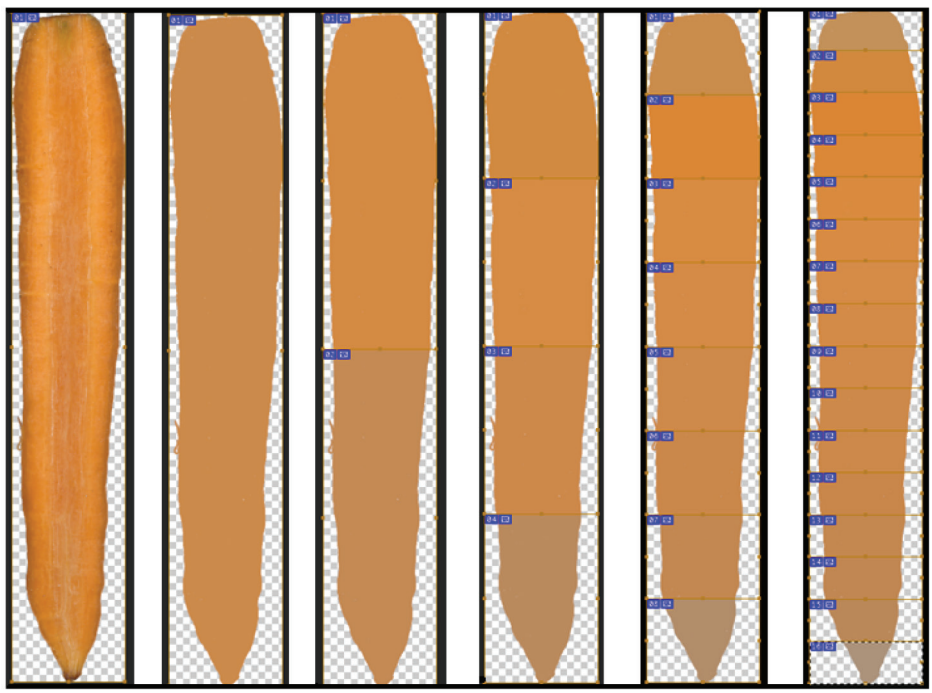

Fig. 1. Segmentation of carrot root image

The CIE Lab colour components allowed to compare mean colour of whole root (consider as a standard), with mean colour of each segment (consider as a sample) using colour difference metric (ΔE) as follows (CIE 15 2004):

$$\Delta E = \sqrt{(\Delta L)^2 + (\Delta a)^2 + (\Delta b)^2} \tag{1}$$

where: Δ symbol stands for the difference between sample and standard in lightness L, redness a (green-to-red colour component) and yellowness b (blue-to-yellow colour component) respectively.

Results and discussion

In the first stage, an initial colour assessment of selected material was conducted based on colour analysis of unsegmented longitudinal sections of examined roots. Standard deviations of colour components reached the highest value for 'Amsterdam 3' which indicates that this cultivar was characterised by the greatest degree of uneven colouring (Tab. 1). The values of ΔE metric were also determined between mean colour components obtained for all roots of the same cultivar (standard) and mean colour components obtained for individual roots of a given cultivar (sample). The ΔE symbol of this metric was marked with the upper horizontal line to distinguish it from other metrics (Tab. 2). Assuming that ΔE metric reflects human ability of colour perception, its values may be classified into five ranges, starting from difference not perceivable by human eye (ΔE<1) and finishing at the impression of perceiving two different colours (ΔE>5) (SHARMA 2003). On this basis it was concluded that roots of 'Amsterdam 3' cultivar were characterised by noticable differences in colour, while for other examined cultivars differences were definitely smaller. High values of variation coefficients determined for each cultivar allowed for making the following conclusion: identification of representative (in terms of colour) segment of carrot root within a sample of much higher cardinality is not cultivar-dependent.

Table 1

Mean values and variations of CIE Lab colour components of root longitudinal sections of examined carrot cultivars

Cultivar	'Amsterdam 3'			'Flakke 2'			'Daucus Carota'		
Colour component	*L* [–]	*a* [–]	*b* [–]	*L* [–]	*a* [–]	*b* [–]	*L* [–]	*a* [–]	*b* [–]
Mean	62	20	39	61	18	35	56	26	44
Standard deviation	3	4	6	1	1	4	1	2	1

Table 2

Means and variation coefficients of ΔE metric determined individually for each carrot cultivar

Specification	Symbol	'Amsterdam 3'	'Flakke 2'	'Daucus Carota'
Mean colour difference	$\overline{\Delta E}$	6.82	3.04	2.12
Coefficient of variation	$CV_{\Delta E}$	33.70%	32.60%	35.52%

Colour analysis of carrot roots' segments

Tables 3, 4, 5 and 6 contain ΔE for subsequent divisions of six samples, i.e. sections of six carrot roots of 'Amsterdam 3' cultivar, indicating a distribution of colour difference in subsequent segments of longitudinal sections of roots in comparison with mean colour of whole root. Further divisions of roots' images into segments of smaller length did not change the location of segment characterised with a minimum ΔE metric. Table 7 presents global mean values of colour differences of successive segments in comparison to the whole root, determined for each cultivar. In order to generalise results for all cultivars, an overall mean values of ΔE were obtained for all samples.

Table 3

'Amsterdam 3' cultivar: ΔE values obtained for 2-segment division

Segment	ΔE					
	Root 1	Root 2	Root 3	Root 4	Root 5	Root 6
1	6.02	8.61	4.71	9.05	6.75	7.85
2	6.18	8.43	14.88	20.55	19.69	7.37

In most samples, the segment which colour differed the least from the colour of the whole root, was identified between 9^{th} and 11^{th} segment of the root total length. Figure 2 presents a trend line of ΔE metric between mean colour of longitudinal root section and mean colour of its individual segments. The graph clearly shows an existence of a global minimum of colour difference at $\Delta E \cong 3.55$, within the 10^{th} segment.

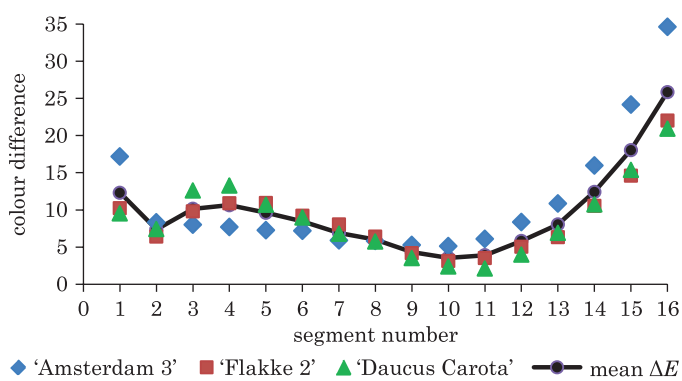

Fig. 2. Values of ΔE metric determined for individual segments of examined carrot cultivars

Table 4

'Amsterdam 3' cultivar: Δ*E* values obtained for 4-segment division

Segment	Δ*E*					
	Root 1	Root 2	Root 3	Root 4	Root 5	Root 6
1	6.16	8.61	8.51	13.66	7.89	4.24
2	6.39	8.61	1.91	4.72	5.32	12.22
3	1.50	2.69	4.74	11.77	11.03	1.44
4	13.41	18.80	24.98	28.91	28.58	14.71

Table 5

'Amsterdam 3' cultivar: Δ*E* values obtained for 8-segment division

Segment	Δ*E*					
	Root 1	Root 2	Root 3	Root 4	Root 5	Root 6
1	1.50	4.96	16.65	22.36	13.38	5.19
2	13.07	11.90	1.31	5.36	3.31	12.13
3	7.87	8.99	2.52	5.73	5.06	13.29
4	5.36	8.24	1.34	4.23	6.02	11.17
5	1.89	4.78	2.54	8.02	10.27	3.69
6	1.39	1.89	7.36	15.56	12.21	4.29
7	5.48	9.43	11.48	22.47	20.74	10.57
8	20.94	28.28	37.68	35.63	36.16	18.86

The most representative section for the examined samples is the section $^{10}/_{16}$ determined for 65% of the examined samples and a neighbouring segment for further 15%. The average error of colour assessment for the above segment was equal 3.7% its minimum was equal 1.36%, and maximum – 11.80%. After the separation of five samples, whose representative sections were not adjacent to the determined section, colour deviation average decreased to 1.84% with the minimum and the maximum values being equal 1.36% and 3.66%. respectively. The results of colour analysis of all representative sections of respective roots indicate that the colour deviation of each of them relative to the average colour of the whole root was between 0.59% and 4.21% with the median equal 1.39% and the average of 1.6%.

In the conducted research. measurement uncertainties might have been caused by the method of material preparation for research. i.e. asymmetrical cutting of carrot roots into two even halves, as well as rough surface of the carrot root section, resulting in inaccurate adherence of the section surface to the scanner glass. Results uncertainty may also be attributed to the material property of carrot roots. i.e. its flexibility, which may also cause inaccurate adherence to the scanner surface. The elimination of these uncertainties in the laboratory conditions is only possible by the use of a more precise cutting tool, or possibly

Table 6

'Amsterdam 3' cultivar: Δ*E* values obtained for 16-segment division and marked with pseudocolours

Segment	Root 1	Root 2	Root 3	Root 4	Root 5	Root 6
1	13.85	22.36	29.74	26.51	1.64	9.07
2	5.41	4.53	14.45	6.56	11.64	7.24
3	12.05	2.28	6.20	1.50	12.27	13.83
4	12.33	3.95	4.52	1.55	11.90	11.96
5	12.33	4.25	5.02	2.85	10.10	8.97
6	13.79	6.07	6.01	2.00	8.15	7.16
7	11.88	4.91	4.21	1.27	8.24	4.94
8	9.75	7.15	4.15	1.34	7.50	4.94
9	5.55	8.34	6.21	2.08	6.54	2.98
10	1.90	11.80	9.83	2.73	2.96	1.47
11	2.82	11.08	13.65	6.25	1.90	0.76
12	6.21	12.95	18.33	8.50	2.22	1.94
13	10.24	18.10	19.81	8.93	3.41	4.73
14	11.23	22.66	25.2	15.00	15.11	6.72
15	11.83	31.65	31.50	32.15	26.02	11.88
16	24.61	40.92	39.61	42.73	30.15	29.89

Table 7

Global mean Δ*E* obtained for root segments of each carrot cultivar and overall mean Δ*E* marked with pseudocolours

Segment	Global mean Δ*E*			Overall mean Δ*E*
	'Amsterdam 3'	'Flakke 2'	'Daucus Carota'	
1	17.20	10.23	9.53	12.32
2	8.31	6.42	7.42	7.38
3	8.02	9.79	12.62	10.14
4	7.70	10.90	13.28	10.63
5	7.25	10.94	10.69	9.63
6	7.20	9.21	8.98	8.46
7	5.91	8.03	6.79	6.91
8	5.81	6.39	5.75	5.98
9	5.28	4.17	3.53	4.33
10	5.12	3.14	2.39	3.55
11	6.08	3.52	2.10	3.90
12	8.36	5.05	4.00	5.80
13	10.87	6.33	6.90	8.03
14	15.99	10.55	10.76	12.43
15	24.17	14.60	15.40	18.06
16	34.65	22.01	20.94	25.87

appropriate adhesives applied temporarily on the section surface adjacent to the scanner surface. In technological conditions, however, where the measurements should be fast simple and accurate, it is necessary to limit the area in order to improve the accuracy of the reading and determine colour discriminants, according to the results of the presented work.

Conclusions

The research assumption that there is a section segment representative for the whole carrot root in terms of colour was confirmed. The obtained results are not absolutely satisfactory due to a limited number of research samples examined. Nevertheless, the results confirmed the existence of a representative section located at ¾ of the carrot root length from the head and limited the area of this section to the area between $^{9}/_{16}$ and $^{11}/_{16}$ – indicating the expected value of colours at $^{10}/_{16}$ of the root length. It was presented in the form of a trend line of a change in the difference between the average colour of the whole carrot root and the average colour of its individual segments. The obtained result applied to 65% of examined sections of roots. This fact can be attributed to the phenotypic growth conditions and error generated by the green colour of carrot root heads, which requires further detailed analysis and explanations.

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