Statistical Evaluation of Dynamic Changes of 'Idared' Apples Colour During Storage

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Summary

Colour changes on fruit during storage from brighter to darker nuances are caused by chemical reactions which often have degradative changes as a consequence. In this paper, evaluation of colour changes was done in CIE Lab colour model by using Minolta colorimeter CR-300 and in RGB colour model by applying digital image analysis method. In the aim of increasing of sample representativity analyzed apples were taken from different positions on trees and from different trees in orchard that was planted in 1983. Apples were harvested at a big commercial orchard in two different harvest times during one season. 30 apple pieces of Idared cultivar were analyzed immediately after harvest and periodically during storage for 20 weeks at 0 °C and 85-88% relative humidity. Apple temperature of all analyzed samples during storage period was T=0±0.4 °C. Mean colour change of apple skin determined in CIE Lab was ΔE_{ab}=1.53, while in RGB color model was ΔE_{RGB}=1.81. Total apple skin colour changes in Lab colour model was ΔE_{ab}=5.90, while in RGB colour model was ΔE_{RGB}=8.48. Both methods showed apple skin colour changes in the same way. Correlation between results was found to be 0.32 ($p<0.05$).

Key words

'Idared', storage, colour, CIE Lab, RGB

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Introduction

The objective of this research was to determine dynamics of colour changes on apples, cultivar Idared, after harvesting and during storage by comparing two different techniques. To achieve this goal, the apple colour characteristics were measured using Minolta colorimeter CR-300 and image analysis system consisted of camera, computer and monitor.

During storage skin colour of apples changes, usually we expect changes from brighter to darker nuances. One of the most often reasons are small brown spots caused by enzymatic browning, very often unnoticed during first few visual inspections after harvest. These brown colour nuances can be successfully detected by image analysis of apple surface. Very often these areas are centers of apple spoiling.

The most practical and the most successful techniques in a nondestructive evaluation of fruit quality are based on optical and textural characteristics of fruit. Scientists started to study optical characteristics of fruit and vegetable long time ago (Birth et al., 1964; Worthington et al., 1976; Nattuvetty et al., 1980; Dull et al., 1989; Chen et al., 1991; Felfoldi et al., 1995). The main goal was to find correlation between surface colour and internal changes caused by chemical and biochemical changes. Colour evaluation and determination of colour changes very often were done by measuring colour in Hunter Lab colour space using colorimeter. If two points in Lab colour space, representing two stimuli, are coincident then the colour difference between the two stimuli is zero. As the distance in space between two points (L^*_1, a^*_1, b^*_1 and L^*_2, a^*_2, b^*_2) increases it is reasonable to assume that the perceived colour difference between the stimuli that the two points represented increases accordingly. One measure of the difference in colour between two stimuli is therefore the Euclidean distance ΔE_{ab} between the two points in the three-dimensional space.

Depend on chosen area of apple surface Lab values differs because of small diameter of measuring head of instrument (8 mm in diameter) and give us nonobjective results. Most objective colour assessment can be obtained by using image analysis of all visible surface of apple skin. These techniques can be applied on both sides of apple, reddish and greenish to ensure much more objective results because almost 100% of apple surface is captured in an image. In the same way colour changes were measured in RGB colour model, where R (red), G (green) and B (blue) were separate colour channels with intensity values from 0 to 255.

Material and methods

Apple sampling

Apples from Idared cultivar used in this research were sampled in one of the biggest orchard in Europe ("Borinci" near Vinkovci, in eastern part of Croatia). Harvest was done in two weeks period from different positions on tree and from different locations in an orchard. 35 apple samples, 80 mm in diameter, were taken in analysis. 30 samples from each harvest were marked by numbers and five were used as reserve. All samples were stored in chamber with 0 °C and 85-88% relative humidity for 20 weeks and both apple sides (reddish and greenish) were analyzed always in same position. Series from 0 to 20 meant series of analysis: 0 was during harvest while 3, 7, 11, 16 and 20 meant number of weeks after harvest. Apples for this research were harvested in year with normal temperatures but with higher humidity than it is usual for this region. Samples were harvested in orchard planted in 1983 year from all positions on tree and from all boundary and middle positioned trees in orchard.

Colour measurements

Immediately after harvest and five times later, during storage, colour measurement was done by using Minolta colorimeter CR-300 and by image analysis system with camera, computer and monitor. Data were stored in CIE Lab and RGB colour models and colour changes during this period were evaluated. Colour changes in CIE Lab colour model defined as

$$\Delta E_{ab} = \sqrt{(\Delta L)^2 + (\Delta a)^2 + (\Delta b)^2}$$

where ΔL, Δa and Δb were differences between values of color components on a day of harvest and last day of storage period. Colour was measured always on the most reddish place on reddish side and the most greenish place on greenish side of apple sample.

Colour changes in RGB colour model were followed by imaging samples under indirect, halogen, low voltage (12 V, 20 W), dichroic illumination with wide flood (38° angle of spread) at 760±5 luxes. Colour temperature of the light sources was 3100 K. Images were stored in bitmap (BMP) graphic format with 8-bit pallet (2^8=256 colours) and after that were processed and analyzed. This graphic format stores information about colours in RGB-triplets for every pixel on the image where red (R), green (G) and blue (B) are intensities of mentioned colours in range from 0 to 255. Software, made for this research, calculated average percentage of red (R), green (G) and blue (B) colour in every pixel of the apple surface while background was not used in analysis. Colour changes were followed in separate R, G and B channels and percentage shares for every colour were calculated. An average share of each colour on sample surface was presented as final result. Colour changes in RGB colour model were defined as

$$\Delta E_{RGB} = \sqrt{(\Delta R)^2 + (\Delta G)^2 + (\Delta B)^2}$$

where ΔR, ΔG and ΔB were differences between values of color components on a day of harvest and last day of storage period.

Final results for both analyses represent average values for 1st and 2nd harvest and for both (reddish and greenish) sides of apple samples.

Pearson's coefficient of partial correlation was determined at significance level of $p \leq 0.05$. Coefficient of variability (cv) defined as share of standard deviation in average value was presented in percents.

Results

Mean ΔE_{ab} during 20 weeks was calculated from Table 4 and was found to be 1.53±0.41 with coefficient of variability cv=27.15. Mean of RGB-triplet of 'Idared' skin surface at harvest was (176, 95, 86) for both harvest times. Means of percentage shares of red (R), green (G) and blue (B) colour components in RGB-triplets on 'Idared' apples from 1st

Table 1. Means of colour on reddish (R) and greenish (G) sides from 1st harvest

Time (weeks)	L_R	L_G	a_R	a_G	b_R	b_G
0	43.97	67.59	27.88	-2.95	18.45	34.69
3	40.57	66.11	31.12	-2.13	18.23	34.96
7	41.86	68.21	30.03	-3.80	16.96	35.91
11	41.60	67.04	31.52	-0.29	17.30	35.26
16	41.78	67.16	31.27	1.37	17.52	35.94
20	42.35	68.92	32.42	0.49	18.35	37.80
$\Delta_{(20-0)}$	-1.62	1.33	4.55	3.44	-0.10	3.10

Table 2. Means of colour on reddish (R) and greenish (G) sides from 2nd harvest

Time (weeks)	L_R	L_G	a_R	a_G	b_R	b_G
0	44.40	66.49	25.81	-0.77	18.72	33.84
3	43.16	67.80	28.39	-1.20	19.08	36.38
7	43.16	67.04	30.97	2.25	21.61	36.24
11	44.92	67.05	30.34	2.66	20.41	36.04
16	44.33	68.59	31.89	2.82	21.62	37.68
20	43.87	68.62	32.91	3.08	23.58	39.97
$\Delta_{(20-0)}$	-0.53	2.12	7.10	3.85	4.86	6.14

Table 3. Means of ΔL, Δ a and Δ b values in both harvests

	ΔL_R	ΔL_G	Δa_R	Δa_G	Δb_R	Δb_G
AVG	-1.075	1.725	5.825	3.645	2.38	4.62

Table 4. Means and standard deviations of 'Idared' colour components in CIE Lab colour model (n=120)

Time (weeks)	L	a	b	ΔE_{ab}
0	55.61 ±11.44	12.49 ±14.39	26.43 ±7.85	
3	54.41 ±12.59	14.05 ±15.74	27.16 ±8.53	2.10
7	55.07 ±12.57	14.86 ±15.79	27.68 ±8.56	1.17
11	55.15 ±11.95	16.06 ±14.91	27.25 ±8.47	1.27
16	55.47 ±12.84	16.84 ±14.75	28.19 ±8.76	1.26
20	55.94 ±14.83	17.23 ±15.47	29.93 ±9.18	1.84
$\Delta_{(20-0)}$	0.33	4.73	3.50	5.90

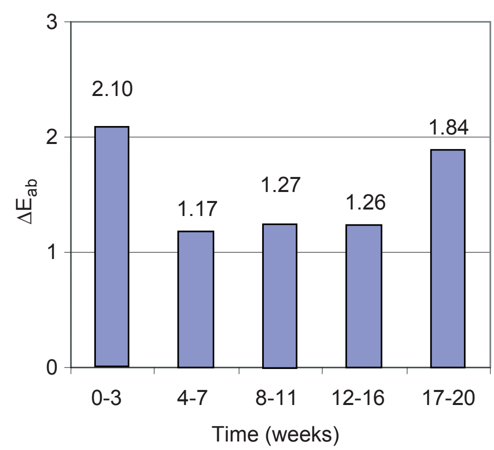

Figure 1.
Means of colour changes in CIE Lab colour model

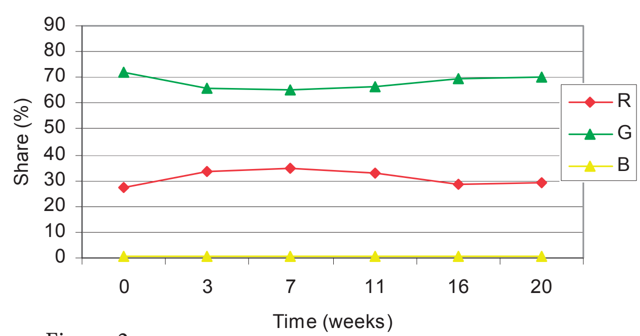

Figure 2.
Means of colour shares on 'Idared' apples from 1st harvest

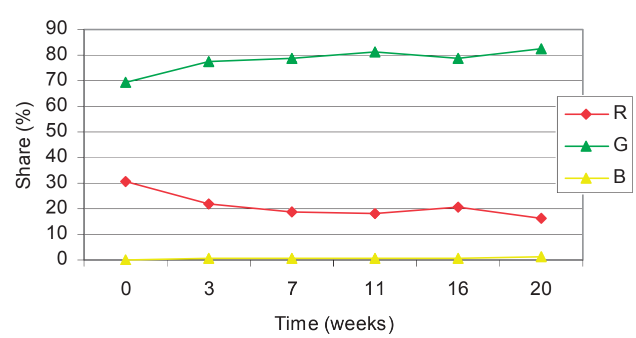

Figure 3.
Means of colour shares on 'Idared' apples from 2nd harvest

Table 6. Means of colour shares (%) and changes in RGB-triplets on apples from 1st harvest

Time (weeks)	R	G	B
0	27.51	72.04	0.45
3	33.77	65.83	0.40
7	34.53	64.88	0.60
11	32.81	66.52	0.67
16	28.28	69.51	0.52
20	29.07	70.19	0.74
$\Delta_{(20\text{-}0)}$	1.56	-1.85	0.29

Table 7. Means of colour shares and changes in RGB-triplets on apples from 2nd harvest

Time (weeks)	R	G	B
0	30.59	69.15	0.26
3	21.93	77.44	0.63
7	18.75	78.72	0.85
11	18.17	81.47	0.36
16	20.62	78.91	0.47
20	16.54	82.41	1.05
$\Delta_{(20\text{-}0)}$	-14.05	13.26	0.79

Table 8. Means and standard deviations of 'Idared' colour components shares (%) in RGB colour model (n=120)

Time (weeks)	R	G	B	ΔE_{RGB}
0	29.05 ±1.54	70.60 ±1.45	0.36 ±0.10	
3	27.85 ±5.92	71.64 ±5.81	0.52 ±0.12	1.60
7	26.64 ±7.89	71.80 ±6.92	0.73 ±0.13	1.24
11	25.49 ±7.32	74.00 ±7.47	0.52 ±0.16	2.49
16	24.45 ±3.83	74.21 ±4.70	0.50 ±0.03	1.06
20	22.81 ±6.27	76.30 ±6.11	0.90 ±0.16	2.69
$\Delta_{(20\text{-}0)}$	-6.25	5.71	0.54	8.48

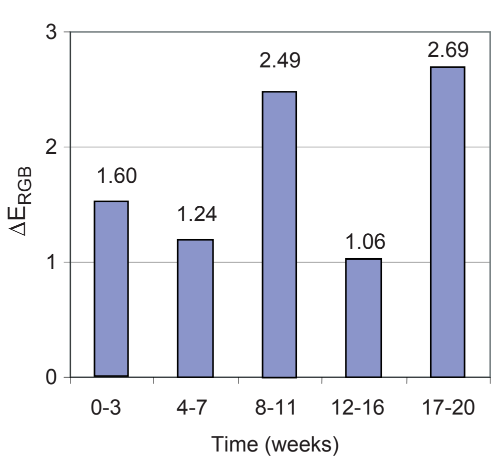

Figure 4.
Means of colour changes in RGB colour model for red and green side of apples from both harvest

and 2nd harvest on both sides of samples during storage are presented in following tables and diagrams.

Mean ΔE_{RGB} during 20 weeks was calculated from Table 8 and was found to be 1.81±0.74 with coefficient of variability cv=40.52.

Figures 5 and 6 show RGB colour spaces for an average 'Idared' apple at harvest and after 20 weeks, at the end of storage period. Both figures were made by image analysis of the same apple sample. Crossed lines show where central colour points were for chosen sample at the harvest time.

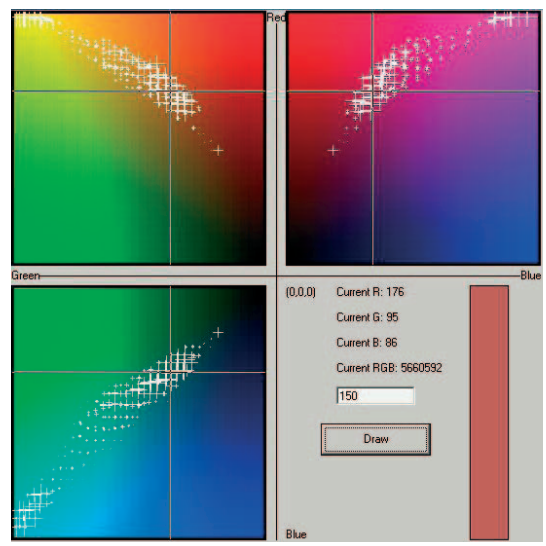

Figure 5.
One randomly chosen RGB colour space for apple sample in harvest

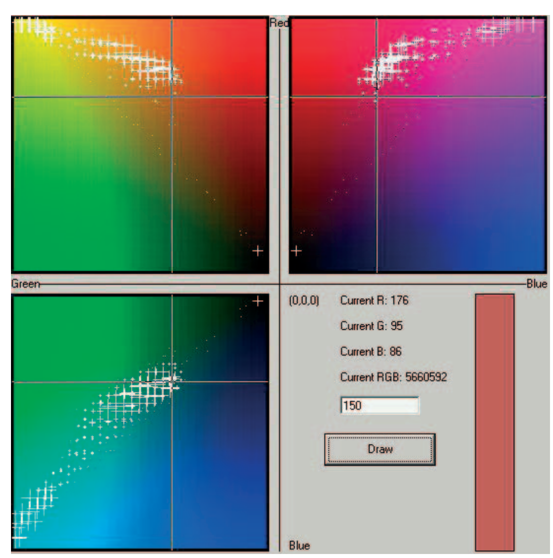

Figure 6.
One randomly chosen RGB colour space for the same apple sample after 20 weeks storage period

Discussion

Colour changes on apples from both harvests and on both sides of apples during 20 weeks measured by colorimeter were in average ΔL=0.33 or 0.59%, Δa=4.73 or 37.88% and Δb=3.50 or 13.25%, while mean colour change ΔE_{ab} from time to time was found to be 1.53±0.41 with coefficient of variability cv=27.15. From Table 3 it is visible that L-values decreased on red side and increased on green side of apples, while on average became higher for 0.59%. It means that red side became little darker and green side became little lighter during storage period and average colour became brighter. a-values and b-values increased during storage so it can be said that apples got intensified red (37.88%) and yellow (13.25%) color nuances.

Individual standard deviations in CIE Lab colour model for L-, a- and b-values were much bigger than individual standard deviations for R-, G- and B-values in RGB colour model. Using colorimeter one can measure colour parameters only on small area and can not be sure that after few weeks will analyze colour at the same place. Meanwhile, using image analysis in RGB colour model one analyses both apple hemispheres and area included in analysis is almost total apple surface. Because of that standard deviations for results obtained using image analysis were smaller.

The biggest changes in Lab colour model were measured in the first and in the last three weeks of storage period. Total colour change during 20 weeks of storage in Lab colour model was calculated to be ΔE_{ab} =5.90.

Colour changes on apples from both harvest and on both sides of apples during 20 weeks determined by image analysis were on average ΔE_R=-6.25, ΔE_G=5.71 and ΔE_B=0.54, while mean colour change ΔE_{RGB} from time to time was 1.81±0.74 with coefficient of variability cv=40.52. Such small change is not visible by naked eye in first few visual inspections and potential damage during storage period can not be recognized nor predicted. At the moment when by visual inspection damages are noticeable on apple skin it is too late. Damaged apples can be processed into juice or other products but damages make production more expensive in comparison with processing of healthy fruit.

In RGB colour model the biggest change was measured in the last three weeks, while changes in the middle of storage period were bigger than changes in the first three weeks. Total colour change during 20 weeks of storage in RGB colour model was calculated to be ΔE_{RGB}=8.48.

Small correlation among colour changes during 20 weeks storage period was determined between Lab and RGB parameters. Coefficient of correlation between five determined changes in Lab and RGB colour models was 0.32 ($p<0.05$). Results obtained by both methods show skin colour changes in the same direction.

RGB spaces of colours clearly show distribution of RGB triplets found on Idared apples and confirm measured and calculated colour changes. In case of skin colour browning both methods could help in prevention of spoiling but image analysis is much more accurate because almost all apple surface area is included in analysis. When browning appears, it is clearly visible in RGB colour space after three weeks of storage while it is not possible to find any differences by naked eye. The similar correlations between these methods were obtained for analysis of ‘Gloster’ and ‘Florina’ apple cultivars in same harvesting year and storage conditions while for ‘Golden Delicious’ correlation was found to be negative (Magdić, 2003). Stochastic error of these results can be decreased by increasing number of analyzed samples. Apple samples analyzed in this research had 80 mm diameter and considered to be average samples.

Figures 1 and 4 clearly show that highest colour changes, no matter which method was used, were found to be in first three weeks of storage and later from 8^{th} to 11^{th} and from 17^{th} to 20^{th} week.

Conclusions

Colour measured by Minolta colorimeter CR-300 on both side of ‘Idared’ apples from both harvests changed during storage period and became higher (brighter) for 0.59%, more reddish for 37.88% and more yellow for 13.25%, on average. Variability inside the sample group was found to be 27.15%. The biggest changes in Lab colour model were measured in the first and in the last three weeks of storage period. Total colour change during 20 weeks of storage in Lab colour model was calculated to be ΔE_{ab} =5.90.

Colour changes followed by image analysis were on average ΔE_{RGB}=1.81 with 40.52% variability. Red component decreased for 6.25, green component increased for 5.71. It means that apples became darker on a red side and brighter on a green side. Total colour change during 20 weeks of storage in RGB colour model was calculated to be ΔE_{RGB} =8.48.

Both methods showed similar colour changes, with correlation equal to 0.32 ($p\leq0.05$). From presented results it is obvious that normal ‘Idared’ apples during storage change red and green colour in brighter and into more intensive nuances.

The highest colour changes of apple skin were found to be, with both of the methods used, in first three weeks of storage and later from 8^{th} to 11^{th} and from 17^{th} to 20^{th} week.

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