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INFLUENCE OF LIGHT ON SYNTHESIS OF PLANT PIGMENTS INPOST-HARVESTED *JONATHAN GOLD* APPLES

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The article shows the results of impact of white and ultraviolet light on color of apples during storage. The light with spectrum from 312-600nm, applied for 72 hours, significantly increases the intensity apple color variety Jonathan Gold. This technology leads to increase the marketability of fruits, harvested under sub-optimal conditions.

Apples, plant pigments, anthocyanins, light, post-harvest.

Apples are seasonal fruits and the quality of color varies due to uncontrolled fluctuations in growing conditions as light and temperature and geographical variations. Therefore, the use of technology for the regulation of production of natural colors as pigments has been much interest over the last decade. Plant pigments are essential for the attractiveness of fruits, accumulating most often in the skin during ripening process [8]. The important pigments of fruits include anthocyanins. Beside their role in pigmentation, they are important for human health andserve as antioxidant compounds [7].

Anthocyanins are a class of flavonoid compounds, which are widely distributed in plant as polyphenols. Anthocyanins belong to the class of flavonoids derived ultimately from phenylalanine, synthesized in the cytosol, and localized in vacuoles[1]. They are widely distributed in the plant kingdom. They are water-soluble plant secondary metabolites responsible for spread range of colors from blue to purple and red. They can be found in leaves, fruits, vegetables, flowers, and grains. Anthocyan in serve numerous functions in plants including photo-protection, scavenging of free radicals, and attraction of insects and other animals facilitating pollination and seed dispersal. They also protect plants from damage caused by UV and visible light. A number of factors which influence the accumulation of pigments including light,

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temperature, hormones, etc. Therefore scientists together with orchard management practices are studying nowadays how to obtain consumer-desirable coloration of fruits.

From the polyphenol-oxidase enzyme that has been found to be one of the key factors causing decrease in anthocyanin concentration, a number of factors as oxygen content, light quantity and quality as well as temperature during pre- and post-harvest might also contribute to the increasing or loss of anthocyanins [8].

Materials and methods. We have developed the design of the light-chamber for improving the color of apples, harvested under the sub-optimal conditions. This chamber contain white and ultra-violet lamps with ultraviolet, blue and white spectrum (312 nm, 380 nm and 600 nm).

Color measurement (L*a*b*).The color measurement was carried out using a Konica Minolta spectrophotometer, Type CM-600d,calibrated with a standard tile and observed under the international system L*a*b*.

The L*a*b*-color system is the spread system for color measurement and is used in nearly all application areas. The color space of the L*a*b*-system is characterized by brightness L*, which ranges from 0 (black) to 100 (white), and color coordinates a* and b*. At the coordinate of origin the color is neutral grey without any color. The sign makes the color direction recognizable. +a* points the amount of red color and – a* points the green color, accordingly +b* stands for yellow and – b* for blue. Increasing a*b* values indicate a greater color saturation. Figure1 displays a complete color field of the L*a*b* - system and shows a horizontal cross-section at constant brightness L*.

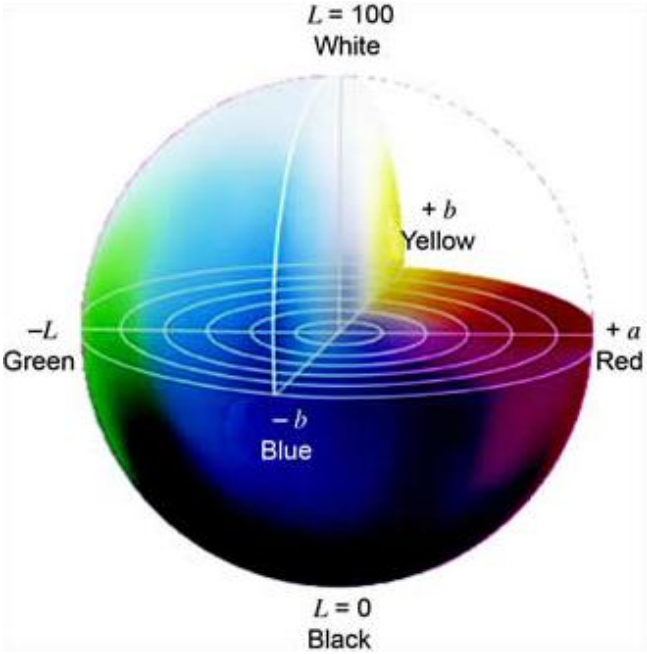

Figure1.Color field of the L*a*b* - system

Through initiating the measuring process, the emitted light of the xenon flash lamp is scattered in the calibration ball and the sample is measured from all solid angles. In SCE (specular component excluded) mode, the directed

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part of reflection is eliminated and only the diffused part is measured. It evaluates the color like an observer evaluates the sample. In SCI (specular component included) mode the diffused and the directed reflection are measured at the same time. This method evaluates the color regardless of the surface structure. In these investigations the SCI mode was chosen and five measurements for each sample were performed and the values averaged. Surfaces with structure or design lead to general and inferior reproducibility. Multiple measurements at different positions of the sample, followed by averaging, enhance the measuring accuracy.

For comparison of the different measurement values delta E is used. Delta E is defined as the difference between two colors in an L*a*b* color space. The CIE L*a*b* formula calculates the Euclidian distance, which means the purely distance between two points in a three-dimensional color space. Thereby the actual position of the points is irrelevant.

The value of delta E is calculated by the difference of two points of color using the following formula:

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

Since the human eye cannot recognize small differences in color, the delta E value graduates the color differences in the following groups (Table 1):

1. Meaning of delta E values (Electronics For Imaging, Inc., 2014)

Delta E value	Meaning
0 – 1	A normally invisible difference
1 – 2	Very small difference, only obvious to a trained eye
2 - 3.5	Medium difference, also obvious to an untrained eye
3.5 – 5	An obvious difference
> 6	A very obvious difference

This classification indicates the sensitivity of the human eye to see the difference.

Results and discussion. In our experiments we have used Jonathan Gold apples, harvested in sub-optimal maturity stage: the color of the peel was not regular, at least a half of the surface was green, when the other part was red. Our intent was to obtain red color on the whole surface of fruits. It is known the correlation between color change and fruit maturity to serve as maturity index of fruits. The use of peel color as a maturity index usually entails the establishment of the relationship among color change, storage life and eating quality. In apples, peel color can be manipulated in order to ensure that internal maturity and quality is reflected in the appearance of the peel color. If climacteric fruits were harvested immature, will ripe off the tree and attain full color during storage. In fruits like apples, where pigment synthesis is affected by environmental conditions, most notably light and temperature, the relation between maturity and color may vary according to the position on the tree and at different localities [3].

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Elevated sunlight promotes ripening associated pigment changes in apple peel, including anthocyanins. In case of apple, anthocyanin production tightly depend on not only the light intensity but also the quality, which influences anthocyanin formation. Both phytochrome and specific UV-B photoreceptors appear to be involved in a synergistic activation of anthocyanin synthesis (Figure 2).

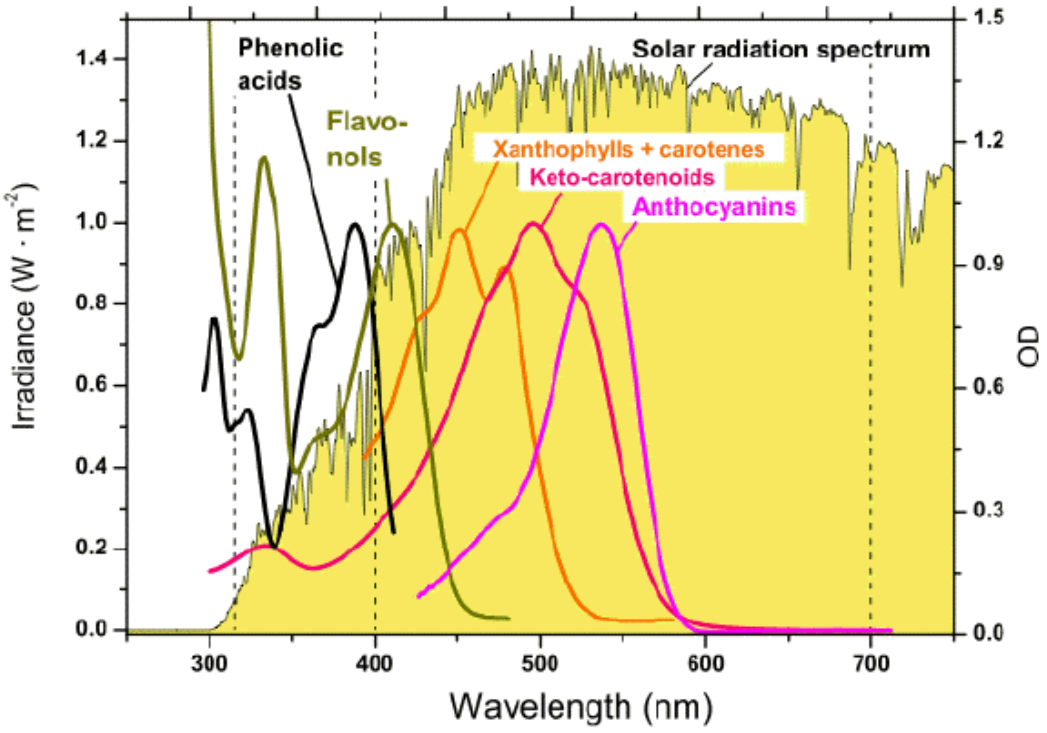

Figure 2. Influence of light on the synthesis of plant pigments [4]

In different studies, transcription of MdMYBA, MdCHS, MdDFR, MdLDOX, and MdUFGluT in apple peels was also found to be regulated by light, particularly UV-B radiation [2]. When fruits are unbagged and exposed to light, MdCHI transcription increases by 240-fold, followed by MdCHS and MdLDOX at 80- and 60-fold, respectively. MdMYB1 was identified as the lightresponsive regulatory factor controlling transcription of apple flavonoid genes (figure 3). Flavonols accumulate in apple peel during acclimation to strong sunlight. It serves as an efficient UV-B screen, playing an important role in the resistance of the photosynthetic apparatus to the UV-B component of solar radiation.

Reay and Lancaster (2001) studied the potential of detached fruit to accumulate anthocyanins and quercetin glycosides and found that the shaded side of the fruit has a much greater potential than the exposed [5]. They concluded that the fruit peels previous exposure to light is a modifying factor in the potential for accumulation of anthocyaninsby „Gala" and „Royal Gala". Moreover, position of fruit on the tree can affect the pattern of anthocyanin deposition in „Honey crisp" apple. More striped fruit are produced on southwest- facing branches, these fruits were additionally more strongly

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striped than those on the least sun exposed northeast branches. These results suggested that in this cultivar, higher light incidence or temperature on the bud are the fruit correlates with an increase in the occurrence and strength of stripes.

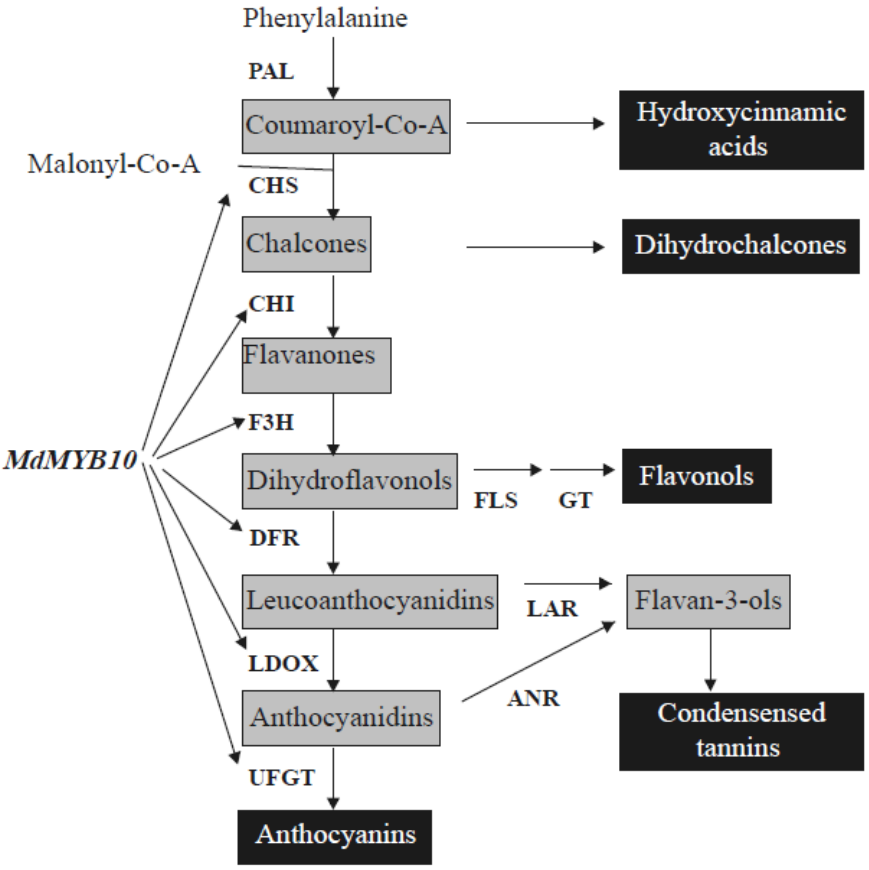

Figure 3. Biosynthesis of anthocyanins [7]

In our experiments post-harvested Jonathan Gold apples were stored at +5 ° C in the dark. For the treatment they were placed into the chamber with the lamps for maximal 94 hours. The spectrum of lamps has been selected in order to obtain the best possible response through the influence on anthocyanins synthesis. Thus, it is well known to stimulate, that white and ultra-violet light and synthesis. Therefore we have treated apples with the lamps with ultraviolet, blue and white spectrum (from 312 until 600 nm).

The color of the apples have been measured with Minolta colorimeter according to L*, a*, b* scale on the beginning of the experiment as well as 24, 48, 72 and 96 hours after the light exposure.

The response of Jonathan Gold apples on light registered have been already after 48 hours of light exposure, the color continued to be improved until the exposure for 72 hours, afterwards was stable.

We have registered changes in brightness of apples. After 72 hour of light the L* (brightness) of apples has changed from 56,20 to 48,17. The explosion of light until 96 hours decreased the lightness until 49,56 (table 2).

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Further irradiation for 72 and 96 hours did not significantly change the brightness of apples. A week later the brightness of all apples, treated for 48, 72, and 96 hours was rather similar.

Scale a* shows opposite red-green color. Thus Redness is positive versus Greenness is negative. The measurements of a* has changed after 72 hours from 16.59 until 32.13 (table 3). Application of light for 96 hour did not essentially influences on the red color. It increased up to 34.52. It is necessary to admit that the red component became very similar in all treated and non-treated apples. It reached 24.96 in non-treated apples and 29.56, 28.03, and 24.90 in apples, exposed to light for 48, 72, and 96 hours, respectively.

2. Changes in brightness of apples (L)

Light exposure								
Sample / Time, hours	A	B	C	D	E	F	Average	Deviation
0	64,20	68,11	61,54	67,3	58,95	54,73	56,20	5,12
48	52,93	50,07	44,82	51,55	53,44	46,77	47,51	3,46
72	44,41	38,30	47,22	45,55	48,77	46,33	46,63	3,64
96	51,90	46,39	44,44	48,99	47,78	49,56	48,17	2,59
							Δ 12,03	
				7 days after light exposure				
0	62,33	66,21	59,88	55,33	57,87	53,13	51,89	4,75
48	48,75	47,1	43,31	43,44	45,15	46,17	45,15	2,12
72	44,80	37,94	47,44	46,66	47,8	43,33	48,78	3,70
96	58,69	45,44	46,81	53,33	57,77	55,42	52,91	5,59
							Δ 1,02	

3. Changes in red-green colors (a*)

Light exposure								
Sample / Time, hours	A	B	C	D	E	F	Awerage	Deviation
0	4,80	2,06	12,51	11,04	10,39	17.,63	16,59	4,48
48	20,33	18,39	27,04	24,55	26,33	25,15	26,89	3,47
72	28,45	29,13	30,09	29,77	31,33	32,15	32,13	1,37
96	33,43	37,17	32,16	34,58	35,26	37.68	34,52	1,89
							Δ 17,93	
				7 days after light exposure				
0	23,34	21,14	21,67	22,57	20,37	22,78	24,96	1,11
48	26,64	27,65	30,5	28,77	25,67	28,48	29,56	1,70
72	29,23	29,76	31,42	30,33	32,58	33,74	28,03	1,73
96	21,91	26,41	28,82	26,73	25,37	20,16	24,90	3,24
							Δ 0,06	

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The other opponent color axis, *b**, is positive for the yellow color and negative for blue color. The yellow color for Johnathan Gold has decreased from 33.66 until 22.40 after 72 hours light treatment (Table 4). However, 96 hours treated apples became b* 27.94. This means, the exposure of light for 72 hours decreased the yellow component.

The application of light for 96 hours has caused the increase of yellow color. However, this can be explained by aging processes in apples. The changes like wrinkled surface and loss of turgidity could be observed even without measurements.

4. Changes in blue-yellow colors (b*)

Light exposure								
Sample / Time, hours	A	B	C	D	E	F	Average	Deviation
0	35,42	35,67	31,09	38,75	33,09	27,99	33,66	3,79
48	32,36	29,28	25,15	27,56	28,13	29,12	28,60	2,36
72	22,3	22,79	23,21	24,33	17,45	24,35	22,40	2,56
96	26,64	25,85	27,45	27,09	28,84	31,77	27,94	2,12
							Δ 5,52	
7 days after light exposure								
0	39,97	42,25	41,74	40,66	38,63	40,55	40,63	1,28
48	30,13	27,66	28,87	30,74	27,77	28,13	28,88	1,28
72	24,56	25,55	27,02	25,68	21,13	28,00	25,32	2,38
96	33,56	29,18	30,33	30,61	24,16	28,63	29,41	3,08
							Δ 11,22	

One week after the treatment the yellow component of the color has increased in all plots: from 33,66 until 40,63 in non-treated apples, from 28,60 until 28,88 in apples treated for 48 hours, from 22,40 until 25,32 in apples treated for 72 hours, and from 27,94 until 29,41 in apples treated for 96 hours.

Conclusions. Fruit ripening is a multi-complex, irreversible phenomenon involving a cascade of physiological, biochemical, and organoleptic changes that leads to the development of soft and edible ripe fruit with desirable quality attributes. The color changes during the fruit ripening due to the unmasking of previously present pigments or due to synthesis of pigments like anthocyanins and their accumulation in vacuoles. It is possible to conclude, that application of light with the wave lengths 312-600 nm for 72 hours strongly increase red color of harvested apples. This method can be used for the color improvement of apples harvested during weather conditions which are sub-optimal for ripening.

List of literature

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Наведені результати досліджень впливу білого та ультрафіолетового світла на зміну кольору яблук під час зберігання. Обробка світлом (спектром від 312 до 600 нм) тривалістю 72 год значно підвищує інтенсивність червоного кольору у плодів сорту Джонаголд. Використання цієї технології сприяє підвищенню товарності плодів зібраних за субоптимальних природних умовах.

Плоди яблуні, рослинні пігменти, антоціани, світло, післязбиральний період.

Приведены результаты исследований влияния белого и ультрафиолетового света на изменение цвета яблок во время хранения. Обработка светом (спектром от 312 до 600 нм) в течение 72 час значительно увеличивает интенсивность красного цвета плодов сорта Джонаголд. Использование этой технологии

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способствует повышению товарности плодов собранных при субоптимальных природных условиях.

Плоды яблоки, растительные пигменты, антоцианы, свет, послеуборочный период.

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