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CHANGES IN APPLE FRUIT QUALITY DURING A MODIFIED ATMOSPHERE STORAGE

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A B S T R A C T

Water evaporation and changes in texture and colour caused by biophysical processes are important in fruit storage. Using various modified atmospheres, fruits of apple cultivars 'Štaris', 'Auksis', 'Cortland' and 'Spartan' were stored at +1± 1 °C and relative humidity of 90-95%. The fruits were tested in the Biochemistry and Technology laboratory of the Institute of Horticulture, Lithuanian Research Centre for Agriculture and Forestry. Fruit texture and the colour parameters: L*, a*, b*, h° and C were measured before and after 8 months of storage. Soluble solids, respiration rate, sugar content and the amount of ascorbic acid were determined with standard methods. It was found that skin firmness of 'Spartan' apples was the highest (355.4 N/cm^2). 'Auksis' apples had the softest skin (215.8 N/cm^2). Fruit firmness changed slightly when the carbon dioxide concentration in the modified atmosphere was increased. The same tendency was found for flesh firmness at 2% and 4% of carbon dioxide. The amounts of soluble solids and sugars in fruits at 4% CO_2 were stable. The obtained results showed that ascorbic acid losses in the modified atmospheres with 2% and 4% CO_2 were respectively 18% and 10.5%. Fruit colour properties were more affected in terms of the colour coordinates a* and b*.

Key words: cultivar, modified atmosphere, respiration rate, chemical composition, colour parameters

INTRODUCTION

In order to satisfy the need of the Lithuanian consumer to get high-quality fresh fruits and to preserve their quality during storage, it is necessary to introduce the latest storage technologies, such as storage in a modified atmosphere and an atmosphere with ultra-low oxygen concentration, and packaging in a modified atmosphere. Thus it is not only that fruit quality attributes are greatly preserved and storage losses reduced as much as possible, but also the time span of fruit usage is extended (Brackmann et al., 1994; Dixon and Hewett, 2000; Aaby et al., 2002; Elhadi and Yahia, 2009). Modification of carbon dioxide and oxygen concentrations in the atmosphere surrounding the product allows fruit respiration rate, microbiological changes, enzymatic activity and oxidation to be controlled (Elhadi and Yahia, 2009). Fruit quality indices are affected by storage conditions and depend on fruit mineral, biochemical composition, the amount of different nutrients and their interrelation in the leaves and fruits (Gudkovski et al., 1990; Bunnemann, 1980; Hopfinger et al., 1984; Johnson et al., 1987; Švagždys and Viškelis, 1999). It is possible to establish more easily and accurately the level of fruit ripeness and the optimal time of picking on the basis of multiannual observations of fruit quality dynamics (Meresz et al., 1996; Kviklienė, 2001, 2002). The degree of ripeness is one of the main factors affecting long-term storage of apples.

Storing fruit under optimal conditions, which have not yet been fully described for the kinds of fruit grown in Lithuania, makes it possible to preserve the fruit crop usually until May, depending on the cultivar. After investigating variations in the physiological and biochemical processes and chemical composition of fresh fruits, by storing them in various ways it is possible to optimize storage conditions in order to preserve to a large extent the natural biochemical composition of fruits, ensuring their quality and storability, and to minimize the natural weight loss during storage.

The aim of the study was to evaluate apple cultivars in terms of how the quality attributes of their fruit crop are affected by storage in a modified atmosphere.

MATERIAL AND METHODS

Apple fruits for the experiments were taken from the Institute of Horticulture orchards grown according to intensive technologies (Uselis, 2005). The apple cultivars included in the experiments were: ‘Štaris’, ‘Auksis’, ‘Cortland’ and ‘Spartan’.

Soluble solids – with a refractometer, sugars – with an AOAC method (AOAC, 1990), vitamin C – by titration with 2,6-dichlorphenolindophenol sodium chloride solution (AOAC, 1990) were determined in fresh and stored fruits (after eight months). The results are presented as an average of three measurements.

Respiration rate was measured with “Anagas CD95”, which is used to determine the direct amount of two types of gases (CO_2 and O_2), according to the methodology established at the laboratory (Viškelis, 2002), and calculated with the program VinSkaPro.

Fruit storage was carried out in three replications in storehouses of the Institute of Horticulture, under optimal conditions, i.e. at a temperature of +1±1 °C, relative humidity 90-95%, and various compositions of modified atmosphere. The air composition of 21% O_2 + 0.03% CO_2, 6% O_2 + 2% CO_2, 6% O_2 + 4% CO_2 was determined with a STOREX B.V. (Netherlands) device. Ethylene content was measured with an ICE analyzer and expressed as the amount (mol l^{-1}) of ethylene released by one kilogram of fruit.

One replication consisted of a 15 kg bag of apples. Ama-Digit instruments measuring air temperature and relative humidity were used for the evaluation of storage conditions.

Fruit texture was measured with a texture analyzer (TA.XT Plus, Stable Micro Systems, Godalming, England). A P/2 probe (cylinder with a 2 mm diameter and flat end) was used for piercing the skin and flesh of apples (without peeling the skin). Ten fruits from each combination were used for analysis. Skin and flesh firmness of each fruit was measured on two diametrically opposite sides: coloured and non-coloured. The results of the tests were processed with the program "Texture Exponent".

Fruit colour coordinates in areas of equal contrast were measured with a MiniScan XE Plus spectrophotometer (Hunter Associates Laboratory, Inc., Reston, Virginia, USA). In mode measure reflectance, the parameters L*, a* and b* (i.e. lightness and the coordinates of redness and yellowness according to the scale CIEL*a*b*) were measured and colour purity calculated as $C = (a^{*2} + b^{*2})^{1/2}$, and colour tone as $h° = \arctan (b^*/a^*)$ (McGuiere, 1992). The values of L* were measured as a percentage; C, a* and b* were measured in NBS units; colour tone h^o – in degrees from 0 up to 360°. The tests were carried out in areas of equal contrast CIEL*a*b* (CIE L*a*b*, 1996). Skin blush or the ground colour of an apple was measured in an average of 8 points. Colour coordinates were processed with the program Universal Software V.4-10.

The experimental results were evaluated with Fisher's protected LSD and Duncan's multiple-range t-test at $p = 0.05$.

RESULTS

Respiration rate of the various apple cultivars in the normal atmosphere was different. 'Štaris' fruits were characterized by the highest respiration rate (7.22 mg CO_2/kg h) and 'Cortland' fruits – by the lowest one (5.95 mg CO_2/kg h) (Fig. 1).

The amount of carbon dioxide, and also of the endogenous hormone ethylene, increased in the packages during storage. Ethylene is a hormone that stimulates ripening. Fruits cease to synthesize ethylene as carbon dioxide concentration in a modified atmosphere increases (Fig. 2). Among the cultivars, ethylene synthesis in 'Auksis' apples dropped when carbon dioxide concentration was the highest.

'Spartan' fruits were distinguished by the firmest skin – 355.4 N/cm^2, while the softest skin was that of 'Auksis' apples – 215.8 N/cm^2 (Fig. 3A). Fruit skin firmness slightly decreases

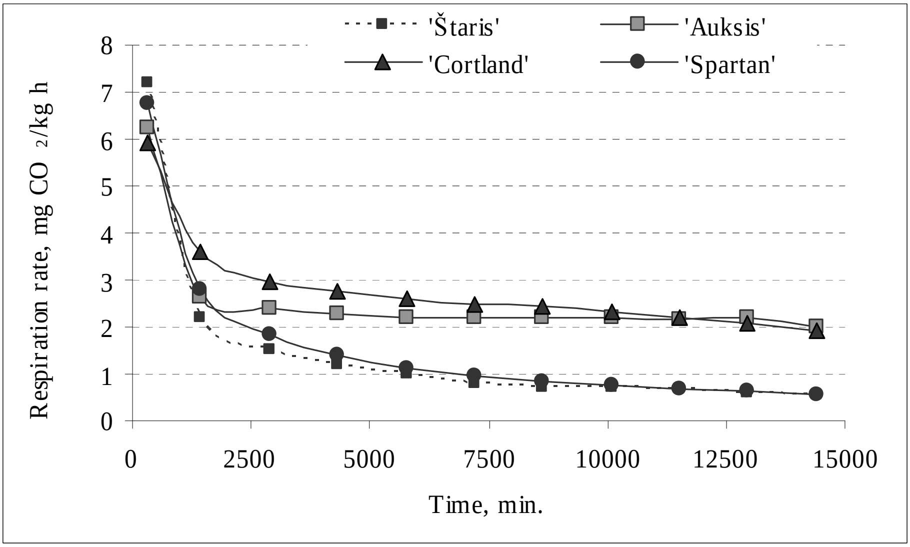

Figure 1. Respiration rate of various apple cultivars

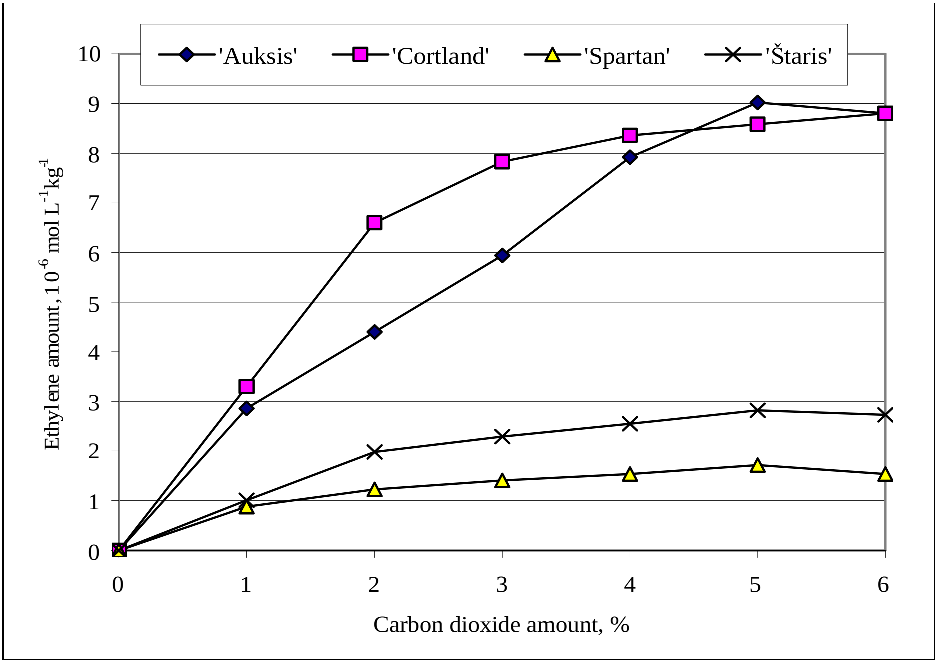

Figure 2. Accumulation of ethylene in the packages of various apple cultivars

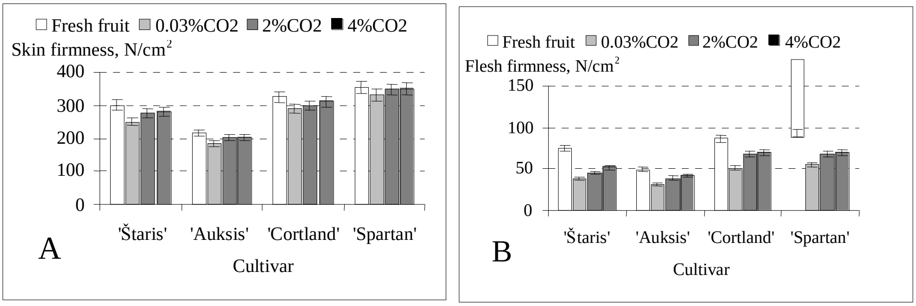

Figure 3. Firmness of apple fruit skin (A) and flesh (B)

during storage. Generally, skin firmness decreases when fruits are stored in the normal atmosphere. During storage, fruit skin firmness decreased insignificantly as carbon dioxide concentration in the modified atmosphere increased. 'Auksis' apples were rather soft; the firmness of their flesh was 49.3 N/cm^2 (Fig. 3B). After eight months of storage in the normal atmosphere, the flesh of 'Štaris' apples softened the most – 48.5%, compared with the flesh firmness of fresh apples. As the concentration of carbon dioxide in the modified atmosphere increased, flesh firmness during storage fell less than during storage in the cold store. The changes in flesh firmness when apples were stored in the modified atmospheres with 2% and 4% of carbon dioxide differed slightly and were often statistically insignificant. This shows that carbon dioxide concentration of 4% in the modified atmosphere is more than enough to preserve flesh firmness.

Among the tested cultivars, 'Štaris' fruits accumulated the greatest amount of sugars – 10.93% (Tab. 1). The amounts of sugars in 'Auksis', 'Cortland' and 'Spartan' apples were not significantly different. After storing apples for eight months under optimal conditions, i.e. at a temperature of +1±1 °C and 90% relative humidity, the amount of sugars in fruits decreased depending on the composition of the modified atmosphere (Tab. 1). The least amount of sugars was lost as a result of respiration while storing apples in the atmosphere with 4%carbon dioxide. The amount of sugars in 'Auksis', 'Cortland' and 'Spartan' apples decreased to a statistically insignificant extent compared with fresh fruits, after storing them for 8 months in the atmosphere with 4% carbon dioxide. This shows that carbon dioxide concentration of 4% in a modified atmosphere significantly reduces fruit respiration rate, ageing and ripening processes. The amount of sugars in 'Štaris' fruits decreased significantly as they were stored in the modified atmosphere with 4% of carbon dioxide; it is not advisable to store this cultivar in a modified atmosphere. The greatest changes in dry soluble

Table 1. Influence of the controlled atmosphere composition on apple fruit chemical composition

Parameters of chemical composition	Air composition	Cultivar			
		Štaris	Auksis	Cortland	Spartan
Soluble solids [%]	Fresh fruit	11.7±0.58*	11.0±0.29	11.8±0.38	11.2±0.44
	0.03% CO_2	8.2±0.34	7.8±0.23	9.2±0.27	9.6±0.38
	2% CO_2	9.0±0.33	9.1±0.34	9.9±0.35	10.3±0.29
	4% CO_2	9.7±0.41	10.7±0.28	11.1±0.31	11.1±0.45
Sugars [%]	Fresh fruit	10.93±0.27	8.27±0.39	8.8±0.40	8.62±0.43
	0.03% CO_2	7.2±0.18	6.6±0.25	6.58±0.31	7.1±0.27
	2% CO_2	8.5±0.29	7.5±0.33	7.5±0.29	7.8±0.23
	4% CO_2	9.2±0.23	8.0±0.28	8.0±0.35	8.2±0.32
Ascorbic acid [mg $100g^{-1}$]	Fresh fruit	6.4±0.39	5.2±0.19	5.2±0.24	4.8±0.14
	0.03% CO_2	3.0±0.23	3.2±0.11	3.7±0.17	2.7±0.14
	2% CO_2	4.9±0.20	4.1±0.28	4.9±0.20	4.1±0.19
	4% CO_2	5.6±0.28	4.8±0.24	4.9±0.18	4.5±0.31

*Mean ±SD; n = 3

solids were found in 'Štaris' fruits. The amount of dry soluble solids in them decreased significantly and reached 9.7% when carbon dioxide concentration in the modified atmosphere was 4%.

The amount of ascorbic acid, as the apples of the investigated cultivars were stored in the modified atmosphere, decreased less than when they were stored in the normal atmosphere (21% of oxygen and 0.03% of carbon dioxide). After 8 months of storing apples in a cold storehouse, the losses in ascorbic acid averaged 41% compared with the ascorbic acid content of fresh fruits. When 'Auksis', 'Cortland', 'Spartan' and 'Štaris' apples were stored in the modified atmospheres with 2% and 4% carbon dioxide, ascorbic acid losses in them were respectively 16.2% and 8.5%.

Colour lightness L* and the coordinate a* changed the most as apples ripened during storage (Tab. 2). The lightest in colour were 'Štaris' and 'Auksis' fruits. Fruit colour of these cultivars was respectively 77.0% and 75.2%. As the fruits were stored under optimal conditions in the normal atmosphere, colour lightness of all the investigated apple cultivars increased, while the increase in colour lightness of apples

Table 2. Influence of the controlled atmosphere composition on apple fruit colour parameters

Colour parameter	Air composition	Cultivar			
		Štaris	Auksis	Cortland	Spartan
a*	Fresh fruit	0.4 b*	-6.4 c	-7.4 c	3.9 a
	0.03% CO_2	5.5 ab	-1.1 c	-1.6 c	8.8 a
	2% CO_2	3.5 b	-3.5 c	-3.1 c	5.2 a
	4% CO_2	3.3 b	-4.2 c	-3.9 c	5.0 a
b*	Fresh fruit	35.3 b	35.9 b	42.7 a	37.7 b
	0.03% CO_2	48.3 b	49.5 ab	51.8 a	48.8 ab
	2% CO_2	41.0 c	43.3 bc	48.9 a	48.0 a
	4% CO_2	40.6 c	42.8 ab	47.7 a	43.8 ab
L*	Fresh fruit	77.0 a	75.2 a	67.4 b	66.6 b
	0.03% CO_2	89.2 a	87.5 a	75.2 b	75.2 b
	2% CO_2	83.1 a	82.5 a	71.2 b	72.0 b
	4% CO_2	81.2 a	82.5 a	67.0 c	71.8 b
C	Fresh fruit	35.3 c	36.5 bc	43.3 a	37.9 bc
	0.03% CO_2	48.6 ab	49.5 ab	51.8 a	49.6 ab
	2% CO_2	41.1 c	43.4 b	49.0 a	45.3 ab
	4% CO_2	40.7 b	43.0 ab	44.1 a	44.1 a
h°	Fresh fruit	89.4 b	100.1 a	99.8 a	84.1 bc
	0.03% CO_2	83.5 b	91.3 a	91.8 a	79.8 c
	2% CO_2	85.1 b	94.6 a	93.6 a	83.4 b
	4% CO_2	85.4 b	95.6 a	94.7 a	83.5 b

*Means followed by the same letter do not differ significantly at $p = 0.05$ according to Duncan's t-test

stored in the modified atmospheres was insignificant in comparison with freshly picked apples. After storing apples for 8 months in a normal cold store, the lightness coordinate L* increased from 7.8% ('Cortland') to 12.3% ('Auksis'). When apples were stored in the modified atmospheres, the change in the lightness coordinate was smaller and increased on average by 5.6% in comparison with fresh fruits when carbon dioxide concentration was 4%. The colour coordinate a* of 'Štaris' and 'Spartan' fruits increased during storage, i.e. they became redder. The values of the colour coordinate a* of 'Auksis' and 'Cortland' indicate that the green apple colour became less bright. The colour coordinate b* increased during storage; this indicates the predominance of the yellow colour in fruits. Colour purity C also increased during storage; however, the changes in colour purity were usually insignificant when apples were stored in the modified atmospheres. The main colour tone of freshly picked apples was on average 93.3°. This shows that the main colour of the tested fruits was yellowish-green. The changes in colour tone were small and generally insignificant during storage in the normal and modified atmospheres (Tab. 2).

DISCUSSION

Respiration is an important biological process in stored fruits. Fruit respiration rate decreases when the amount of oxygen decreases and the concentration of carbon dioxide increases. Carbohydrate monosaccharides are used up in respiration; consequently, the weight of stored fruits decreases. As carbon dioxide concentration in a modified atmosphere increases, not only does the respiration rate and the associated natural weight losses decrease, but fruit ripening and ageing processes are also retarded (Kozlovski and Pallardy, 2002). Nevertheless, it is possible to increase carbon dioxide concentration only up to a certain limit, because when this concentration is too high, apples 'suffocate' and become brown. The results presented in Figure 2 show that a carbon dioxide concentration of 2-3% is sufficient to retard fruit ripening and ageing processes.

When carbon dioxide concentration in a modified atmosphere increases, flesh firmness remains greater than after storing in a cold store. The changes in flesh firmness in the modified atmospheres with 2% and 4% carbon dioxide differed slightly from each other and were often statistically insignificant. This shows that a carbon dioxide concentration of 4% is a threshold concentration in a modified atmosphere. Polish scientists have noticed that various apple cultivars respond differently to the influence of carbon dioxide concentration in a modified atmosphere. Fruit quality parameters can differ considerably from those of apples stored in the normal atmosphere, or the differences may be insignificant (Konopacka and Plocharski, 2004). It has been established that apple fruit texture parameters can strongly correlate with weight loss, but the changes in these parameters depend on cultivar properties (Link et al., 2007). It is not always statistically reliable that sugar losses are smaller as carbon dioxide concentration in the modified atmosphere increases. Nevertheless, the amount of ascorbic acid in fruits can decrease by more than 50% after storing fruits for 6 months in the normal atmosphere (21% of oxygen and 0.03% of carbon dioxide) (Lee and Kader, 2000; Elhadi and Yahia, 2009). Our investigations show that the ascorbic acid content decreased the most in 'Štaris' (53.1%) and 'Cortland' (43.7%) fruits. Ascorbic acid losses during storage can be reduced 4.5 times when apples are stored in a modified atmosphere. Both the changes in chemical composition and sensitivity to carbon dioxide concentration show that it is not advisable to store 'Štaris' fruits in a modified atmosphere.

Fruit colour intensity depends on cultivar properties, but mostly it depends on environmental factors and orchard maintenance. Fruit colour can change by 10-12% during a week. The results of our investigations coincide with the results of other investigators – the changes in fruit colour parameters are smaller when fruits are stored in a modified atmosphere than when they are stored in the normal atmosphere. No differences in fruit quality of the cultivar 'Gala' were observed when apples were stored in a modified atmosphere with 1% O_2 and 1% CO_2 in comparison with fruits stored in 2% O_2 and 3% CO_2 (Drake and Eisele, 2007).

CONCLUSIONS

The obtained results show that a carbon dioxide concentration of 4% is already a threshold concentration for apples stored in a modified atmosphere. The respiration rate decreased approximately 8 times and ethylene synthesis about 3 times in most of the investigated cultivars when carbon dioxide concentration was 2%. 'Spartan' apples were distinguished by the firmest skin – 355.4 N/cm^2, and 'Auksis' apples the softest – 215.8 N/cm^2. Colour lightness L* and the coordinate a* changed the most as apples ripened during storage. As carbon dioxide concentration in the modified atmosphere increased, skin firmness fell slightly. Both the changes in chemical composition and sensitivity to carbon dioxide concentration indicate that the carbon dioxide concentration of 4% is too high for 'Štaris' fruits. It is not advisable to store apples of this cultivar in a modified atmosphere.

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ZMIANY W JAKOŚCI JABŁEK PRZECHOWYWANYCH W ZMODYFIKOWANEJ ATMOSFERZE

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STRESZCZENIE

Wyparowywanie wody oraz zmiany tekstury i wybarwienia spowodowane procesami biofizycznymi są ważne w przechowywaniu owoców. Stosując różne zmodyfikowane atmosfery, owoce odmian jabłoni ‘Štaris’, ‘Auksis’, ‘Cortland’ i ‘Spartan’ przechowywano w temperaturze +1 °C (± 1 °C) i wilgotności względnej 90-95%. Owoce badano/testowano w laboratorium Biochemii i Technologii Instytutu Ogrodnictwa Litewskiego Centrum Badawczego Rolnictwa i Gospodarki Leśnej. Tekstura owoców oraz parametry wybarwienia L*, a*, b*, h° i C mierzono przed przechowywaniem i po 8 miesiącach przechowywania. Zawartość ekstraktu, współczynnik transpiracji, zawartość cukrów oraz ilość kwasu askorbinowego oznaczano metodami standardowymi. Stwierdzono, że jabłka odmiany ‘Spartan’ miały najwyższą jędrność skórki (355,4 N/cm^2), a jabłka odmiany ‘Auksis’ najniższą (215,8 N/cm^2). Jędrność owoców zmieniła się nieznacznie, kiedy zwiększono stężenie dwutlenku węgla w zmodyfikowanej atmosferze. Tę samą tendencję stwierdzono dla jędrności miąższu w atmosferze zawierającej 2% i 4% CO_2. Zawartości ekstraktu oraz cukrów w owocach w atmosferze z 4% CO_2 były stabilne. Wyniki wykazały, że straty w zawartości kwasu askorbinowego w zmodyfikowanych atmosferach zawierających 2% i 4% CO_2 były odpowiednio 18% i 10,5%. Właściwości wybarwienia owoców były najbardziej zmienione pod względem współrzędnych koloru a* i b*.

Słowa kluczowe: odmiana, atmosfera zmodyfikowana, współczynnik transpiracji, skład chemiczny, parametry wybarwienia