Investigation of the reflection coefficients of apple skin when removing in the garden and during storage

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Abstract. Antonovka apples, yellow and green, which were picked on August 25 and September 1 have been analyzed. The reflection coefficients of the apple surface were measured at wavelengths of 700 and 750 nm. R750 / R700 ratio was used to estimate the chlorophyll content in the skin. It is shown that the reflection coefficients decrease in storage with time. It is proved by the change in the structure of the apple tissue; the light is absorbed to a greater extent by it. The change in the content of chlorophyll in the skins of apples remains at the same level during the storage. There are some fluctuations in its content. It has been shown that fruit diversity increases with the storage time.

1. Introduction
It is known that the development of plants, their aging and the action of unfavorable environmental factors are accompanied by changes in the content and composition of pigments. Changes in the color of leaves and fruits are mainly associated with the transformation of the dominant photosynthetic pigments: chlorophylls and carotenoids [1, 2].

It was previously found that the fruits are sunburned from the shady side of the apple, and this cannot only be associated with the presence of natural antioxidants, for example, anthocyanins, on the sunny side, in the formation of which solar radiation plays a significant role [3].

Many apple fruits have a different, mainly red, surface color, depending on their location relative to solar radiation [4, 5]. Some varieties do not have this color, but remain green, and depending on weather conditions (number of sunny days, air temperature), but mainly from direct sunlight, they can acquire a yellow color from the sunny side of the apple surface. Overripe fruits are more yellow over the entire surface than fruit that have not reached full maturity. The ripeness of the fruit can be determined by the presence of starch on the cut of the fruit by applying a solution of potassium iodide with crystalline iodine to its surface [6, 7].

2. Materials and methods
The ripening process of apples of the Antonovka ordinary variety was the object of the investigation. During the period of fruit ripening in the garden, they were removed from the tree at intervals of 3-7 days for measurements. The fruit were analyzed from July 27 to September 6. For the analysis, the fruits of two variants were used: the sunny and shady sides of the fruit of the sunny side of the tree [8]. The sunny side is determined by the presence of a yellow color on the sunny side of the fruit at the time of harvest. Also, two batches of fruits were formed by maturity: green and yellow. The fruits of two pickup
dates were analyzed: August 25 and September 1. The shelf life of Antonovka ordinary apples in a normal atmosphere is approximately until December-January. In addition, by this time they are affected by the browning of the skin, sunburn. Diffuse reflection measurements were carried out no later than 30 minutes using a SPECORD M-40 spectrophotometer. The resolution of a two-beam spectrophotometer "Speccord M40" (Germany, Carl Zeiss) using a photometric sphere with an inner diameter of 110 mm is not more than 0.3 nm. We also used an SF-26 spectrophotometer (Russia, LOMO) with an attachment [9]. Barium sulfate was used as a standard for 100% reflection, and an absolutely black hollow body was used as a standard for 0% reflection. To characterize the change in pigments in ripening fruits, wavelengths were used: 700 nm, in which chlorophyll is mainly absorbed, and 750 nm, in which absorption of chlorophylls does not appear, and light absorption is determined by the structure of the apple tissue [5].

3. Results and discussion
The apples were selected into two groups while analyzing the maturity of green (less mature) and yellow (more mature). The maturity of apples can be assessed by the chlorophyll content in their skins. For example, figure 1 shows the reflection spectra of the surface of the apples in the visible region of the spectrum of immature (green) and mature (yellow) apples. It can be seen that the green apples have significant absorption of light by chlorophylls, which manifests itself at a wavelength of 678 nm. Fully mature apples have practically no absorption at this wavelength.

![Figure 1](reflection_spectra.png)

Figure 1. Reflection spectra of the surface of fruits in the visible region of the spectrum: 1 - more mature apple; 2 - less mature apple.

The reflection coefficients were measured at wavelengths of 700 and 750 nm (nanometers). The apples of the dates of removing on August 25 and September 1, yellow and green, were analyzed. Figure 2 shows that for yellow apples of September 1 removing, the reflection coefficients increase by the end of December, and by the end of February they decrease and become less than when removing. For green apples with removing date September 1, the reflection coefficient decreases by the end of December and by the end of February it rises to the level of yellow apples. For apples which were removed on August 25, the reflection coefficient is 7% less and until the end of December it remains at the same level, and by the end of February it decreases. The change in reflection coefficient is almost the same for green and yellow apples.

Reflection coefficients at a wavelength of 750 nm (figure 3) for green apples with the picking date of September 1 remained at the same level during the entire storage period. Only for yellow apples does the reflectance decrease at the end of February. For apples of the picking date on August 25, a decrease in the reflection coefficient is observed already at the end of December and significantly decreases at the end of February. If the reflection at the wavelength is mainly determined by the content of chlorophyll a in the apple skin, then the reflection of the surface of the apples at a wavelength of 750 nm is determined by the structure of the apple tissue. Earlier, we found that light mainly penetrates into the apple tissue to a depth of about 7 mm [10].
Based on figures 2 and 3, it should be assumed that in order to measure the chlorophyll content by reflection coefficients, it is necessary to take into account the reflection at a wavelength of 750 nm, since figure 2 shows that at a wavelength of 700 nm, where chlorophyll a is absorbed, absorption associated with structural changes in apple tissue must be considered.

**Figure 2.** Change in the reflection coefficients of the surface of apples at a wavelength of 700 nm during storage. 1 - picking date September 1, green apples; 2 - picking date September 1, yellow apples; 3 - picking date August 25, green apples; 4 - picking date August 25, yellow apples. (Average error is shown).

**Figure 3.** Change in the reflection coefficients of the surface of apples at a wavelength of 750 nm during storage. 1 - removing date September 1, green apples; 2 - removing date September 1, yellow apples; 3 - removing date August 25, green apples; 4 - removing date August 25, yellow apples (Average error is shown).

Figure 4 shows the graphs converted from reflectance to chlorophyll content. The ratio \( R_{750} / R_{700} \) was used as an indicator of the chlorophyll content in relation to the reflection coefficient. The reflection coefficients for the chlorophyll a content were recalculated according to the formula \( \text{Chl a} = 5.881 \times \frac{R_{750}}{R_{700}} - 5.614 \) [10].

The chlorophyll content in the skin of green apples picked on August 25 is 1.85 μg / cm\(^2\) and does not change during storage, in yellow fruits, chlorophyll decreases by December, and in February it reaches the level of green ones.

When removing on September 1, chlorophyll in the peel of green apples is 1.09 μg / cm\(^2\) and by December increases to the level of green apples which were removed on August 25, and slightly decreases in February. In yellow apples, chlorophyll decreases by December and increases by February, repeating the course of the removing curve from August 25, but lower in level.
Figure 4. Change in the content of chlorophyll a in the skin of apples during removing and during storage in relation to the reflection coefficients R750 / R700 of the surface of apples: 1 - change in chlorophyll content during removal; 2 - removing date - August 25, green apples; 3 - removing date - September 1, green apples; 4 - removing date - August 25, yellow apples; 5 - removing date - September 1, yellow apples. (Average error is shown).

It was shown that the surface reflectance of the fruit which were removed on August 25 is lower than that of those taken on September 1. It was also found that yellow fruit have a large error in the average reflection coefficient, that shows their great heterogeneity. During storage, the error of the average indicator increases and, therefore, the heterogeneity of the fruit increases (figure 5, 6).

Figure 5. Change in the error of the surface reflection coefficient of the of apples at a wavelength of 700 nm during removal and storage: 1 - removing date - August 25, yellow apples; 2 - removing date - September 1, yellow apples; 3 - removing date - August 25, green apples; 4 - removing date - September 1, green apples.

Figure 6. Change in the error of the of the apples surface reflection coefficient at a wavelength of 750 nm during removal and storage: 1 - removing date - August 25, green apples; 2 - removing date - September 25, yellow apples; 3 removing date September - 1, yellow apples; 4 - removing date - September 1, green apples.

Figure 7. Change in the error of chlorophyll a content in the skin of apples during removing and storage: 1 - removing date - August 25, yellow apples; 2 - removing date - September 1, green apples; 3 - removing date - September 1, yellow apples; 4 - removing date - August 25, green apples.
4. Conclusions

It was shown that the chlorophyll content in the skin of green apples taken early in the garden, on August 25, does not change during storage. In yellow fruit, chlorophyll decreases by December, and in February reaches the level of green ones. In fruit which were removed a week later, on September 1, the chlorophyll in the skin of green apples increases by December to the level of green apples which were removed on August 25, and decreases slightly in February. In yellow apples, chlorophyll decreases by December, and increases by February, repeating the course of the removing curve from August 25, but with lower values.

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References

[1] Minakov I A and Nikitin A V 2019 Agricultural market development: Trends and prospects International Journal of Innovative Technology and Exploring Engineering 9(1) 3842-7
[2] Nikitin A, Kuzicheva N and Karamnova N 2019 Establishing efficient conditions for agriculture development International Journal of Recent Technology and Engineering 8(2) 1-6
[3] Antsiferova O Yu, Myagkova E A and Tolstoshein K V 2019 Formation of the development strategy of the agro-industrial complex of the Tambov region on the basis of the scenario approach IOP Conference Series: Earth and Environmental Science 274(1) 012084
[4] Grigoreva L V 2018 Biological growth peculiarities of the cuttings of various rootstocks in a horizontal nursery International Journal of Pharmaceutical Research 10(4) 632-40
[5] Rodikov S A 2001 Express diagnostics of apple maturity Gardening and Viticulture 1 9-12
[6] Tselyuk N A 1969 Determination of the term for picking the fruits of seed crops (Moscow: Kolos)
[7] Rodikov S A 1995 Electron-optical control during processing and storage of fruits (Moscow)
[8] Rodikov S A 2001 Application of the attachment in the spectrophotometer SF-26 for measuring the reflection of intact plant objects Bulletin of Moscow State Agrarian University: scientific and production journal 1(4) 78-81
[9] Rodikov S A 2005 Influence of pigments, peel and parenchymal tissue of an apple on the depth of light penetration into them Proceedings of the All-Russian Scientific Research Institute of Horticulture. I.V. Michurin. Scientific foundations of gardening: Sat. scientific. works (Voronezh: Quarta) p 393 - 9
[10] Rodikov S A 2009 Methods and devices for analyzing the maturity of apples (Moscow: FIZMATLIT)