Dependence of tuber fluorescence on potato storage duration

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Abstract. Fluorescent control methods are very sensitive and able to capture the ultra-weak reactions of tubers to lighting. However, they have not been developed due to the high sensitivity and complexity of the analysis of diverse information from natural samples. An important biological feature of tubers is repair, i.e. an ability to renew the cover tissue in places of mechanical damage. To assess the quality of tubers, natural, and wound periderms, a spectrofluorimeter was used. Optical measurements were performed. The spectra were recorded at a low voltage on a photovoltaic multiplier with a slit width of monochromators – 5 nm, in which the object fluorescence was illuminated by light with a variable wavelength. Results of the spectral reaction to these excitations were recorded. Tubers of potato varieties of different maturity groups were used for research. The relationship between the intensity of fluorescence of vitamins (max 468 nm) and flavins (max 520 nm) most fully reflects the state of tubers in different periods of storage. The aim of the study was to assess the quality of tubers by applying the fluorescent method to create a database for the development of portable devices that do not destroy the control of tubers during their storage.

1. Introduction

Effectiveness of a study focused on the quality of potatoes depends largely on the possibilities of instrumental assessment of parameters of tubers during storage. Optical methods of non-destructive express quality control of tubers are promising, but not fully studied for the diagnosis of potatoes. These methods allow one to monitor the status after diagnosis and, if necessary, make changes in the process of storage. Fluorescent control methods are very sensitive and capable of capturing the super-weak reactions of tubers to lighting; however, they have not received proper development due to the high sensitivity and complexity of analyzing diverse information from natural samples [1], [2], [3]. The non-destructive method allows one to enhance the quality control of potatoes during storage, minimizing both temporary and food losses [4], [5].

Reparation, as the ability to renew the integumentary tissue in places of mechanical damage, is an important biological feature of tubers. The course of wound reactions in potatoes is closely related to the respiration of tubers. The importance of this feature increases due to the extensive mechanization of harvesting and post-harvest handling, as a result of which macro- and micro-cracks of tubers, cuts, dents, occur [6], [7]. A well-formed wound periderm protects the tuber from evaporation and penetration of microorganisms. It contains a large amount of the following compounds of phenolic and glycoalkaloid nature: caffeic acid, scopoletin, solanine, chakoin, and other phytoalexins [6], [8].

The work of K. Ryan and his colleagues made the most significant contribution to understanding the processes of a wound repair. They showed that mechanical injuries of tomato and potato leaves
systematically expressed proteinase inhibitor (PI) genes. They were recognized as a marker of wound signaling. PIs function as protective proteins that protect plant tissue from the effects of mechanical wounds, as well as damage caused by insects [9], [10].

The purpose of the study is to assess the quality of tubers using the fluorescent method to create a database when developing portable devices that do not destroy the control of tubers during storage.

2. Materials and Methods
The Spectropluorimeter “MPF-44A” (Sweden) was used to assess the quality of natural and wound periderm tubers. Optical measurements were performed. The spectra were recorded at low voltage on a photomultiplier with a monochromator slit width of 5 nm, where the object was illuminated with variable wavelength to excite its fluorescence; and the results of the spectral response to these excitations were fixed. Tubers of different varieties of potatoes in groups of ripeness used for research. Studies were conducted on the basis of the Lorch Potato Research Institute and the Carcinogenesis of Blokhin Russian Cancer Center (Russia).

3. Research Results
The relationship between the fluorescence intensity indicators of vitamins (max 468 nm) and flavins (max 520 nm) most fully reflects the state of tubers during different periods of storage (Table 1).

| Varieties          | Cleaning A μ (nm) | Cleaning B (nm) | The end of treatment period A μ | The end of treatment period B (nm) | The end of deep peace A μ | The end of deep peace B (nm) | Correlation A μ-B (nm) | Correlation A μ-B (nm) |
|--------------------|-------------------|-----------------|-------------------------------|-----------------------------------|--------------------------|----------------------------|------------------------|------------------------|
| Early varieties    | 15.8              | 1.60            | 24.3                          | 1.77                              | 29.3                     | 2.06                       | 30.5                   | 1.86                   |
| Medium early       | 23.5              | 1.61            | 25.84                         | 1.75                              | 30.1                     | 1.96                       | 32.3                   | 1.79                   |
| Late varieties     | 6.8               | 1.51            | 34.3                          | 1.84                              | 39.7                     | 2.03                       | 40.3                   | 1.94                   |

Some notes: \( \lambda_0 \) is the wavelength of fluorescence excitation; \( A \) is the thickness of the periderm; \( \mu \) is the micron; \( \mu \) is the fluorescence intensity; nm – nanometer; \( K_{A,B} \) is the correlation between the thickness of periderm and spectral characteristics before the tubers emerge from deep dormancy; \( K_{A,B} \) is the correlation between periderm thickness and spectral characteristics during the entire storage period.

The analysis of changes in the shape of the fluorescence spectral bands during the healing process was carried out in young tubers devoid of peel, either partially or from the entire surface (peel of the peel), of tubers cut in half. Comparison of the intensity values of the luminescence intensity of tubers without mechanical damage showed that in undamaged tubers, the luminescence during the treatment period during ripening smoothly increases, and in mechanically damaged ones, these indicators tend to align with those of intact (whole) tubers (Table 2). Depending on the variety, the dynamics of the values of fluorescence intensity ratios B (I_{468 nm}/I_{520 nm}) have a temporary length of the treatment period, healing and entry into deep rest in 2 to 4 weeks.
Table 2. Dynamics of the fluorescence intensity ratio values during the treatment period of mechanically intact tubers and tubers with mechanical wounds (Nevskiy variety).

| Time after injury (days) | Fluorescence intensity ratio values | Control (intact tubers) | Peel skin (from the whole surface) | Sections (cut in half) |
|------------------------|------------------------------------|-------------------------|-----------------------------------|-----------------------|
|                        | $I_{468\text{ nm}}/I_{520\text{ nm}}; \lambda_B=368\text{ nm}; t=20^\circ\text{C}$ |                        |                                   |                       |
| Before injury          | 1.58                               | 1.60                    | 1.64                              |                       |
| Immediately after injury | 1.58                              | 0.86                    | 1.06                              |                       |
| 3                      | 1.60                               | 1.14                    | 1.31                              |                       |
| 6                      | 1.63                               | 1.27                    | 1.40                              |                       |
| 9                      | 1.63                               | 1.34                    | 1.46                              |                       |
| 12                     | 1.69                               | 1.41                    | 1.52                              |                       |
| 15                     | 1.73                               | 1.52                    | 1.60                              |                       |
| 18                     | 1.74                               | 1.63                    | 1.65                              |                       |
| 21                     | 1.78                               | 1.75                    | 1.72                              |                       |

Note: Nm is a nanometer; I is the fluorescence intensity; $\lambda_B$ is the fluorescence excitation wavelength.

4. Discussion

As can be seen from Table 1, during the treatment period, morphological and optical parameters changed quite quickly; due to the formation of durable peel, the activity of chemical processes takes place in the tissues.

In the phase of deep and forced rest of the studied varieties, rather stable indices of luminescence of vitamins with insignificant discrepancies are characteristic of the fluorescent characteristics of potatoes. The time corresponding to the occurrence of tubers in a state of deep dormancy is characterized by a slowdown in the increase in the luminous intensity ratio of these components, which occurs within 2-4 weeks and depends on the group of ripeness of the variety.

In the deep rest phase, the natural periderm thickening slows down. During this period, the growth of the values of this optical indicator begins to weaken noticeably, and with the beginning of the awakening of the ocelli, it completely stops. With the onset of forced dormancy, despite the fact that the periderm thickness continues to grow slowly, this indicator begins to gradually decrease, which is associated with the opening of the lentils, due to increased respiration activity and the appearance of microcracks on the aging peel, which increased the fluorescence yield of substances in the subcutaneous layer. The mechanisms of wound repair are activated, both directly at the sites of injury and in tissues remote from the site of local exposure, as a result of which the plant’s protective system responses are induced. A mobile signal that transmits wound stress information throughout the plant or its organ is involved in the induction of systemic protection. Currently, it has been established that the main components of the mobile signal are the 18-amino peptide, called systemin, as well as jasmonic acid (JA), and possibly some oxylipins, which appear during lipoygenase oxidation. It has been established that JA can be transported along the phloem to remote areas of the plant. The Plasmodesma system allows JA to reach the target cell, notifying the plant of a stressful situation and including the expression of PI genes [11], [12], [13], [14].

The established relationship between the fluorescence of potatoes and the duration of its storage makes it possible to monitor the condition in the surface tissues of tubers and to evaluate the physiological state of the latter in the post-harvest period by the shape of the spectral bands using the indicator $I_{468\text{ nm}}/I_{520\text{ nm}}$. This can be used as a component of indicators of the state of potatoes during storage.

When fluorescence of the damaged areas of tubers was excited by light with a wavelength $\lambda_B=386$ nm, the obtained spectral bands resembled undupened tubers in their form. At the same time, they had a much higher yield of fluorescence in the region $\lambda_P=490-550$ nm, than the young unripe tubers. Thus, the lower limit of the fluorescence intensity variation values with the flavin maximum $\lambda_P=520$ nm was always higher for them than the upper variation limit for non-mature tubers. It is not possible to identify
a mechanical damage with a very thin peel of undigested young tubers, which formed wound periderm (healed). Varietal features did not affect this.

In connection with the participation in the healing process of mechanically damaged tubers of various types of tissue (hypoderm, vascular bundle area, the core), the formation of various forms of wound periderm is possible.

The study of a batch of tubers with a diameter of 5-6 cm, in order to determine the magnitude of the discrepancy between the fluorescence intensity values at their registration at points \( I_{468\ nm} \) and \( I_{520\ nm} \) depending on the depth of the lesion, showed the following. Minor discrepancies are observed only in the surface layer of the tuber, depending on the basal or apical zone.

The established relationship between the values of a “peak” fluorescence intensities at wavelengths \( \lambda_p=468\ nm \) and \( \lambda_p=520\ nm \), obtained when the fluorescence is excited by light with a wavelength \( \lambda_B=386\ nm \), on the quality of the covering tissue can serve as a criterion for evaluating the healing of mechanical damage, physiological maturity of tubers and their readiness for long-term storage.

As noted, the freshly harvested and mechanically damaged potato tubers can form new covering tissues. A wound periderm is formed at the site of injury, which is impregnated with a wax-like substance, which prevents microorganisms from entering the tuber. This is how a mechanical barrier is formed. In addition to the mechanical barrier, a chemical barrier appears. In the wound area under conditions of actual harvesting of potatoes, infection of damaged tubers is possible [15], [16]. Phytoalexins are formed in response to contact with microorganisms, they are absent in healthy tissues and occur in them after being affected by disease [10], [11], [12], [17]. Phytoalexins have antibiotic properties and are able to suppress the development of microorganisms. The faster and larger quantities are formed, the more resistant this species is to pathogenic microorganisms. As it is stored, the ability of tubers to produce phytoalexins decreases, which reduces their resistance to disease.

Such research on the biochemical mechanisms of species immunity and their timely assessment should help to identify resistance of a plant as a whole.

5. Conclusion

The relationship between fluorescence \( \lambda_B=368\ nm \) of potatoes and the duration of its storage allows one to monitor the state of the surface tissues of tubers by the shape of spectral bands using \( I_{468\ nm} / I_{520\ nm} \), as well as to evaluate the physiological state of the tubers in the post-harvest period. This can be used as a component of indicators of the state of potatoes during storage.

Dependence of a “peak” fluorescence intensity ratio at the wavelengths \( \lambda_p=468\ nm \) and \( \lambda_p=520\ nm \), obtained by excitation of fluorescence with the light of a wavelength \( \lambda_B=386\ nm \), on the quality of the covering fabric can serve as a criterion for assessing the healing of mechanical damage, physiological maturity of tubers, and their readiness for long-term storage.

Further improvement of plant disease detection systems can be achieved by combining multisensory spectral and florescent methods.

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