On the possibility of using the optical method for express quality control of fruits

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Abstract. The necessity of express control of fruit quality in various situations has been substantiated. Various methods for the implementation of express control of fruit quality in express mode are considered. A method for express control of fruit quality using laser radiation has been developed. The change in the degree of spatial coherence in the recorded reflected laser radiation from defects on the surfaces of fruits was investigated. Experimental results of the study of various defects on fruits, as well as their hardness and degree of ripening, are presented using the method developed by us.

1. Introduction
At present, much attention is paid to monitoring the state of various media (water, air, etc.), as well as materials [1-9]. The greatest difficulties arise while controlling various products, especially in express mode [10-17]. Among the products, one of the most difficult areas is fruit quality control [18-24]. Since the products must have a marketable condition preference is given to non-destructive various methods, for example, using nuclear magnetic resonance [24-31] or illuminated microscopes to visualize anatomical features using microscopes [32, 33]. In some cases, acoustic or electromagnetic methods are used. All these methods are rather laborious and in most cases require a stationary laboratory. While using them for express control, a large number of problems arise or it is required to take a sample from the object under investigation (for example, a piece of skin from a fruit), which will not allow this fruit to be put up for sale in the future or stored for a long time before processing. Optical non-invasive methods based on color, spectrozonal or luminescence characteristics are ineffective [34-39] if structural changes are not accompanied by significant and unambiguous biochemical processes.

In this paper, we consider the possibility of using the correlation parameters of laser light scattering to register tissue structural rearrangements without significantly affecting the vital activity of organic compounds found in fruits or vegetables. It is extremely important that vitamin complexes in fruits are not destroyed during control.

2. Methodology for determining the quality of fruit and its practical implementation
Our studies allowed us to develop a technique for express control of fruits, based on obtaining the contrast of the interference pattern, which, when the intensities of the interfering beams are equal, is
equal to the degree of spatial coherence (DSC). Figure 1 shows a diagram of the setup for obtaining DSC in laser radiation reflected from the surface of the fruit.

![Figure 1. Installation diagram: 1 - helium-neon laser; 2 - biological object; 3 - polarization interferometer; 4 - CCD camera; 5 - PC; 6 - program for processing the results; L1, L2 - collimator lens; D1 - Fourier filter, D2 - aperture diaphragm.](image)

The radiation of a single-mode laser is directed to a collimator objective with a Fourier filter and an aperture diaphragm, after which a weakly diverging coherent Gaussian beam is incident on a biological object. The radiation scattered by it falls into a polarization interferometer, whose interference pattern is recorded by a CCD camera connected to a personal computer. The program installed on it determines the extrema of the interference fringes and calculates the DSC.

In addition, this design of the experimental setup allows, on the basis of this method, to develop a portable device that is connected to a personal computer to determine the quality of the fruits in the express control mode (at the place of storage).

3. **Results of experimental studies and its discussion**

To confirm the reliability of the methodology developed by us, various fruits with the most typical defects for them were studied. It was found that the DSC for all types of fruits (for example, apples, pears, grapes, etc.) is significantly reduced in the case of defects in them. It should be noted that the possibility of using the developed method does not depend on the biochemical state of the defect and the color of the fetus. The measurement results are presented in table 1.

| Object of study | The condition of the integumentary tissue | DSC (%)    | Defect recognition probability |
|-----------------|-----------------------------------------|------------|-------------------------------|
| Apples          | Intact                                  | 0.480±0.114| 0.99                          |
|                 | Peel off the skin                       | 0.090±0.056|                               |
|                 | Puncture                                | 0.030±0.017|                               |
| Plums           | Intact                                  | 0.510±0.041| 0.99                          |
|                 | Peel off the skin, puncture             | 0.093±0.038|                               |
| Cherry          | Intact                                  | 0.560±0.063| 0.99                          |
|                 | Crack                                   | 0.102±0.037|                               |
|                 | Intact                                  | 0.413±0.190|                               |
| Pears           | Peel off the skin, puncture             | 0.074±0.064| 0.99                          |
|                 | Peel off the skin, puncture             | 0.074±0.064|                               |
| Orange          | Intact                                  | 0.290±0.018| 0.95                          |
|                 | Dry rot                                 | 0.103±0.009|                               |
The ripeness of the fruits was also tested with this method, since the structure of the skin and pulp changes during the ripening process, which leads to a change in the DSC. Many fruits are removed unripe so it is easier to transport and store them. This process takes place during storage. For each type of fruit the data on the hardness of the pulp obtained using a penetrometer coincide with the results of the considered optical method with a correlation coefficient of at least 0.95 (see table 2).

Table 2. Results of measurements of the degree of fruit ripeness.

| Object of study | Unripe fruits | Ripe fruits |
|-----------------|---------------|-------------|
|                 | DSC (%)       | Hardness (kg/cm²) | DSC (%)(fruits with skin) | Hardness (kg/cm²) |
| Pear:           |               |               |                           |                   |
| Krasavitsa Chernenko | 16.2±1.7 | 6,8±0,4       | 3,83±1,4                  | 1,2±0,34           |
| Avgustovskaya Rosa | 13.9±0.8 | 4,6±0,4       | 3,65±0,7                  | 0,65±0,05          |
| Osennee Yakovleva | 11.8±2.2 | 4,4±0,4       | 6,30±0,7                  | 1,5±0,22           |
| Yanvarskaia       | 14.5±2.8 | 5,8±0,4       | 7,20±0,8                  | 1,2±0,35           |
| Apricot           | 12,53±0,37 | 2,9±0,17      | 7,62±0,57                 | 1,48±0,17          |

Using the proposed method, it is also possible to determine the dynamics of fruit ripening, which is useful for predicting the keeping ability of fruits or controlling the duration of storage. For this, the degree of spatial coherence of light scattering in the process of accelerated ripening was recorded using the example of pears. A sample of 20 pears with winter ripening in December was removed from storage in a refrigerator with a controlled atmosphere, kept in a room at room temperature for 24 days, and the DSC was measured every 3 days from the equatorial surface (Figure 2).

Figure 2. Changes in the DSC of light scattering of pear fruits during ripening.

Fruit hardness was measured at the beginning, in the middle and in the end of ripening (see table 3). Fruit hardness was assessed by two criteria, since DSC is more dependent on the state of the superficial, mainly epidermal layer of cells.
Table 3. Measurement of hardness and DSC of pears in the process of accelerated ripening.

| Ripening time at room temperature | Destructive method (penetrometer) | Non-destructive method (laser) |
|----------------------------------|----------------------------------|-------------------------------|
|                                  | Hardness of fruit with skin, kg/cm² | Pulp hardness (kg/cm²) | DSC (%) (fruits with skin) |
| 1 day                            | 9.45±0.26                          | 6.35±0.18                  | 12.2±1.4                   |
| 12 days                          | 4.42±0.2                            | 3.17±0.17                  | 5.7±0.7                    |
| 24 days                          | 4.08±0.16                           | 2.85±0.14                  | 3.77±0.6                   |

The correlation coefficient between the DSC and the hardness of the fruit with the skin is practically equal to the correlation coefficient between the DSC and the hardness of the pulp, which indicates a fairly close relationship between the phase parameters of light scattering and general physiological and physicomechanical changes occurring during ripening in all tissues of the fruit.

4. Conclusion
The data obtained confirm the possibility of using the method under consideration to control the quality of fruit in the express mode. The use of the DSC as an assessment of the characteristics of the state of the fruits has a sufficiently high accuracy, and the non-invasiveness and simplicity of the method make it attractive for the usage. The method allows you to assess not only the defects of fruits and the degree of their ripeness, but also to predict the dynamics of ripening.

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