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NON-DESTRUCTIVE METHOD IN DETERMINING THE BARLEY GRAIN VITREOUSITY

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Abstract

Possibilities of non-destructive express-evaluation of the barley grain vitreousity using machine vision and digital image processing methods were studied. The study was carried out with the proprietary design hardware and software complex on barley samples of three different varieties provided by the LLC "Nosters". Transmittance in the near IR wavelength range was used as the objective criterion in classifying grains as vitreous, partially vitreous and better use powdery. Classification group boundaries were determined empirically by the cross-section inspection method. The optimal filming mode was experimentally selected, and the algorithm for digital processing of grain images was developed in order to determine the number of better use powdery grains in a sample. In addition to classifying grains by vitreousity, the proposed approach also makes it possible to evaluate uniformity of a sample by this indicator and, thus, to identify a grain of higher quality. It was found out that grain orientation introduces an error of not more than 5 %, and high repeatability of the results and, as a consequence, accuracy of the algorithm are characterized by the variation coefficient of 1.1 %

Keywords

Machine vision, digital image, barley grain, vitreousity, uniformity

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Introduction. Barley is one of the most important agricultural crops occupying the fourth place in terms of sown area and the second place in terms of gross harvest in the Russian Federation after wheat. According to the Federal State Statistics Service information, the gross barley grain harvest in 2019 amounted to 20.4 million tons (wheat ~ 74, 4 million tons) [1, 2]. Barley grain is widely used in food industry in flour, cereals and compound feed production, while certain specialized varieties found application as the main raw material in the brewing industry [1].

Beer production includes many technological operations, during which complex physicochemical reactions are taking place that require a certain ratio of the initial components, including protein, starch and others; therefore, the initial raw material quality is strictly regulated [3]. Malt is produced at the first stage, i.e., the germinated grain, then it is dried at a certain technological temperature [4]. Germination time is closely connected to the grain ability to absorb moisture, as the denser grain needs more time to germinate [5]. The grain density is connected to peculiarities in its composition and internal structure [6–9]. Denser grains contain more protein, loose grains — more starch [10]. These features determine significant difference in the grain ability to permit the optical radiation through, and this feature, as is known [11–13], is used to determine the grain vitreousity.

To assess the wheat and rice grain vitreousity, methods provided in GOST* are used, while vitreousity is not determined in the brewing barley evaluation. Meanwhile, this indicator correlates with the protein content and is important in malting, especially in the first two days of grain germination. Therefore, in parallel with the protein determination, barley vitreousity is evaluated.

The main difference between a barley grain and wheat and rice grains, which analysis is calculated by the standard method using a diaphanoscope [13], lies in the dense fruit coat significantly absorbing optical radiation and strongly complicating the study of barley by this method. The existing method of cutting grains is time-consuming and, therefore, is not suitable for express-evaluation. It is proposed to solve this problem to use the vitreousity evaluation method by the grain digital images obtained in the near IR range [13–15].

It should be noted that methods used to evaluate vitreousity could not be applied determining uniformity [16] of a barley sample by this indicator. It characterizes only the range of alterations in grain vitreousity within a sample.

Objective of this work is to study possibility of applying methodology developed by the authors in evaluating the wheat grain vitreousity compared to the barley grain and selecting optimal filming parameters to obtain information on the grain vitreousity.

Scientific novelty of the conducted research consists in the proposed method for non-destructive objective evaluation of the barley grain vitreousity based on the digital image analysis, as well as in the method of grain sample uniformity evaluation by the vitreousity indicator.

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* GOST 10987–76. Grain. Methods for vitreousity determination.

Materials and methods used to solve the problems, accepted assumptions. Samples of three different varieties of barley were used in experimental studies, which were provided by LLC “Nosters”. Grain samples were taken in accordance with GOST*.

A hardware and software complex developed by the authors was used for experimental studies [15] (Fig. 1). The complex consists of upper and lower sources radiating in the visible and infrared ranges, scattering plate, special cassette with 100 cells for placing grain samples and television camera with a lens transmitting digital images of grains to the personal computer for consequent processing.

Fig. 1. Hardware and software complex:
1 is upper radiation source; *2* is camera with lens; *3* is cassette for placing grain samples; *4* is light scattering plate; *5* is lower radiation source

To ensure objectivity of the analysis results, colorimetric, photometric and metric calibrations are performed before measurements are taken. This approach makes it possible to ensure compliance of measurements with the standards of the State System for Ensuring Uniformity of Measurements.

Measurements were taken as follows. The analyzed grains were placed in a special cassette with 100 cells with the same orientation (Fig. 2). This cassette with samples was put into the analysis zone, and the grains were filmed in the transmission mode using the lower radiation source.

The resulting images were processed by an algorithm implemented in the MATLAB environment. The algorithm in the grain image digital processing

* GOST 13586.3–2015. Grain. Rules of acceptance and methods of sample selection.

Fig. 2. Test samples arrangement in the cassette

consisted of two blocks, including digital image segmentation and general vitreousity calculation.

Images were preprocessed in the segmentation block, which consisted in eliminating noise and radiation irregularities in the analysis zone and in increasing the contrast, followed by binarization. The resulting black and white image was segmented [17, 18]. As a result of this procedure, image areas corresponding to caryopses (single grains) were determined.

At the second stage, general vitreousity of the sample was calculated. Vitreousity analysis involves dividing grains into three groups: vitreous, partially vitreous and better use powdery. For this, transmittance of each caryopsis is calculated, and the obtained values are compared with the threshold values for each of the three groups determined empirically using the cross-section inspection method [11, 12].

Transmittance was calculated using the areas obtained by the grain digital image segmentation. Transmittance of each caryopsis in each obtained area of the original image converted into grayscale was calculated by the following formula:

$$V_i = \frac{\sum_{n=1}^{N} \mathrm{Int}_n}{N}, \qquad (1)$$

where V_i is the vitreousity index of the i-th object; Int_n is the pixel value of an image belonging to the object; N is the number of pixels in the digital image belonging to this caryopsis.

To divide grains into groups according to their vitreousity, the following threshold values of transmittance were empirically established. If $V_i > 62$, the object was assigned to the vitreous grain category; if V_i < 52, the object was considered better use powdery; if the vitreousity index was in the range of 52 ≤ V_i ≤ 62, the grains were classified as partially vitreous.

After separating all caryopses into three groups, grain sample general vitreousity calculated using the formula (2) [10] from GOST*:

$$O = F + P / 2, \quad (2)$$

where O is the sample general vitreousity; F is the number of vitreous grains; P is the number of samples, each caryopsis transmittance was calculated; and the obtained values were registered in a special file for further processing. Besides, results were partially vitreous grains.

Then, on the basis of the caryopses calculated transmittance coefficients, for each type of barley grain a distribution histogram was constructed characterizing the sample uniformity in terms of the vitreousity quality indicator.

At the third stage, a number of series of 10 measurements, five in each orientation, i.e., groove up and groove down, were performed to assess the effect of grain orientation on the result of the algorithm for calculating the total general vitreousity. For any of the two orientations, average value of each caryopsis transmittance was calculated. After that, it was assigned to one of the three groups according to vitreousity. Repeatability of results was evaluated using the variation coefficient.

Results. Barley grain is characterized by dense fruit shells; therefore, in order to obtain adequate results in evaluating its vitreousity, it is necessary either to increase the radiation source power or the exposure time, thereby expanding the dynamic range. The second method is used in this work. Exposure time was increased by 3 times in comparison with time used in analyzing the wheat grains [12].

To determine the vitreousity transmittance threshold values, experimental studies were carried out on the barley grain experimental samples of three different varieties. Two samples containing 100 grains of each grade were selected, it was a total of 600 grains. After filming the visualized on the monitor screen (Fig. 3).

Results of evaluating vitreousity of three barley samples are presented in Table 1.

As follows from the data in Table 1, the third variety has the lowest total vitreousity in unnecessarg among the presented barley varieties.

* GOST 10987–76. Grain. Methods for vitreousity determination.

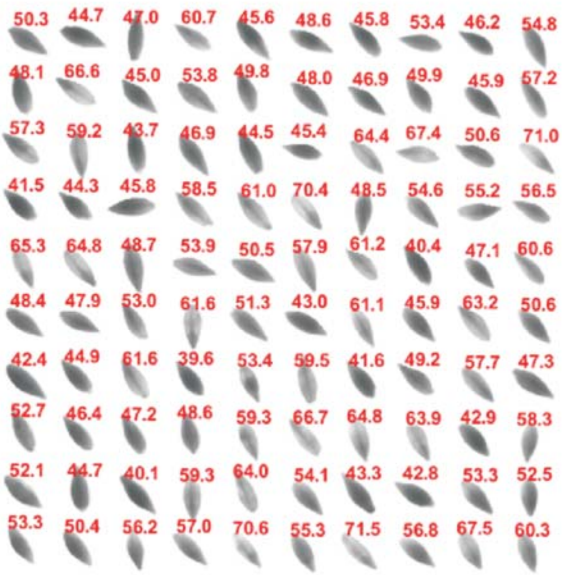

Fig. 3. Obtained results visualization

The general vitreousity indicator is useful, when it is necessary to provide a general characteristic of the grain sample. However, more information is required to evaluate the sample uniformness under this indicator. Grain distribution histograms in terms of transmittance were built for each sample of barley sample presented for this purpose (Fig. 4).

Table 1

General vitreousity evaluation results

Variety	Number of vitreous grains, pieces	Number of partially vitreous rains, pieces	General vitreousity, %
First	15	38	34
Second	15	36	33
Third	4	20	14

Histograms in Fig. 4 analysis demonstrates that most of the third variety grains (78 %) are within the 0.36–0.52 range adopted as the reference for better use powdery grains, in contrast to the first (51.5 %) and to the second (46.5 %) varieties, which gives grounds to assert that the third variety barley grain is more uniform in terms of transmittance.

Results obtained in evaluating the effect of grain orientation on the result of the general vitreousity calculation algorithm introduction are presented in Table 2.

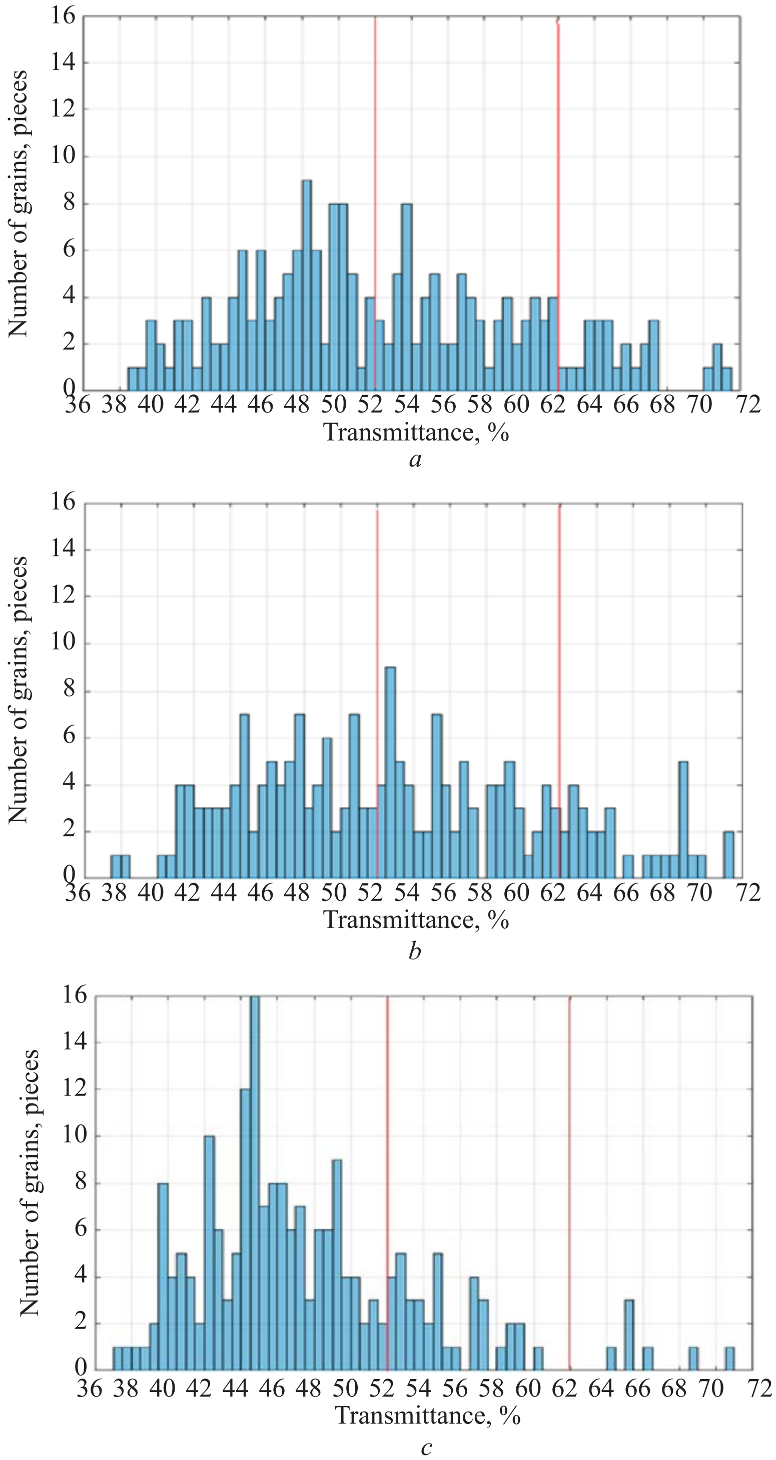

Fig. 4. Histogram of barley grain distribution according to the first, second and third varieties (*a, b, c*) by transmittance

Table 2

Barley sample vitreousity analysis in various orientations

Number of grains, pieces	Grain orientation	
	Crease up	Crease down
Vitreous	18	22
Partially vitreous	24	24
Farinaceous	58	54

Variation coefficient was 4.6 %. Thus, it is important in measurements to keep in mind that this factor could result in discrepancy in the measurement results within the 5 % range.

In order to evaluate the algorithm operation adequacy in determining the barley vitreousity based on the digital image analysis, result repeatability was evaluated by 10 repeated measurements of a single barley sample and calculating the variation coefficient. Results obtained are reflected in Table 3.

Table 3

Evaluation of result repeatability

Measurement number	Vitreous grains, number	Partially vitreous grains, number	Farinaceous grains, number
1	13	13	75
2	12	13	75
3	12	13	75
4	11	14	75
5	12	13	75
6	13	13	74
7	12	14	74
8	12	13	75
9	12	13	75
10	14	12	74

The variation coefficient value was 1.1 % indicating the result high repeatability.

Conclusion. Results of experimental studies confirmed efficiency of the method for determining the barley grain vitreousity by machine vision and digital image processing techniques. Optimal filming mode was selected and algorithm for processing the barley grain images was elaborated in order to classify them by vitreousity. The proposed approach makes it possible to evaluate the grain sample uniformity according to this indicator, which is important in solving the malting problems.

When assessing the sample orientation influence on the algorithm operation result in calculating the general vitreousity, variation coefficient was 4.6 %.

Result repeatability in the algorithm operation was evaluated. Variation coefficient was only 1.1 %, which confirmed high repeatability of the results.

The proposed approach could be introduced to evaluate the barley grain quality in trade operations, as well as within the incoming quality control at the food industry malting factories. Unlike the standard cutting method in accordance with GOST[*], our approach ensures high evaluation performance, is more informative and does not suffer from any disadvantage associated with the human factor.

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