Assessment of the Potential of Digital Technologies in the Implementation of Deep Cycles of Grain Products Processing

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Abstract. Improving the technological component of agro-industrial production through the introduction of digital technologies accelerates the pace of economic growth and contributes to ensuring food security. The adaptation for agriculture of digital technologies already used in various industries is particularly relevant, and their integrated use is more effective. Artificial intelligence systems and, in particular, computer vision have significant prospects for implementation in the production and processing of agricultural products. Computer vision and image processing procedures can be used to control product quality and processing cycles in order to improve the efficiency of production processes. In each processing cycle, it is necessary to control the technological parameters and the quality of the processed raw materials, the results of which affect the duration, the number of operations and the conditions of the processing process. The use of the developed luminescent method to control the moisture content and particle size makes it possible to increase the efficiency of technological processes for processing grain products. The development of an innovative complex for deep processing of grain, as an example of application of new production technologies, is a promising current direction in the development of agricultural production. Increasing production efficiency is based on a significant expansion of the range of finished products, on an increase in the added value of processed products and on a slight decrease in capital costs due to the combination of processes. The increase in the potential for using various end-to-end digital technologies in agro-industrial production is facilitated through their combination and integration into complex systems for digitalization of production, which ensure the development of the agro-industrial complex.

1. Introduction
The integration of digital technologies into all production cycles is an urgent task for modern agriculture and the industry that processes agro-industrial products, and the relevance of this trend will increase \cite{1}. The result will be the creation of an integrated information-driven producing and agricultural processing system that ensures the integration of high-tech solutions in order to increase efficiency and the profitability of agricultural production \cite{2}.

The world experience of introducing new production technologies in the sphere of the agro-industrial complex shows the prospects for the development of technologies for deep processing of grain in order to obtain economic benefits by expanding the range of products with high added value \cite{3}. It will also provide additional jobs and contribute to the development of rural areas.
One of the most promising areas of application of artificial intelligence in the agro-industrial complex is computer vision, implemented on the basis of artificial neural networks. \cite{4,5} The use of CNN (convolutional neural network) methodology for recognizing images obtained in different spectral ranges provides ample opportunities for implementation in the most diverse areas of agriculture.

The computer vision system is used for phenotyping (predicting plants physical traits by analyzing DNA) with a high throughput, and includes the following complex: software for image capture; an image processing program for extracting objects; web application for presenting results \cite{6}. High-throughput image-based phenotyping techniques, including visible light imaging, fluorescence imaging, thermal imaging, spectral imaging, stereo imaging, and tomographic imaging, are promising for implementation \cite{7-12}. Optical sorters have been developed in order to recognize mold-damaged wheat; when using analytical spectrometers, the sorting efficiency reaches 95%.

The potential for the use of various end-to-end digital technologies in agro-industrial production is very different, and therefore solutions for the digitalization of agricultural production are based on a combination of digital technologies.

2. Materials and methods
The need for accounting and control of various product characteristics is determined by the requirements for the production process. When storing and processing agricultural food products, it is imperative to control such quality indicators as moisture and particle size.

The results of the control determine the duration of the processing cycle and the amount of additional production operations required.

The control of moisture content and particle size should be carried out at a certain frequency at all stages of the production process. At present, a number of methods are used to determine the product quality indicators, and it is especially promising to use optical methods that are characterized by high speed, accuracy, and simple preparation of samples.

In this work, we used the luminescent method for monitoring the moisture content and grinding quality of products obtained through grain processing \cite{13}. The main advantages of the developed technique are simplicity of carrying out and the possibility of conducting analysis without preliminary preparation of samples, high efficiency and expressiveness. The use of the synthesis of technologies, including artificial intelligence, sensor systems, systems for processing large data arrays, allows to reduce financial and time costs for control activities, to increase the overall productivity of grain processing industry.

3. Results and discussion
Any grain cultures can be used as raw materials for deep processing. The use of deep processing technology provides for the separation of grain into constituent fractions: the extraction of starches, gluten, vegetable gelatin, from which a wide range of products can be obtained \cite{14}. The industrial methodology is based on multistage technology \cite{15-17}. At the first stage, grain is crushed in order to obtain flour and bran. At the next stages, various fractions are extracted from the flour, which go through the stages of extraction and purification. At the end of the technological process, soluble substances are processed (Figure 1). This technology allows regulating the amount of products obtained at different stages, which meets the needs of the market and increases the economic efficiency of production.

The finished products of the technological cycle will be goods with high added value: native and modified starches, starch syrup, glucose-fructose syrups, glucose, gluten, edible alcohol and biofuel, biogas, feed additives and others.

Starch is further processed in order to obtain glucose, from which organic acids are synthesized, such as citric, succinic and lactic, which, in their turn, will be raw materials for the food industry (amino acids, vitamins, enzymes) or for the production of biopolymers.
Figure 1. Integrated technology of deep grain processing.

The most effective are the complexes that combine from two to four additional technological lines, capable of producing an expanded range of products with partial use of similar technological processes and of the same equipment.

Assessment of the development potential of deep grain processing complexes shows their high efficiency, since in the future they will take on about 8-10% of the total harvest. For large, medium and small grain processing companies, the problem of grain marketing is being solved, which makes the introduction of deep grain processing systems urgent [18,19].

Digital technologies used in agricultural production represent, as a rule, a synthesis of technologies, including artificial intelligence, sensor systems, and systems for processing large data arrays. Thus, at the stage of grain cultures storage, it is proposed to use intelligent decision support systems based on sensors for controlling the moisture content [20], the degree of contamination and seed desease. At the processing stage, it is proposed to use intelligent decision support systems based on moisture and particle size control sensors, as a result of which the product is either sent for further processing or returned to the previous stage of the production cycle.

The technology of express diagnostics of moisture content with the excitation of photoluminescence in the range of about 370-430 nm and its registration in the range of 450-650 nm can be recommended both for cereal seeds (wheat, rye, triticale, barley, oats) and for many other cultures. The structural diagram of the subtechnology for express diagnostics of seed moisture content is shown in Figure 2.

Figure 2. Structural diagram of the process of express diagnostics of seed moisture content.
1. In the process of sample preparation, the studied seeds are placed in a dark, light-proof chamber in one or one and a half layers and are aligned horizontally. It is possible to place light-proof chamber above the leveled seed bed (leveled pile) with the inlet downward. Another option is to integrate the technological process for determining moisture content in other existing technological processes of grain processing.

2. In parallel with this stage, the type of seeds (crop, variety) is identified and other parameters of seeds can be measured, such as size, contamination that are necessary for establishing an appropriate diagnostic algorithm.

3. The photoluminescence of seeds is excited by radiation of a narrow spectral range with a maximum of $\lambda = 424$ nm for 20 $\mu$s.

4. A signal proportional to the photoluminescence flux $\Phi$ in the spectral range of 450-650 nm is recorded. The process takes 2-3 seconds with the result averaging.

5. The obtained photo signal (photovoltage $U$, photocurrent $I$), proportional to the flux $\Phi$, is amplified by an amplifier.

6. The amplified photo signal enters the microprocessor, where it is processed taking into account the a priori information available in its memory which is a linear characteristic of the dependence of moisture on the flow $W$ ($\Phi$), selected according to the diagnostic algorithm for a particular grain culture.

7. Based on the results of moisture determination, a decision is made on further actions with the seeds: processing, storage or additional drying in case of high moisture content with repeated express control.

The measurements are repeated several times with the averaging of the results obtained. When integrated into other technological processes, continuous (in-line) moisture control is possible.

In the process of storage, drying and processing of the obtained grain (Figure 3), it is proposed to use sensors for controlling moisture, contamination and size. If necessary, the grain is sent for additional cleaning, followed by repeated control of the degree of contamination, and, if necessary, of the degree of the moisture content.

![Figure 3](image_url) Technological cycle of grain cultures production.

The following directions of using end-to-end digital technologies in the technological cycle shown in Figure 3:

- when storing grain on the basis of the BSS, the collection and processing of information about the state of the microclimate in warehouses (control of humidity, temperature, air velocity, etc.) can be organized with the subsequent transfer of data to the analytical center;
- when sowing and harvesting, it is reasonable to use robotics and BSS components to automate these technological processes and to control the use of equipment;
  – for maturation control, the use of UAVs (unmanned aerial vehicles), as an element of robotics, in order to control the germination and state of crops, to monitor pests and weeds;
  – in the management support of the technological cycle under consideration, it is advisable to use a distributed register to control and optimize the administration of this process.

The presented list of directions allows you to see only the main applications of end-to-end digital technologies in the cycle of production and processing of grain cultures. In turn, the technological processes under consideration assume their orientation of digital technologies, taking into account their specificity.
4. Conclusion
The study of the possibilities of increasing the efficiency of agro-industrial processes revealed several directions for improving production based on the complex application of digital technologies, including the use of artificial intelligence (computer vision, optical technologies), new production technologies, implemented by the introduction of cycles of grain products complete processing. The potential for using the above end-to-end digital technologies in the technological cycle of agricultural crops processing is as follows:

1. Saving seed material by optimizing its quality through a more express and selective determination of its main parameters: germination, contamination, disease, etc.
2. Minimization of fuel consumption during harvesting by optimizing the work schedule of agricultural machinery based on the results of remote field survey during seed ripening.
3. Optimization of energy consumption during grain drying and processing due to continuous express control of moisture content.
4. Improving the efficiency of grain processing by combining processes and developing products with high added value
5. Reducing the cost of managing technological processes for the production and processing of grain cultures by using express remote selective technologies and optimization algorithms to support decision-making.

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