Practical Applicability of Radiation Technologies in Food Systems

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Abstract. While achieving the food security, the use of radiation technologies for the processing of food wheat grains is distinguished by its practical significance. The use of inactivating (1-5 kGy) and sterilizing (25 kGy) doses of gamma radiation shall ensure the biosafety of radiation-treated grain. Changes in the main signs of freshness (color, odor) after treatment with different doses of ionizing radiation and during storage for up to 30 days have not been established. Varietal (species) grain purity of "Ekaterina" soft spring wheat is 99.7%, its grain purity is 99.93%. As a result of the research, a decrease in grain moisture content by 0.02-0.83% has been found compared to non-irradiated wheat grain at the stage of setting up for the experiment, after 15 days of storage – by 0.15-1.02%, and after 30 days of storage – by 0.44-1.40%, respectively; there is a significant decrease in the grain microflora established by the quantitative parameters of QMAFAnM and fungal microbiota, which makes it possible to establish the positive effect of using gamma radiation to improve the storage capacity of food grains in food systems. Research work needs to be continued in matters of nutritional value assessment.

1 Introduction

The global trends in the agricultural industry integrated development, which includes the production and processing of agricultural raw materials, the food industry, and the consumer market, the so-called "food system", form a conceptual approach to achieving an equilibrium position in ensuring food security and a utilitarian approach to achieving the goals of SDGs 12 in order to ensure transition to rational models of consumption and production. Under these conditions, the growing need for the production of safe food products, on the one hand, and the conservation of valuable food resources, on the other hand, shall be determined by the need to introduce innovative production technologies for the processing and storage of agricultural raw materials.

2 Problem statement

The issues of grain conservation in order to achieve the set threshold level of self-sufficiency in domestic grain up to 95% and seeds up to 75% under the Food Security

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Doctrine shall determine the focus on preserving a strategically important resource at all stages of the food chain, from growing, harvesting, and processing grain crops, the loss of which, as noted [1], according to the FAO, is up to 1/3 in quantitative terms and, according to the Russian Food Portal – up to 25% of wheat from the total volume of world production. In 2021, grain losses in Russia, only at the stage of processing by manufacturers of grain processing products, have amounted to more than 3.8%, which requires a constructive change in the production process, starting from the stage of acceptance and preparation of grain for processing.

Currently, one of the effective technologies is radiation technology. In the research literature, the following terms are used as synonyms: treatment with ionizing radiation, gamma radiation, treatment with a stream of accelerated electrons. Unlike traditional technologies (cooling, freezing, drying, etc.), treatment with ionizing radiation is possible only in the specialized centers, including those opened in Russia (Tecleor, Axenter, Era RCIT (Regional Center for Irradiation Technologies)), the so-called irradiator operators, in accordance with the requirements of regulatory guidance and self-organization of the technological system when controlling the irradiation process using gamma radiation (γ radiation) with ^{60}Co and ^{137}Cs radionuclides, as well as generators of electron beams and X-rays [2].

After harvesting, some pests of grain crops, the most common of which include the grain weevil, lesser grain borer, and saw-toothgrain beetle, can enter granaries along with grain [3]. The introduction of ionizing radiation technology will ensure compliance with phytosanitary standards and protection against the “potato” disease common in Russia, the causative agents of which are potato bacillus and hay bacillus (Bacillus subtilis и Bacillus mesentericus respectively) [4].

Radiation treatment shall provide a high degree of sterility and microbiological purity of agricultural raw materials [5] based on the applied doses of radiation and the type of radiation used. The recommended dose of radiation for the treatment of grain infected with pests is 200 Gy [6]. The advantages of grain treatment with ionizing radiation also include the absence of pesticide residues, in particular fumigants, in grain crops, while reducing raw material and commodity losses from microorganisms and insects can be achieved up to 25-40%. Even small doses of radiation have an irreversible effect on pests: the sterilization of pest individuals will be followed by a reduction in the population in the territories. If the impact is repeated over several years, the elimination of the pest species in the region is highly likely. According to [7], when using ionizing radiation for pest control, it was found that the temperature and relative humidity of the air play an important role in the susceptibility of the small grain beetle to gamma irradiation. The lowest doses of gamma radiation required to eradicate 25% (14.2 Gy) and 50% (610.8 Gy) of the beetle population have been recorded at 21°C and 85% relative humidity; with a decrease in humidity to 50% 99% reduction in populations shall be achieved.

Grain is a favorable substrate for the development of microorganisms, the most dangerous of which, in accordance with phytosanitary requirements and from a technological point of view, are microscopic (mold) fungi. When growing, grain is affected mainly by the so-called “field” fungi (Altemaria, Cladosporium, Helmintosporium, Fusarium, etc.). During storage, the species composition of mycoflora changes with the appearance of storage fungi or mold (Aspergillus spp., Penicillium spp.). When treated with gamma radiation and a stream of accelerated electrons (the absorbed dose is 725 Gy and 700 Gy, respectively), QMAFAnM shall decrease to 87-88% after treatment with gamma radiation and to 93-97% when treated with accelerated electrons [8].

According to [9], a decrease in the number of fungi in infected wheat shall occur at doses from 1 kGy to 25 kGy of ^{60}Co gamma radiation. At the same time, at a dose of 25 kGy, complete decomposition of ZEA (zearalenone), a product of the activity of the

fungus Fusarium roseum, shall occur. While grain quality does not change, as it usually occurs when treated with fumigants or fertilizers.

This promising technology can be considered as one of the available alternatives to microbiological and mycotoxin decontamination of grain crops and products based on them [10-12].

Wheat grain is the most important raw material resource of plant origin for various sectors of the food industry: flour milling, cereal and pasta production; brewing, alcohol, and bakery industries. Accordingly, the quality of the finished product shall depend on the quality of the raw materials and the applied processing and preservation technologies. Based on the foregoing, **the goal** of the study is to assess the biological safety of wheat grain as a result of its treatment with different doses of gamma radiation.

3 Materials and methods

One of the effective ways to decontaminate food grain, which is further processed into flour or cereals, according to TR CU 015/2011 *On the Safety of Grain* and the Instructions for Pest Control of Grain Stocks, is the radiation effect on grain in order to eradicate pests (lesser grain borer, grain moth, grain weevil, etc.) and microorganisms for ensuring grain safety. The processing of grains of "Ekaterina" soft spring wheat has been carried out at the Era RCIT, using the RTU-3000 unit. Sources of gamma radiation were Co^{60}, GIK-A6 type, and M60K60. The current total activity of the sources was 270 kCi. The grain has been placed in boxes and, as a result of the movement of the PTK-80/150 type conveyor, it came from the loading area of the technological hall into the irradiation chamber with the product passing along the sides of the irradiator planes. Treatment has been carried out with radiation doses of 0.2 kGy, 1 kGy, 5 kGy, and 25 kGy. The control process has been held using an automated control system (ACS).

Assessment of the pest control effectiveness has been carried out after 15 days and 30 days of storage, in accordance with the requirements of GOST 9353-2016 *Wheat. Specifications* and the Instructions for Pest Control of Grain Stocks, which is due to control over changes in the number of pests (if any) and the period of death of pests after pest control and the necessary examination periods at temperatures below +5°C – after 15 days and above +5°C – after 30 days. Determination of odor, color, and discoloration has been held, according to GOST 10967-2019, seed purity – according to GOST 12037-81, weed and grain impurities – according to GOST 30483-1997, pest infestation – according to GOST 13586.6-1993 by sifting average samples. The sampling of microorganisms from the surface of wheat grain has been carried out by washing with distilled water, inoculation on a nutrient medium in the Petri dish, and the subsequent counting of colonies after 48 hours at a temperature of 28±2°C. At the same time, according to the requirements of TR CU 015/2011, microbiological indicators shall not be regulated. All observations and analyzes have been carried out, according to generally accepted methods. Statistical processing has been conducted, using the packages of applied statistical programs Statistica.

4 Results and discussion

When assessing the quality of commercial/food grain treated with different doses of ionizing radiation and used for food purposes, signs of freshness (color, odor) shall be established and grain moisture content, grain infestation with pests, and its contamination shall be determined. For the subsequent study of the content of mycotoxins, an important indicator shall be the microbiological contamination. The odor of wheat samples before and

after treatment with ionizing radiation for up to 15 days and 30 days of storage was characteristic of healthy wheat grain, without moldy, malty, musty, and foreign odors. When laying the grain for storage, both after 15 days and after 30 days of storage, the color of the grain in all groups was light yellow, characteristic of the grain variety and no change in the color of the grain treated with different doses of radiation has been observed. Varietal (species) purity is 99.7%; grain purity is 99.93% – within the established standards, in accordance with the requirements of GOST 9353-2016. No smut formations and clavus, seeds of weeds, including wild oat, have been found. After treatment with ionizing radiation, there was a decrease in grain moisture by 0.02-0.83% compared with control samples, after 15 days of storage – by 0.15-1.02%, and after 30 days of storage – by 0.44-1.40%, respectively, with an increase in the quantitative indicators of the dose load up to 25 kGy (Table 1).

Table 1. Study of indicators of contamination of marketable grain with pests and microbiological indicators during storage.

Indicators	**Control**	**Experimental samples treated with different doses of ionizing radiation, kGy**			
		0,2	1,0	5	25
After 0 days of storage					
Grain moisture, %	12,20±0,01	12,18±0,01	12,17±0,01	12,05±0,02	11,37±0,01
Infection with pests, specimen/kg	not detected	not detected	not detected	not detected	not detected
QMAFAnM, CFU/g	$1{,}1\cdot10^3$	$0{,}9\cdot10^3$	$0{,}5\cdot10^3$	$0{,}1\cdot10^3$	$0{,}4\cdot10^2$
Fungal microbiota, CFU/g	$3{,}4\cdot10^3$	$3{,}1\cdot10^3$	$2{,}5\cdot10^3$	$1{,}7\cdot10^3$	$1{,}6\cdot10^2$
After 15 days of storage					
Grain moisture, %	12,42±0,02	12,27±0,01	12,21±0,01	12,09±0,01	11,40±0,01
Infection with pests, specimen/kg	not detected	not detected	not detected	not detected	not detected
QMAFAnM, CFU/g	$2{,}2\cdot10^3$	$1{,}3\cdot10^3$	$0{,}7\cdot10^3$	$0{,}2\cdot10^3$	$0{,}5\cdot10^2$
Fungal microbiota, CFU/g	$5{,}4\cdot10^3$	$3{,}8\cdot10^3$	$3{,}1\cdot10^3$	$1{,}8\cdot10^3$	$1{,}7\cdot10^2$
After 30 days of storage					
Grain moisture, %	12,81±0,03	12,37±0,02	12,26±0,01	12,10±0,02	11,41±0,01
Infection with pests, specimen/kg	not detected	not detected	not detected	not detected	not detected
QMAFAnM, CFU/g	$2{,}3\cdot10^4$	$5{,}2\cdot10^3$	$2{,}8\cdot10^3$	$1{,}2\cdot10^3$	$0{,}9\cdot10^2$
Fungal microbiota, CFU/g	$3{,}2\cdot10^4$	$7{,}3\cdot10^3$	$5{,}8\cdot10^3$	$3{,}0\cdot10^3$	$2{,}3\cdot10^2$

With an increase in the radiation dose to 25 kGy, a decrease in QMAFAnM by 27.5 times and fungal microbiota – by 21.3 times has been found compared to non-

irradiated grain due to the sterilizing effect of radiation, which is consistent with the technologically recommended limits of the maximum absorbed doses for reducing the number of microorganisms – 5 kGy set for grain by the International Consultative Group on Food Irradiation, according to [13]. During storage, an increase in the gap in quantitative indicators has been found after 15 days, too – it was 44.0 and 31.8 times, respectively, which may be due to the continuing effect of sterilization. Similar results have been obtained after 30 days of storage.

Treatment with ionizing radiation makes it possible to ensure the effectiveness of radiation treatment after 15 days of storage and safe performance, in accordance with the requirements of TR CU 015/2011 and TR CU 021/2011. Experiments have shown that with an increase in the radiation dose from 0.2 kGy to 25 kGy, a decrease in grain moisture and the content of microorganisms shall occur as a result of an increase in the effect of stimulation during storage up to 30 days after irradiation of wheat grain and the use of inactivating (1 kGy and 5 kGy) and sterilizing (25 kGy) doses of gamma radiation.

5 Conclusions

The results are distinguished by their practical applicability for ensuring the grain safety of "Ekaterina" soft spring wheat and increasing its storage capacity. Further research is required in this direction.

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