Assessment of the efficiency of application of ionising radiation for grain disinfestation

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Abstract. The paper considers the results on the efficiency of application of ionising radiation for grain disinfestation. It is shown that gamma-irradiation of confused flour beetle (imago stage) inhabiting on the barley grain, in a dose range 0.7–1.0 kGy caused the 100% mortality of the pest in 15 days after irradiation at a dose rate 0.5 kGy/h. The similar occurred at doses 0.15–0.6 kGy and dose rate 1.8 kGy, and at the dose rate 0.1 kGy/h the total pest mortality occurred in 30 days after the irradiation. The use of the bremsstrahlung and electron radiation for treatment of barley contaminated with confused flour beetle allowed to establish that the mortality of 100% of the insect-pests occurs in 15 days after irradiation at all studied doses and dose rates in case of both radiation types, with exception of the dose 0.25 kGy (bremsstrahlung radiation), when the organisms perish in 30 days after irradiation. The use of gamma-irradiation for radiation disinfestation of grain affects its quality, which depends both on the radiation dose and the dose rate. It was found that the gamma-irradiation caused the increase of the ash content in the grain by 4–6% at doses 0.2–0.6 kGy (dose rate 0.1 kGy/h) and by 9–19.9% at doses 0.75–1.0 kGy (dose rate 1.8 kGy/h). The application of the bremsstrahlung and electron radiation within the investigated dose range had no significant effect on the quality of barley grain of Nur variety. The results obtained on the assessment of the sensitivity of insect-pests (Tribolium confusum Duv.) to the effects of different ionising radiation types indicate the prospects of the use of ionising radiation for grain disinfestation.

1. Introduction
Insect-pests of grain and grain products are widespread everywhere and cause great harm to agricultural products during storage. They cause not only large losses of grain but also its damage, reduce baking qualities of flour and feeding value of grain fodder and compound feeds.

To ensure secure disinfestation of seeds in Russia they usually use chemicals, particularly contact insecticides. Application of chemical agents (fumigation) is not always effective against the internal contamination of products, and its mass application leads to the emergence of pest forms resistant to the used chemicals agents [1].

In addition, in the process of fumigation, the harmful effects of chemicals agents on the personnel performing treatment are not excluded, and there is practically no possibility of full desorption of the fumigant from the product.

Therefore, during last years the efforts of many scientists and specialists are aimed at finding the new methods of grain decontamination without using pesticides. One of such methods is radiation disinfestation. Use of the gamma-radiation for insect-pests’ sterilisation, turned out to be a technically feasible alternative to conventional methods of the pest control in the stored products [2, 3].
Radiation disinfestation of agricultural products in comparison with existing chemical methods has undoubted advantages: environmental pollution is excluded; no pesticides residues in irradiated products [4–6].

Use of radiation treatment is the most promising for the destruction of insect-pests in grain crops. Economic assessments showed that even at a relatively low plant capacity, radiation disinfestation provides greater economic efficiency compared to chemical methods.

The necessary doses for life suppression or control of different pests depend on many factors, and, first of all, on the type of pest and its development stage [7–9].

This work aims to study the efficiency of various doses and types of radiation including gamma, electron and bremsstrahlung, on the viability of the grain pest, confused flour beetle (*Tribolium confusum* Duv.).

2. Materials and methods
A subject of study was insect-pest, confused flour beetle (*Tribolium confusum* Duv.) from the Tenebrionidae family and spring barley (*Hordeum vulgare* L.) of Nur and Vladimir varieties. Grain, contaminated with pests, was irradiated:

(a) on the facility GUR-120 (γ-radiation) in the dose range of 0.2–1.0 Gy at dose rates of 0.1, 0.5 and 1.8 kGy/h;

(b) in the bremsstrahlung mode of impulse electron accelerator (bremsstrahlung radiation) in the dose range of 0.25–1.0 kGy at the dose rate 1 Gy/s;

(c) on the electron accelerator (electron radiation) in the dose range 0.5–1.0 kGy (dose rate 1Gy/s).

Modern clinical dosimeter DKS-101 was used to measure absorbed doses in air and objects material. The universal dosimeter DKS-101 is intended for the measurement of absorbed dose and dose equivalent and absorbed dose rate and dose equivalent rate for a wide energy range of photon and electron radiation.

The grain contamination by insect-pests was identified according to GOST 13586.4-83 existing in Russia [10].

The grain quality after treatment (the content of ash, proteins, fat, cellulose, dry matter, nitrogen-free extractive fractions (NFEF)) was determined by the method of diffuse reflective spectroscopy in the near infra-red region of the spectrum on the «Infrapid-61» infra-red analyser. During the analysis, the sample of the refined product was placed in a cuvet with a transparent window and illuminated by radiation with wavelengths lying in the near infra-red region of the spectrum. The analysis time was 2 minutes. It included the readout of the spectrum of the reference standard built into the device, the readout of the spectrum of the analysed sample and processing of the data obtained using an external computer built into the device [11, 12].

The experimental results were processed using Microsoft Excel 2003 software.

3. Results and discussions
Radiation dose is one of the leading factors determining the viability of insects at irradiation process. The inhibiting effect of ionising radiation on the functional activity of the organism is directly dependent on the irradiation dose. The value of absolute lethal dose (LD100) depends on the insect species and development stage and varies in a wide range [8, 13–15].

Barley grain of Nur variety contaminated with imagos of confused flour beetle was irradiated in a dose range 0.7–1.0 kGy at a dose rate 0.1 kGy/h on the facility GUR-120. The verification of grain contamination in 15 days after irradiation showed that the number of living flour beetle was rather high. The average contamination density was 20–40 organisms per kg (table 1).

During the recording of barley contamination 30 days after the treatment, it was found that flour beetles were completely dead at all studied irradiation doses.
Table 1. Influence of gamma-irradiation on barley grain contamination with *Tribolium confusum* (dose rate 0.1 kGy/h).

| Irradiation dose (kGy) | Average contamination density of grain after treatment (organisms per kg) | in 15 days | in 30 days |
|------------------------|-------------------------------------------------------------------------------|------------|------------|
| 0 (K)                  | 20                                                                           | 20         |            |
| 0.70                   | 40                                                                           | 0          |            |
| 0.80                   | 40                                                                           | 0          |            |
| 0.90                   | 20                                                                           | 0          |            |
| 1.00                   | 20                                                                           | 0          |            |

Irradiation of barley grain in the same dose range (0.7–1.0 kGy) but at a higher dose rate 0.5 kg/h, was lethal for imago stage of flour beetles even in 15 days after irradiation. This is the evidence of the significance of the dose rate for effect, i.e. dose rate increase leads to a reduction of radiation dose for mortality of 100% of insects (table 2).

Table 2. Influence of gamma-irradiation on contamination of barley grain with *Tribolium confusum* (dose rate 0.5 kGy/h).

| Irradiation dose (kGy) | Average contamination density (organisms per kg) | before treatment | after treatment | in 15 days | in 30 days |
|------------------------|--------------------------------------------------|------------------|----------------|------------|------------|
| 0 (K)                  | 100                                              | 100              | 0              | 85         |            |
| 0.70                   | 100                                              | 0                | 0              |            |            |
| 0.80                   | 60                                               | 0                | 0              |            |            |
| 0.90                   | 180                                              | 0                | 0              |            |            |
| 1.00                   | 120                                              | 0                | 0              |            |            |

The irradiation efficiency at a dose rate 0.5 kGy/h was 100% even at the first registering of contamination in a period of 15 days after the treatment, while, at a dose rate of 0.1 kGy/h, it occurred only in 30 days after the treatment.

The reduction of the dose range for gamma radiation to 0.15-0.6 kGy and the dose rate increase to 1.8 kGy/h showed 100% efficiency of treatment by a degree of influence on the survival of insects in the contamination determining even in 15 days after the treatment at all studied doses (table 3).

Table 3. Influence of gamma-irradiation on contamination of barley grain with confused flour beetle (*Tribolium confusum*) (dose rate 0.5 kGy/h).

| Irradiation dose (kGy) | Average contamination density (organisms per kg) | before treatment | after treatment | over 15 days | in 30 days |
|------------------------|--------------------------------------------------|------------------|----------------|--------------|------------|
| 0 (K)                  | 200                                              | 200              | 200            | 200          |            |
| 0.15                   | 200                                              | 0                | 0              |              |            |
| 0.20                   | 200                                              | 0                | 0              |              |            |
| 0.35                   | 200                                              | 0                | 0              |              |            |
| 0.40                   | 200                                              | 0                | 0              |              |            |
| 0.60                   | 200                                              | 0                | 0              |              |            |
The application of bremsstrahlung and electron radiation for treatment of barley contaminated with confused flour beetle allowed to establish that the mortality of 100% of the insect-pest occurs in 15 days after irradiation at all studied doses and dose rates and in case of both radiation types, except the dose of 0.25 kGy (bremsstrahlung radiation), when the organisms perish in 30 days after irradiation. Therefore, the analysis of the grain for the flour beetle contamination after treatment by different types of ionising radiation showed that the insect viability depends on both the radiation dose and the dose rate.

One of the main requirements of ionising radiation application for the treatment of food products is the quality conservation and absence of harmful substances. The studies [16] evaluated the treatment quality of raw materials according to the accepted standards.
Analysis of the grain irradiated to destroy pests at a dose range 0.25–1.0 kGy showed no changes in the content of protein, starch, fat and vitamin complex [17, 18].

Treatment of barley grain of Nur variety in the same dose range but at different dose rate and consequential determination of its quality revealed that at the dose rate 0.1 kGy/h and the radiation dose 0.8 kGy, there was a statistically significant decrease of ash and dry matter content by 4.2 and 0.25%, respectively (figure 1a). While at the dose rate 0.5 kGy/h there was a statistically significant increase of the ash content by 3.6-6.5% at all studied doses and the cellulose content in grain increase by 19.8% at the radiation dose 0.8 kGy (figure 1b).

Barley grain disinfection in the dose range 0.15–0.5 kGy at the dose rate of 1.8 kGy/h and consequential determination of its quality defined a statistically significant effect of treatment only on the ash content. It increased by 4% at 0.15 and 0.5 kGy doses and decreased by 2.5 and 3.5% at doses 0.3 and 0.4 kGy, respectively (figure 2).

Figure 2. Influence of gamma-irradiation on the quality of barley of Nur variety (radiation dose rate 1.8 kGy/h).

Our research found out that varietal characteristics of the crop did not have a significant effect on the irradiated grain quality. Gamma-irradiation of barley grain of Vladimir variety in the dose range 0.17–1.0 kGy and at radiation dose rate 0.1 kGy/h caused a statistically significant increase of the ash content by 6% at doses of 0.17 and 0.3 kGy and its decrease by 5.3% at the dose of 0.9 kGy.

Investigations of the influence of the bremsstrahlung and electron radiation on the quality of barley grain of Nur variety showed that in the studied dose range, both types of radiation did not have a significant effect compared with reference values, except experimental alternative with bremsstrahlung irradiation at the dose of 0.5 kGy. In this case, the content of protein decreased by 5% and fat content decreased by 8%, moreover, at electron irradiation with the dose of 0.75 kGy fat content in grain decreased by 14.6%.

4. Conclusions
The research on the effectiveness of the influence of different doses and types of radiation - γ, electron and bremsstrahlung on the viability of pests from the Tenebrionidae family identified that the viability of confused flour beetle depends on both the irradiation dose and dose rate.
Gamma-irradiation of confused flour beetle (imago stage)) inhabiting on the barley grain, in a dose range 0.7–1.0 kGy caused the 100% mortality of the pest in 15 days after irradiation at a dose rate 0.5 kGy/h. The similar occurred at doses 0.15–0.6 kGy and dose rate of 1.8 kGy, and at the dose rate of 0.1 kGy/h the total pest mortality occurred in 30 days after the irradiation.

The use of the bremsstrahlung and electron radiation for treatment of barley contaminated with confused flour beetle allowed to establish that the mortality of 100% of the insect-pests occurs in 15 days after irradiation at all studied doses and dose rates and for both radiation types, except the dose of 0.25 kGy (bremsstrahlung radiation) when the organisms perish in 30 days after irradiation.

Nutrient content in barley grain changed variously at gamma irradiation: at the dose rate 0.1 kGy/h and the radiation dose 0.8 kGy, there was a statistically significant decrease of ash and dry matter content by 4.2 and 0.25%, respectively; at the dose rate 0.5 kGy/h there was a statistically significant increase of the ash content by 3.6–6.5% at all studied doses, and the cellulose content in grain increased by 19.8% at the radiation dose 0.8 kGy.

The chemical composition of irradiated grain does not depend on varietal characteristics of the same crop.

The application of the bremsstrahlung and electron radiation in investigated dose range generally had no significant effect on the quality of barley grain of Nur variety compared with reference values, except experimental alternative with bremsstrahlung irradiation at the dose of 0.5 kGy. In this case, the content of protein decreased by 5% and fat content decreased by 8% (figure 3), moreover, at electron irradiation with the dose of 0.75 kGy fat content in grain decreased by 14.6%.

Therefore, it was established that application of ionising radiation in the dose range of 0.15–0.6 kGy (at the dose rate 0.5 kGy/h and higher) caused a complete suppression of the viability of Tribolium confusum Duv. without any reduction of barley grain quality and it can be used for grain and grain products disinfection.

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