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PHYSICAL AND TECHNOLOGICAL EFFECTS OF WHEAT GRAIN INFESTATION BY GRANARY WEEVILS

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Summary. The paper presents the results of preliminary studies on wheat grain infestation by granary weevil. The test material was constituted by grain of winter wheat cv. Nawra, infested by adult individuals of granary weevil. Analyses were performed of areas on the surface of infested wheat kernels, where eggs had been laid by females of the pest, as well as of areas of foraging of adult individuals. Considering the duration of the development cycle of a granary weevil individual, technological parameters of wheat kernels were determined for four periods of its growth and development, i.e. after 5, 10, 15 and 20 days from the moment of kernel infestation. The determinations were performed with the help of an Elektronika 25 system for X-ray image analysis and an SKCS. Results of the analyses showed that the preferred area of foraging of young and adult individuals is the bottom zone of the kernel, although in the initial stage both incubation and foraging took place mainly in the top zone of the kernels. Results of the tests performed using the SKCS showed an increase in moisture content and a decrease of hardness index of wheat grain with increasing duration of the pest foraging in the grain

Key words: wheat grain, granary weevil, infestation, development cycles

INTRODUCTION

The range of problems relating to the search for solutions aimed at the acquisition of safe food is at the forefront of research in the world, and especially in the European Union. A fairly common and irreplaceable food product in the human diet is bread, reference to which as „our daily bread" is justified by the fact that it is the only food product that, in the form of a slice or chunk, can be truly consumed daily from the youngest childhood to old age. The basic ingredients for the production of bread (wheat and rye grain) require continuous control of the raw material quality from the viewpoint of sanitary and health requirements.

The most popular material for the production of bread in the world is common wheat (*Triticum aestivum* L.). Wheat occupies a leading position in the group of cereal crops, both in terms of area of cultivation and of the volume of grain production. As the "queen of cereals", wheat accounts for about a third of the world cereal production, and its global yield reaches the level of about 600 million tons every year. Almost 90% of wheat grain produced is used to feed the human population of the world, and the material provides 20% of the total energy consumed by man, mainly in the form of bread and other baked and cooked products [Grundas and Wrigley 2004a, b].

Cereal grain is susceptible to a reduction in its usable value and quality under unfavourable storage conditions. Quality control of food materials and products becomes, therefore, a statutory duty of institutions involved in their production and turnover. As a vast majority of food materials and products are cereal materials and products, considerable attention is devoted to the problem of detection of grain infestation by pests feeding in it [Gołębiowska *et al.* 1976]. Wheat grain infestation by granary weevils causes significant deterioration of its technological and nutritional value and gives rise to hygienic problems. Granary weevil (*Sitophilus granarius* L.) is one of the more dangerous pests for wheat grain. Females of the species lay eggs inside kernels, or else hatching larvae gnaw their way into wheat kernels [KFPZ 2005]. Cereal grains meets in 100% the total energy requirement of the species, necessary for its survival.

According to the American standard for wheat grain, a sample containing more than 31 infested kernels per 100 g of grain is classified as material constituting a hazard to human health. The standard for cereal grain mills permits the presence of 5 infested kernels in a 100 g grain sample [GIPSA 1993].

The fundamental difficulty in early detection of grain infestation by granary weevil is hidden infestation of kernels. Part from the obvious quantitative losses caused by granary weevil, there is also the contamination of grain with dead individuals and with the excrement of the pest. This creates the hazard of stored products and materials infection with micro-organisms, transported on the bodies of the pests, whose secondary metabolites are strongly toxic [Wu 2005]. The metabolites are particularly dangerous as, apart from quantitative losses and the reduction in the technological and nutritional value of the products affected, they cause allergies constituting a hazard to human health [Nawrot 2001].

In view of the above, what is needed is rapid and objective methods for the identification of the pests feeding inside kernels. The most effective method for the identification of the stages of granary weevil growth and development in kernels is the X-ray method [Haff and Slaughter 1999, Grundas 2001, Fornal *et al*. 2003].

During its development, a larva of granary weevil sheds its cuticular layer four times, then metamorphoses into an elongated protonymph, and then into a chrysalis. The development of a larva at a temperature of 25ºC is complete after 21 days, and at 17ºC after 84 days. The chrysalis stage, under favourable conditions, lasts for 9 days. Once out of the chrysalis stage, the beetle remains inside the kernel for several to over a dozen days, then gnaws a hole in the seed coat of the kernel and emerges outside. Holes in kernels indicate the presence of the pest in grain. Figure 1 presents the development stages of granary weevil in a wheat kernel [Błaszczak 1976].

Under the conditions of grain storage facilities in Poland, two to three generations of granary weevils develop within a year [KFPZ 2005]. Beetles of granary weevil can endure long periods of hunger. Adult individuals live on average for 150 days, up to a maximum of 873 days. In its lifetime, a granary weevil beetle consumes from about 0.5

to 1 mg of grain. Wheat grain mass losses caused by the pest are estimated at the level of 5% of the total of the material in storage, with simultaneous lack of knowledge concerning the technological-nutritional effects for grain used in the cereal industry.

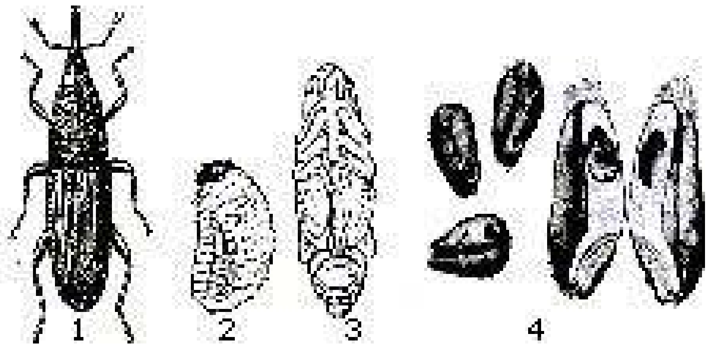

Fig.1. Development stages of granary weevil: 1) beetle, 2) larva, 3) chrysalis, 4) damaged kernels

The objective of the study presented herein was the determination of the physical and technological effects of granary weevil foraging on and inside wheat kernels, through visual analysis of X-ray images and reports obtained by means of the Single Kernel Characterization System (SKCS).

MATERIAL AND METHODS

The test material was constituted by kernels of spring wheat cv. Nawra, infested with granary weevil at the laboratory of the Institute of Plant Protection in Poznań. The method of grain infestation applied consists in placing, in suitable containers, grain samples containing 20 pairs of adult individuals of the pest per 100 kernels of wheat. The process of incubation and then of foraging of the pest was conducted under laboratory conditions at relative air humidity of 70% and temperature of 26ºC. The combined time of incubation and foraging lasted for 5, 10, 15 and 20 days, respectively. Those periods included also the samples being couriered from Poznań to the laboratory of the Institute of Agrophysics in Lublin.

Upon delivery of the containers with infested grain, random samples of 30 kernels were taken for particular periods of incubation, and attached with glue onto measurement cassettes. Every such cassette, made of self-adhesive paper, was used to mount 30 kernels which were then subjected to X-ray detection by means of the Russian-made Elektronika 25 apparatus (Fig. 2). X-ray detection was applied to a series of 10 sets of such kernels from every period of foraging. Figure 3 presents an example viewof a measurement cassette and of an X-ray image of the tested kernels.

The cassettes were marked in a manner permitting the identification of the cassette number and the experimental treatment. The obtained X-ray images, after scanning and saving in a computer system, were analysed for the number of eggs laid by the females in particular zones of kernels, or for the presence of areas eaten away by individuals growing inside kernels, and for the number of adult individuals foraging on the outside of kernels. If the X-ray image of a tested kernel is divided into three parts, it is possible to determine with a high level of accuracy in which zone the kernel has been damaged.

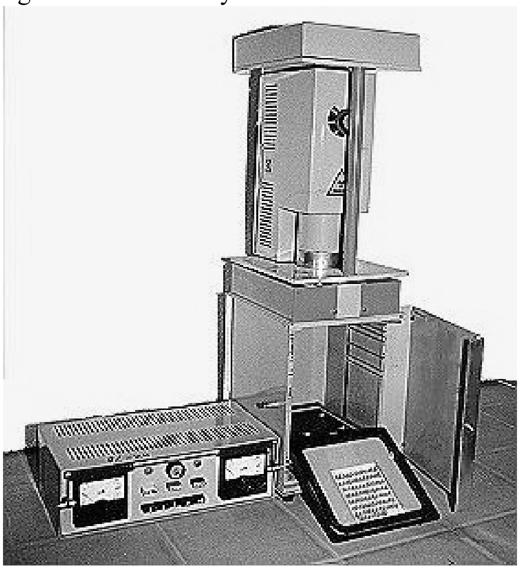

Fig. 2. Elektronika 25 X-ray inspection apparatus

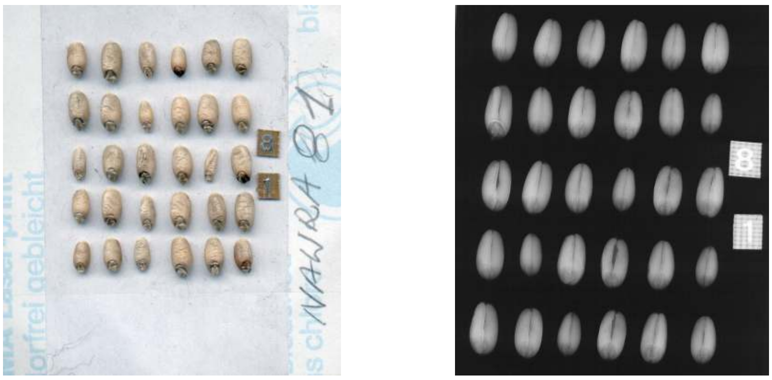

Fig. 3. Measurement cassette with mounted kernels (a) and their X-ray image (b)

The zones of kernels infested with granary weevil were examined on the basis of the X-ray images, using a grid of single kernel X-ray image placed against the screen of the monitor, as shown in Figure 4.

After the X-ray detection, grain samples were subjected to testing by means of the SKCS in order to determine the level of moisture content and hardness index of kernels infested with granary weevils at various stages of development. The SKCS, after performing measurements in each measurement cycle comprising standard analysis of 300 kernels (10 replicates × 30 kernels per one cassette), delivers a report on the mean values and standard deviations of the following technological features of individual kernels: mass, equivalent diameter, hardness index and moisture content. Figure 5 presents an overview of the apparatus.

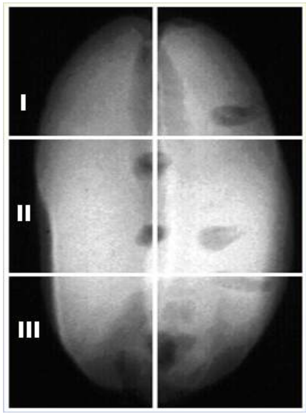

Fig. 4. Schematic of division of X-ray image of wheat kernel infested by granary weevil into three zones: I – top, II – centre, III – bottom (close to the germ)

Fig. 5. Operation schematic of the SKC

From among the data contained in the reports only the mean values of moisture and hardness index of the tested kernels were taken for the estimation procedure. The remaining values, such as kernel mass and equivalent diameter, were left out due to the lack of observable tendencies under the effect of time of incubation and foraging of the pest in the tested grain samples.

RESULTS

Physical effects of the pest foraging in the tested samples of wheat kernels were estimated on the basis of the number of areas of internal infestation of kernels visible in the X-ray images and of the number of gnawed out areas on the outside of kernels observable in the X-ray images. The results of measurements include the number of granary weevil individuals identified per 30 kernels mounted on one cassette. The X-ray images include clearly observable darker areas indicating the foraging places of granary weevil individuals.

In X-ray images from the early stage of the pests development it is possible to distinguish tiny spots which represent granary weevil larvae. At a later period of foraging one can see in the X-ray images parts of kernels gnawed away by adult individuals foraging on the outside of kernels.

After 20 days of foraging there are clearly observable changes caused by the presence of the pests. Considerable sections of wheat kernels have been gnawed away by adult individuals, which can be definitely identified during visual inspections of the X-ray images.

Figure 6 presents an example of an X-ray with control kernels of the tested wheat cultivar, and Figure 7 an X-ray with weevil-infested kernels after 20 days of foraging.

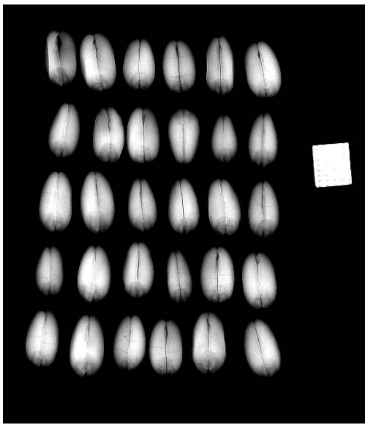

Fig. 6. X-ray image of control kernels of wheat mounted on a measurement cassette

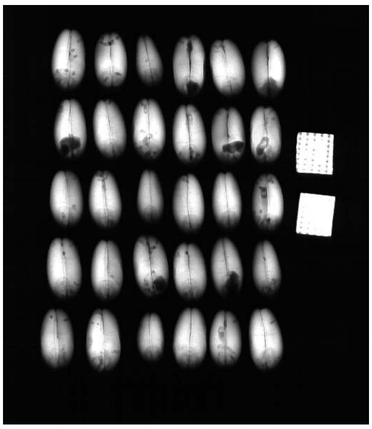

Fig. 7. X-ray image of wheat kernels infested by granary weevil, after 20 days of foraging

PHYSICAL EFFECTS OF GRANARY WEEVIL FORAGING IN GRAIN SAMPLES

The obtained results of determination of the number of young individuals in wheat kernels, identified on 10 measurement cassettes after 5, 10, 15 and 20 days from the moment of infestation by adult individuals foraging within and on the outside of the kernels, are presented in Tables 1 and 2.

Table 1. Mean numbers of foraging areas of young individuals inside kernels identified on a single measurement cassette with relation to the foraging time

Kernel zones	Time of incubation and foraging of granary weevil (days)				
	control	5	10	15	20
Top	0	4.3	5.9	17.1	49.5
Centre	0	4.6	2.8	7.3	17.3
Bottom	0	2.6	13.3	21.4	45.2
In whole kernels*	0	11.5	20.0	46.0	112.0

Table 2. Mean number of foraging areas of adult individuals on the outside of kernels identified on a single measurement cassette with relation to the foraging time.

Kernel zones	Time of foraging of granary weevil (days)				
	control	5	10	15	20
Top	0	0.0	1.0	1.0	0
Centre	0	1.3	1.0	2.0	1.7
Bottom	0	1.9	4.6	5.6	5.6
In whole kernels*	0	2.1	4.8	5.9	7.0

* all the mean values in the Tables refer to the number of 30 kernels mounted on a single measurement cassette

Analysing the results of determinations of the numbers of areas affected by individuals foraging inside the kernels after 6 days, we can formulate the observation that they foraged mostly in zone I of the kernel, that is in the top. After 10 days from infestation the numbers of foraging areas increased notably in zone III of the kernel. After foraging for 15 days from the moment of infestation the numbers of foraging areas were also the highest in zone III of the kernel. After 20 days from infestation the most numerous areas of foraging damage were also observed in zone III of the kernel, i.e. close to the germ, and they were more numerous as compared to the numbers observed in X-rays taken after 5 days from infestation.

TECHNOLOGICAL EFFECTS OF GRANARY WEEVIL FORAGING IN GRAIN SAMPLES

For the identification of trends related to the effect of the development stages of individuals foraging inside kernels on the moisture content and hardness index of the grain the relevant measurement data were approximated with a straight line (Fig. 8 and 9). The linear equations and coefficients of correlation were determined by means of the MS Office Excel software.

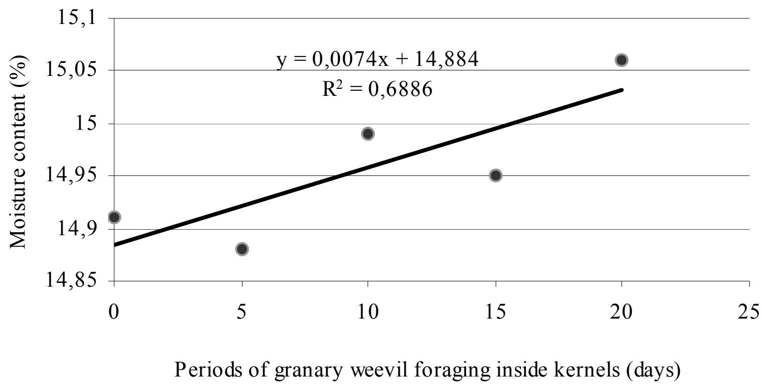

Fig. 8. Effect of periods of granary weevil foraging inside kernels on the grain moisture content

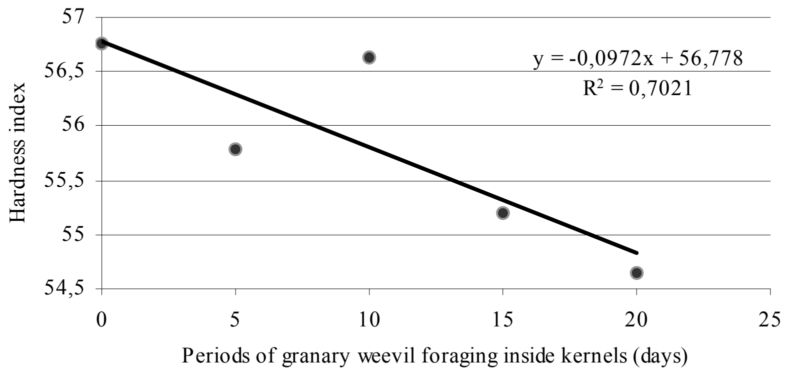

Fig. 9. Effect of periods of granary weevil foraging inside kernels on hardness index

On the basis of tests performed with the help of the SKCS apparatus on the tested wheat kernels, mean values of the grain moisture content and hardness were read from the reports. It was found that within the time periods after 5, 10, 15 and 20 days from infestation the mean moisture content of the kernels systematically increased. Analysing the values of wheat kernels hardness indexes it was found that the values decreased with the passage of time.

CONCLUSIONS

The performed analysis of X-ray images of wheat kernels infested with granary weevil and analysis of the results of tests performed with the help of the SKCS apparatus permitted the formulation of the following conclusions.

1. There exist preferred areas of kernels where eggs laid have optimum conditions for the growth and development of a generation. The performed analysis showed that the most preferred area for egg-laying was the top zone of the kernel, and as the larvae developed and further infestation occurred the pests migrated towards the bottom zone, towards the germ.
2. There exist preferred zones of foraging of adult individuals that do not threaten the growth and development of generation individuals. As follows from the analysis, adult individuals foraged mostly in the zone close to the germ.
3. The growth and development of granary weevil in wheat grain entail an increase in the grain moisture content. An increase in grain moisture content is an obvious effect of an increase in body weight of the individuals developing in the grain.
4. The growth and development of granary weevil individuals in grain causes a decrease in the hardness index of the grain. A decrease of the values of grain hardness indexes entails a decrease in the strength of the kernel in the endosperm area.

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