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IMPORTANCE OF WHEAT GRAIN ORIENTATION FOR THE DETECTION OF INTERNAL MECHANICAL DAMAGE BY THE X-RAY METHOD

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A b s t r a c t. In the present work some methodical aspects of X-ray detection of wheat kernels are presented. Part of the work describes the optimal kernel orientations using a special X-ray instrument attachment. The problem of the correct arrangement of a wheat grain sample for X-ray test is considered. New technical approach - solutions and methods - is suggested for the maximum detection leveln of internal mechanical damage of wheat grain by means of roentgenography.

K e y w o r d s: wheat grain, internal damage, roentgenograph projection, grain and sample orientation

INTRODUCTION

The phenomenon of mechanical damage to grain is closely related to grain hardness determined not only by genetic factors but by the environmental effects as well. Studies conducted so far indicate the need to consider this feature, especially in the evaluation of wheat technological quality [3,7].

Internal mechanical damage of wheat grain, both of natural and technological origin, are a frequent phenomenon. It is known that the presence of such damage in grain reduces quality of grain as a consumer product and as sowing material [6]. Therefore the task of detection and quantitative estimation of such damages is quite urgent. An X-ray method is a traditional non-destructive method of defect detection inside various materials. A grain, as an object of the method has its own characteristics. The small size of a whole grain and its parts makes application of X-ray techniques necessary [5]. This technique gives the satisfactory sharpness of images and allows to obtain X-ray projections at a chosen magnification.

Caryopsis (cereal grain) as a whole and its densely packed up parts have a complex form and look differently at roentgenograph in different projections. It is necessary to choose projections in which the required character is visible most precisely. Besides, now in the roentgenography of grain samples, as a rule, simultaneous test of a certain number of grains is applied. It is quite justified in the view of the economy of a place, time, energy and materials. However, in order to examine all the grains in the same projection at simultaneous roentgenographs, we must solve the problem of grain arrangement. Time economy is also very important when the process of grain sample preparation for roentgenography, including grain fixing on paper and then reading of the information from roentgenograms is considered. The above mentioned requirements stated for the X-ray method to be efficient together with further ways of optimising its technology are discussed in this paper. This work has been also presented partially at some conferences in the form of poster and oral presentations [1,4,5].

MATERIALS AND METHODS

The present investigations were carried out on the kernels of three wheat varieties Jara, Alfa and Cando. The kernels were fixed on thick paper cards with a sticky layer. The number of simultaneously tested kernels depended on the level of direct X-ray magnification. The higher the magnification, the smaller number of kernels could be tested simultaneously. A hundred (100) kernels are subjected to double magnification most frequently used for the analysis of grain samples on a card in a rectangular framework of 6 x 8 cm. They are packed in transverse rows with grooves downwards and with their embryos oriented downwards.

Most frequently observed displays of mechanical damage in wheat kernels are cracks within the endosperm. They look as thin dark lines on a rather light background of intact endosperm on the roentgenograms. The number of inner cracks in a kernel was assumed as a parameter of the degree of mechanical damage.

For the roentgenography the microfocus X-ray apparatus "Elektronika-25", made in Russia with the present author's modifications (Photo 1) was applied. An ordinary sheet photographic film Foto-64 (ISO 100), size 13 x 18 cm was used as radiosensitive material. It is much cheaper than the special two-layer X-ray film. Moreover, it gives a high-quality image due to its fine granularity. The roentgenograms for some illustrations were made directly on the photographic paper. The voltage of the X-ray tube was fixed at up to 20 kV at the current of up to 80 μA. Depending on the voltage, the exposition time was from 4 to 8 min for a film and 30 min for photographic paper. Packages from black light-proof paper served as film cartridges. Such packages with film were placed on the flat bottom of the chamber and were pressed along the edges by a metal framework. When testing without magnification, the card with kernels is placed directly on the film. When testing with magnification, the card is located between the focus of the tube and the film at the appropriate height.

For the evaluation of the influence of kernel position on the inner cracks detection, a single kernel was fixed in a specially prepared X-ray instrument attachment [2] that allowed better visualisation of the inner cracks on the radiograms. Photo 2 shows this device.

The treatment of the exposed photomaterials was carried out in the standard way with the application of strongly contrasting developer. The radiograms were viewed on the screen of a defectoscope with the help of a magnifying glass with double magnification.

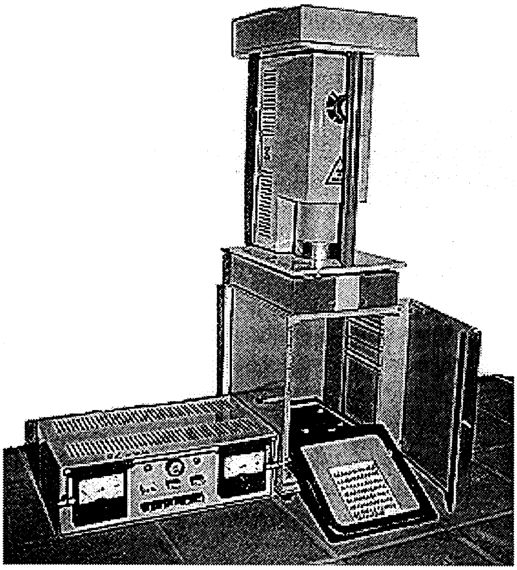

Photo 1. Microfocus X-ray apparatus "Elekronika-25" with the wheat kernels placed on the card.

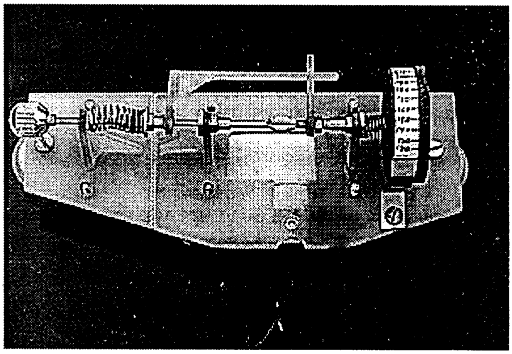

Photo 2. X-ray instrument attachment for fixing the kernel in a chosen position.

RESULTS AND DISCUSSION

Even simple viewing of roentgenograms consisting of 100 kernel images allows to find out that the kernels are roentgenographed in different projections. The embryos in the kernels of upper rows look extended, and these of lower rows - shortened. The endosperm cracks in the middle rows are visible as sharply drawn black lines, whereas in the border rows they are clearly less numerous and present mostly dim grey lines. The scheme (Fig. 1) which demonstrates the course of X-rays explains the reasons for such a phenomenon. If in the upper rows of the kernels, X-rays pass perpendicularly to the plane of the embryo, in the lower rows they penetrate the embryo from the top. As a result in the first case we receive the greatest possible longitudinal projection of the embryo, and in the second - it is strongly shortened.

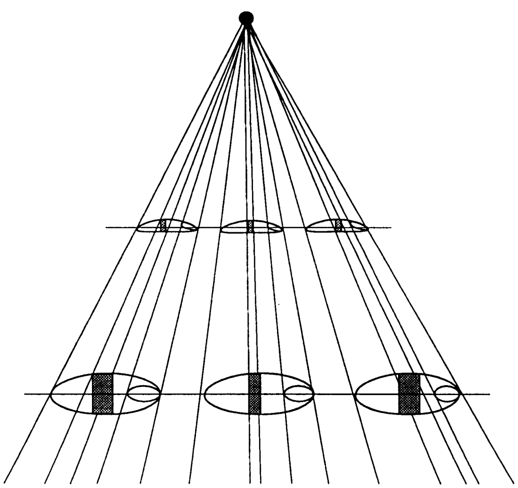

Fig. 1. Schematic of X-ray propagation through the kernel and creation of X-ray projection for plane arrangement of the kernel and the film.

The cracks within the endosperm represent wedge-shaped cavities which occur mostly across a longitudinal axis of the kernel. If the X-rays passing through the kernel cavities they come to the film without visible weakening and leave precise, thin black projections of cracks on it. If they cross crack cavities at any angle, their absorption by the kernels material grows repeatedly, coming nearer to the absorption by the intact material. The cracks are thus not found at all or their projections turn out wide and dim.

To find out to what degree the kernel position on the card effects the exposure of the inner cracks, 16 kernels of wheat variety Jara were tested in the upper, middle and lower rows. The number of inner cracks in each kernel that was visible on the radiogram, and their sum in a row of 16 kernels were counted. The results are presented in Fig. 2a. As it is clear from this figure with the same kernels fixed in the three rows by the usual arrangement of the card with kernels and the film on flat surfaces, a different number of cracks was

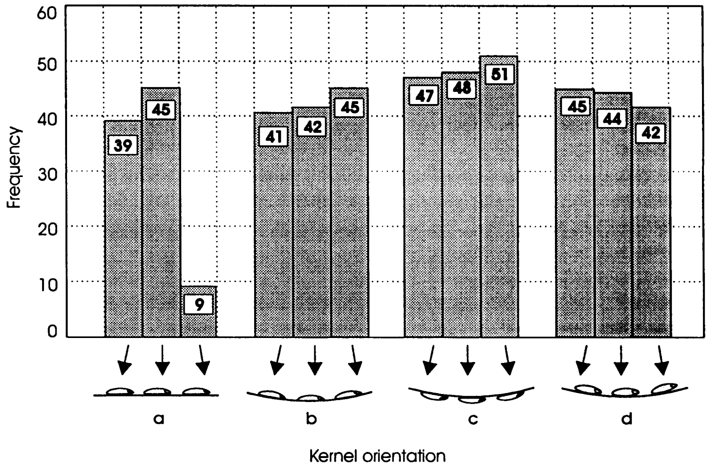

Fig. 2. The number of cracks detectable in 16 kernels as dependent on its orientation.

found in the radiograms depending on the position of the row of kernels. The greatest number of inner cracks is visible when the row of kernels is located in the middle position on the card. That conforms with the lay-out (Fig. 1). However, the diagram does not give any explanations for a clear advantage of the inner cracks exposure at the upper row in comparison to the lower one (39 and 9 cracks).

One possible explanation could be that in order to examine the kernels, a radiogram had been taken from the inside location on the card (Photo 3). One can see on the radiogram, that the cracks in the endosperm pass perpendicularly not to the kernel longitudinal axis, but rather to that bend line which represents a projection of the groove bottom. The kernel might be conditionally presented as two slightly bent "sausages", accreted in the area of a groove; the inner cracks run in the perpendicular plane to their longitudinal axes. The steepest bend is in the area of the embryo. Here, cavities of the inner cracks go almost perpendicularly to the scutellum of the embryo. In the kernels of the upper row, direction of the wedge-shaped cavities of the cracks in this area coincides with the direction of X-rays, whereas in the lower row X-rays run perpendicularly to the cracks. Consequently the inner cracks in the first case are visible on the radiogram, in the second one - invisible. This defect of a traditional flat arrangement of the kernels in a sample may be partially compensated for when the upper kernels are oriented with the embryo end downwards and the lower ones are turned upside - down with the embryo end upwards. Then the embryo end is turned in all the kernels to a line dividing the card into two equal parts.

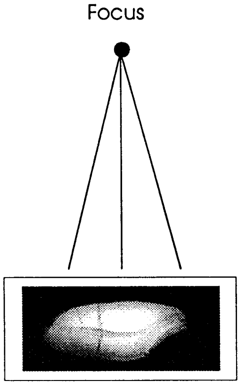

Photo 3. Side radiograph of the kernel.

The diagram and the results of the experiment show that both the arrangement of samples and the film on flat surfaces put the kernels in an unequal position for the cracks detection which leads to mistakes in the estimation of damage both in individual kernels and the sample as a whole. The "flat" variant has at least one more defect. The intensity of X-rays falling on a kernel and then reaching the film in its central part is higher than in the peripheries, which can cause unclear crack projections or projections of other thin details of the kernel on the radiogram. Besides, it may cause a mistake in the densiometric analysis of the radiogram.

The defects in the arrangement of the grain sample and the film on flat surfaces make one think that the arrangement of both elements on spherical surfaces would be ideal. However, it is difficult at present to carry out this idea technically both with respect to fixing the kernels and the photosensitive layer on spherical surfaces and with respect to the visual analysis of a spherical roentgenogram. To find a compromise solution we suggest to put the card with the kernels pasted on it and the film on cylindrical surfaces. The longitudinal kernel axes is then arranged perpendicularly to the cylinder axis. Giving the paper card with kernels and the sheet of photographic film a cylindrical curvature is not difficult. Thus the same angle of X-rays to the longitudinal axes of the kernels in all the rows of the card (90 degrees) is provided. Thus approximately equal conditions are created for all the kernels which gives the same expression of their longitudinal parameters (kernel length and embryo length) in the projections for the detection of cross cracks (Fig. 3). The non-uniformity of the conditions along the rows does not result in any essential mistakes in the estimation of such type of damage.

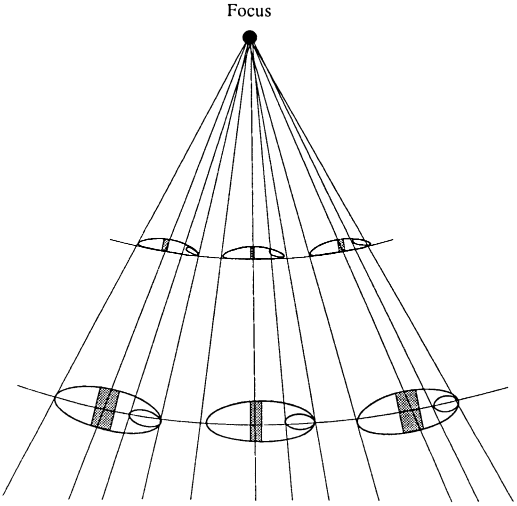

Fig. 3. Schematic of X-ray propagation through the kernel and creation of the X-ray projection for the cylindrical arrangement of the kernels and the film.

The data in Fig. 2b in general conforms with our expectations. Crack detection in all three row positions is rather high and is approximately identical. The incomplete concurrence of the sums of cracks, number in the row in different position (41, 42, 45), probably, indicates that the radii of cylindrical surfaces are not accurate and their axes do not match the tube focus in the particular variant. Detection of inner cracks appears to be more successful (47, 48, 51) if the kernels are roentgenographed not from the back-side, but from the groove-side, with the card turned upside down (Fig. 2c). The reason for it became clear if we consider roentgenograms, showing kernel sideways (Photo 2). The lines of cross cracks on this roentgenogram tend to converge outside the kernel on the groove side. Therefore, if the focus of the tube is located on the groove side, the probability of concurrence of a direction of X-rays with a direction of crack cavities increases and, hence, crack detection increases too.

Roentgenograms of the kernels from the side view (Fig. 2d) are not record by the number of cracks revealed (45,44,42), which shows that the cavities of cross cracks pass at different angles to the longitudinal plane of kernel symmetry, but not only at the right angle.

When revealing the cracks within the endosperm by the X-ray method, the distance between the kernel and the focus of the tube is also important. It adjusts to the degree of magnification of the X-rays projection. The closer the kernel is to the focus of the tube, the higher the magnification. Magnification allows to see fine details of the kernel on the roentgenogram. However, only those thin cracks are seen in which cavity direction coincides with the direction of the X-rays. At the same time, the closer to the focus of the tube the kernel is, the larger angle at which such cracks disperse within kernel length, and the more probability that they will not coincide with the direction of crack cavities and so are not revealed in the roentgenogram.

Six (6) kernels of wheat variety Alfa (only 6 kernels can be simultaneously tested with the x10 magnification were roentgenographed by the flat arrangement of the sample and the film with the magnification of x10, x7, x5, x3, x2 and x1. The roentgenogram with the magnification of x 2 was made in the cylindrical variant, as well. The data on number of inner cracks revealed in these kernels under different conditions of roentgenograph, mentioned above are given in Fig. 4. As it follows from the diagram, the x 3 magnification appears to be the most favourable for the detection of cracks in the flat variant of the sample and the film arrangement.

All the roentgenograph variants considered above were analysed from the point of

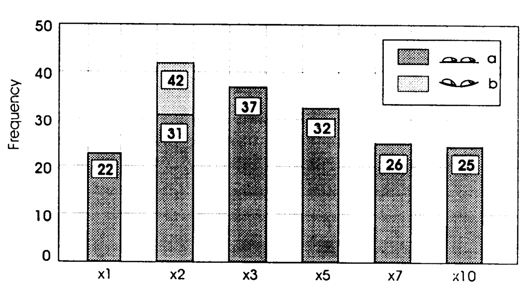

Fig. 4. The number of cracks detectable in six kernels in the plane arrangement of the kernels and the film as related to the degree of magnification.

view of their ability to reveal as high a number of cracks in everyone kernel as possible. None of them revealed all the cracks. Moreover, from the data received one can conclude that for each variant its own set of visible cracks is characteristic and, hence, the set of unravelled cracks, too. Such a test is probably appropriate for the comparative estimation of the internal damage of wheat grain of different origin that undergoes various technological processes. For example, after harvesting by a combine, drying, storage and so on. For more exact estimation of the internal mechanical damage of grain other approaches are necessary.

One of such approaches is realised in the Institute of Agrophysics PAS as a special device, attached to the "Elektronika-25" apparatus [4]. The latter allows to roentgenograph a separate kernel in any position, fixing the angle of turn around any of its axes (Photo 3). It is obvious, that some longitudinal X-ray projections of the kernel received at different angles of the kernel turned around it axis give representation of all the cracks in the endosperm that may be revealed by the X-ray method. Such a result can not be achieved even when roentgenographing a kernel in two decisive positions - in the groove-back view and in the side-view. Thus, Photo 4 gives evidence, that in the position at angle of 120 degrees there are inner cracks in the kernel at

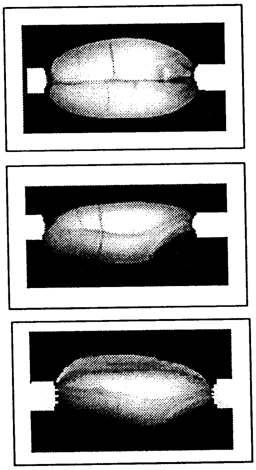

Photo 4. Radiographs of one kernel for various angles of exposition (0 deg - X-ray incident on the kernel from the groove side).

back side which are not visible on the roentgenograms of the positions mentioned. As our experience has shown a kernel turn around its longitudinal axis at angle of 10 degrees is enough for the thin cracks to be clearly visible by eye on the roentgenogram. In the computer analysis this angle may, probably, be increased up to 20 degrees. Hence, for an estimation of the number, length, width and depth of the inner cracks in the kernel about 9 roentgenograms (180:20) are enough.

CONCLUSIONS

By means of calculations and experiments it has been found out that to obtain the most comprehensive information on the internal mechanical damage of wheat grain in a sample it is rational to keep the follow the rules enumerated below:

1. Grain sample should be arranged in rows on a cylindrical surface with kernel longitudinal axes tangent to this surface and perpendicular to the line forming cylindrical surface.

2. Radius of the card surface on which the sample is situated should be equal to the distance between the card and the focus of the X-ray tube.

3. The X-ray film should be also located on the cylindrical surface with the radius equal to the distance from the focus of the tube.

4. Every kernel should be oriented to the focus of the tube by the groove (its crease side) or sideways. However, fixing of the kernel on a side is inconvenient and usually is applied only in special experiments.

5. During the X-ray test direct two- or three-multiple magnification are optimal. By larger magnification a close arrangement of kernel to the focus of the tube is required and that worsens inner cracks' detection on the margins of upper and lower kernels.

It was found that for the identification of all the inner cracks in the kernel, especially those formed as a result of mechanical squeezing, together with the regular ones that are sometimes formed during the pre-harvest period, several - approximately nine - longitudinal projections are needed. The results obtained may be used in the roentgenography of cereal grains as well as in the roentgenoscopy for the calculation of a trajectory of grain movement and subsequent computer analysis of the image series received.

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