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THE ANALYSIS OF INCREMENTS OF INTERNAL DAMAGE TO WHEAT GRAIN AFFECTED BY DYNAMIC LOADING

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A b s t r a c t. An analysis of internal damage increase was performed for samples of winter and spring wheat (three varieties of each), for damage caused by dynamic loading (two levels: 20 m/s and 25 m/s). The internal damage increase was determined separately for every kernel, on the basis of its damage status before and after loading. The internal damage status (endosperm cracks) was assessed by means of a damage index calculated on the basis of results of damage identification within the fields of a square grid superimposed on the X-ray image of a kernel analysed. Increase in the mean damage index for a grain sample was adopted as a measure of the vulnerability of the grain sample to damage caused by the load applied. Quantitative and qualitative analyses were performed for the status of damage of the grain samples of the varieties under study. Especially interesting conclusions were formulated analysing the 'damage balance' of the grain samples. The methods used in the study can be applied also in other laboratory studies on damage to cereal grain or to the seeds of certain crop plants, e.g., when studying the effects of the successive stages of their destruction.

K e y w o r d s: wheat grain, dynamic loading, mechanical damage, X-ray detection, vulnerability

INTRODUCTION

In the investigation of mechanical damage to grain (e.g. wheat) it is useful to possess knowledge of damage increase, originating as a consequence of the effect of a specific factor. The value of this increment may be treated as a measure (index) of vulnerability under the influence of the destructive factor studied. If such indices are well-known for the investigated collection of grain samples, then it is possible to compare them (or at least to set them in order) in terms of wheat varieties, types or levels of destructive factors etc., which means putting them into practice. The analysis of damage increments is useful, e.g. in the investigation of mechanical 'fatigue' of grain as a consequence of the successive stages of their destruction.

The analysis of damage increments is effective when the following conditions are fulfilled:

1) the investigation of damage is carried out on single kernels,

2) the method used for the detection of damage is non-destructive,

3) the assessment of the status of damage is executed by means of a quantitatvie measure.

The aim of this paper is to indicate the possibility of analysis of grain damage if the above conditions are fulfilled.

MATERIAL AND METHODS

The experiment was conducted on grain samples of three varieties of winter wheat (Gama, Liwilla, Panda) and three varieties of spring wheat (Henika, Jara, Kadett). The material was machine threshed. Grains of thickness from 2.9 to 3.3 mm were selected for the tests. The moisture content of the grain during studies was kept within the range from 11 to 13 %. Twenty samples of 100 kernels each were choosen (by means of random sampling from grains of each of the varieties and every hundred of grains was subjected to X-ray detection according to the method described in reference [2]. X-ray exposure of grains was performed at a constant position - groove downwards. This position enables the detecion almost any of damage.

Then, one by one the grains were subjected to dynamic loading according to the method described in reference [3]. The modelling of dynamic loading was performed using an apparatus illustrated in Fig. 1. Kernel by kernel was introduced, by means of an electromagnetic ejector, into the zone of rotation of an arm tipped with a plate - the beater. The apparatus allows for various rates of impact to be applied to the kernel. The experiment was conducted at a rate of 20 m/s (10 grain samples) and 25 m/s (the remaining 10 samples).

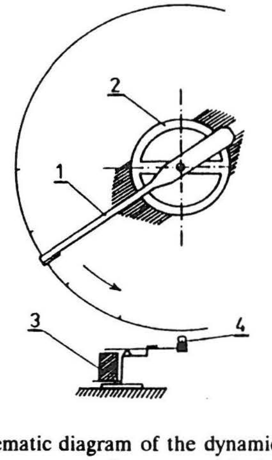

Fig. 1. Schematic diagram of the dynamic loading apparatus: 1 - rotary arm, 2 - motor with ejection control mechanism, 3 - electromagnetic ejector, 4 - kernel.

All the grains were then X-rayed for the second time. This procedure made it possible to compare the state of damage of each kernel before and after loading. In this way 2 000 grains of each variety of wheat were examined. The following symbols have been adopted for the grain samples:

k_1, k_2 - control samples (before loading),

d - sample k_1 after loading at the rate of 20 m/s,

D - sample k_2 after loading at the rate of 25 m/s.

Using a method described in reference [1] an inspection of the mechanical damage visible in the X-ray pictures was made, ascribing to them corresponding values of the damage index. For this purpose, the magnified (6x) X-ray image of every kernel was divided into 3 vertical and 3 horizontal strips of equal width (Fig. 2). A square grid was thus obtained, covering the image of the kernel in full.

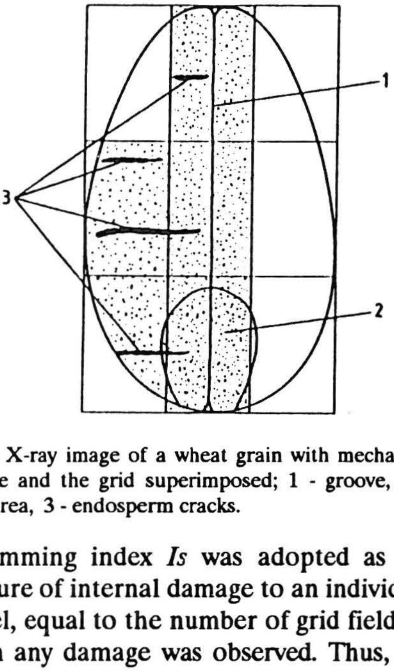

Fig. 2. X-ray image of a wheat grain with mechanical damage and the grid superimposed; 1 - groove, 2 - germ area, 3 - endosperm cracks.

A summing index *Is* was adopted as the measure of internal damage to an individual kernel, equal to the number of grid fields in which any damage was observed. Thus, the *Is* index can assume integer values from 0 to 9. $Is=0$ corresponds to an undamaged kernel, and $Is=9$ corresponds to a kernel with damage in all the fields of the grid. In quantitative analyses the mean of the damage indices for the kernels in a sample was adopted as the measure of damage of the grain sample. As the measure of the grain sample vulnerability to damage, index *V* was adopted - defined as follows:

$$V = Is(\text{load.}) - Is(\text{contr.})$$

where *Is* (contr.) - damage index value before the loading, *Is* (load.) - damage index value after the loading.

In qualitative analyses the following four classes of grain damage were employed: 0 - grains with no visible damage (Is=0); A - grains with little damage (Is=1, 2, 3); B - grains with average damage (Is=4, 5, 6); C - grains with extensive damage (Is=7, 8, 9). The analysis of 'damage balance' of the grain samples was performed on the basis of data from the scheme shown in Fig. 3.

As the measure of grain resistance to damage, index R was adopted, defined as follows:

$$R=100\,(k_{11}+k_{22}+k_{33}+k_{44})\,/N\ .$$

Both the loading levels applied caused an increase in the mean index of damage with relation to the control samples. Grain samples of the spring varieties proved to be more vulnerable to damage than the winter varieties (Table 1). Higher unit loads were associated with a higher vulnerability to damage.

It was not possible to determine a strict overall relation of the index of vulnerability to the initial status of grain damage (in control samples). Such a relation probably exists (and it should be studied, using a larger number of varieties) within the groups of winter and spring varieties separately (Fig. 5).

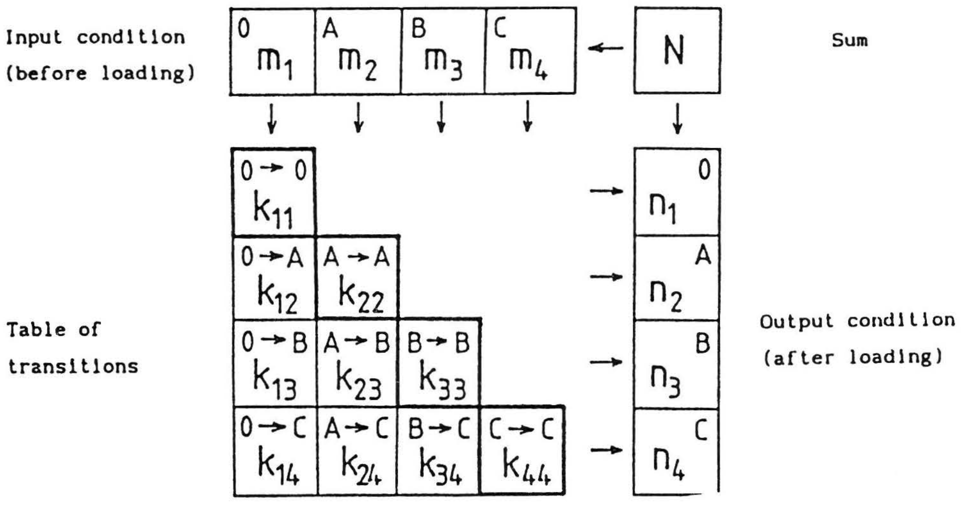

Fig. 3. Grain sample damage balance. N - size of grain sample tested; i, j - numbers of columns and rows; m_i, n_i - numbers of grains in damage classes, input and output; k_{ij} - numbers of grains in the 'windows' of the table of transitions.

RESULTS

The mean indexes of damage for the control samples of all the varieties tested were relatively low, though significantly higher than zero (Fig. 4). Therefore mechanical damage in grain from mechanized harvesting must not be neglected in the evaluation of grain material quality. Generally, grain samples of the spring form had higher mean indexes of damage than grain samples of the winter form - both before and after the loading.

The dissimilar reactions of the two wheat forms to the loads applied was also manifested in the different distributions of the damage index values (Fig. 6). Type (a) distribution is characteristic only for samples of grain of spring varieties after both levels of loading, type (b) distribution - for all the other samples. The form of type (a) distribution indicates that, due to the loading, an unexpectedly large number of grains with the highest degree of destruction appeared in spring wheat grain samples.

Table 1. Mean increases of the index of damage (V) for the grain of the six wheat varieties tested, caused by the dynamic loading applied to the grain

Level of loading			
20 m/s		25 m/s	
Variety	$V=I_s(d) - I_s(k_1)$	Variety	$V=I_s(d) - I_s(k_2)$
Gama	0.08	Gama	0.33
Panda	0.11	Panda	0.47
Henika	0.17	Liwilla	0.77
Kadett	0.36	Henika	1.00
Liwilla	0.43	Kadett	1.47
Jara	0.60	Jara	1.73

95 % Tukey HSD=0.28.

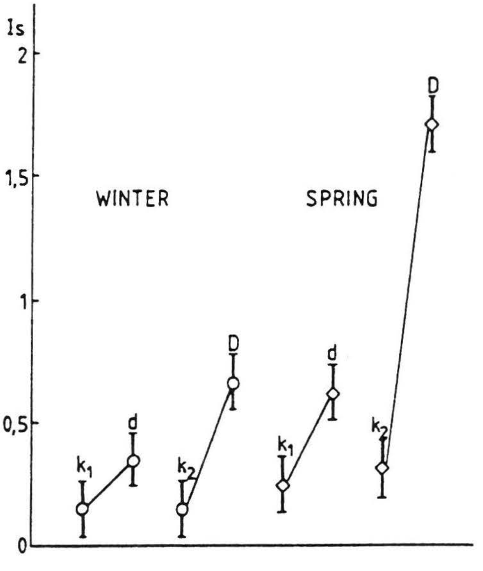

Fig. 4. Mean values of the indexes of damage Is for grain samples of winter and spring wheat varieties before (k_1,k_2) and after loading (d,D). 95 % Tukey HSD=0.21.

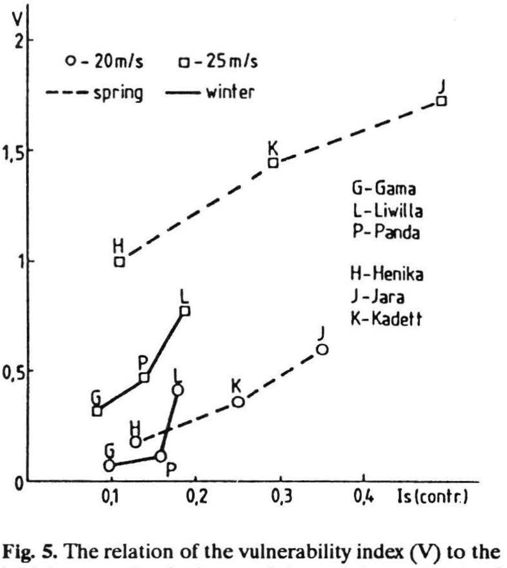

Fig. 5. The relation of the vulnerability index (V) to the initial status of grain damage Is(contr.) for two levels of loading within the groups of winter and spring wheat varieties.

Interesting conclusions can be formulated analyzing the 'damage balance' of grain samples before and after loading (Table 1). The numbers on the diagonal of the table of transitions indicate how many grains avoided further destruction. The sum of such grains, as a ratio of the sample size, can be used as an index of resistance (*R*) damage of the grain sample tested. The *R* index is strongly negatively correlated with the vulnerability index *V* (r=-0.9939 for winter varieties and r=-0.9970 for spring varieties, at α <0.01).

In most of the samples the percentage of grains which were not subjected to further destruction did not decrease in the successive damage classes and remained on a constant level. Only in the Henika and Kadett samples these values decreased from class to class.

The first column of the table of transitions allows for an assessment of the behaviour (distribution of the damage index and its mean value), under the loading applied,

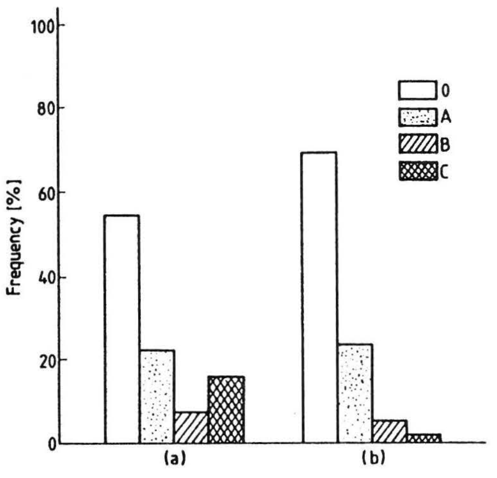

Fig. 6. Histograms of typical distributions of the damage index with respect to the grain damage classes {0, A, B, C} for Jara (a) and Liwilla (b) varieties (after dynamic loading).

of the so-called 'zero' control, i.e., the sample initially completely free from grain damage. There is a strong linear relation between damage indexes calculated in the above manner and the values of the vulnerability index V ($r=0.9988$ at $\alpha<0.01$).

CONCLUSIONS

The analyses of the internal damage of wheat grain samples allowed for the formulation of the following conclusions:

1. The grain of spring varieties is more vulnerable to damage caused by dynamic loading than is the grain of winter varieties. It relatively easily yields to considerable destruction under the effect of such loading.
2. The absence of an overall relation between the initial status of grain damage and grain vulnerability to damage shows that the latter is affected primarily by the differentiated properties of the particular varieties, and especially by the different properties of the two forms of wheat.
3. In the case of dynamic loading there is no supporting evidence for the hypothesis that the more grain is damaged, the more easily it should yield to further destruction.
4. In the case of a lack of 'zero' control, it is possible to make a highly accurate assessment of the behaviour of a grain sample under the effect of loading basing on the damage balance analysis.
5. The damage balance analysis can also be used to assess the resistance index R of a grain sample tested, as the R index is strongly correlated with the vulnerability index V.

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