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METHOD OF ESTIAMATION OF PERMISSIBLE IMPACT ENERGY FOR RAPESEED *

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Abstract. The majority of interactions between seeds and machine units during harvesting and transport has a dynamic nature, so as there is essential to estimate the maximal impact energy delivered to seed, without failure of its structure.

The testing apparatus was constructed in order to simulate dynamic loads to be found in harvesters and transporters. The experiment was conducted on four varieties of winter rape at various moisture content, maturity and size as well as spatial orientation of seeds versus beater. Each experimental combination was exposed to the similar striking energy. The amount of micro- and macro-damage of seeds was the measure of their resistance to dynamic loads.

Keywords: impact, rape seed, maximal energy

INTRODUCTION

In the processes of mechanized harvest, transport, cleaning and storage we encounter the dynamic effect (contact) of elements of machines on seeds. According to numerous papers, an increase in the rate of loading, and therefore also in the rate of strain, results in a change in the limit of plasticity and, consequently, causes a transition of the material towards brittleness.

In grain-steel impact contact, stress and strain are propagated from the point of force application at a finite speed, forming stress and strain waves. Longitudinal and lateral strain waves occur at the point of impact force application. At nodal points, those waves cause particularly high strain, and therefore also high stress. Thus it is hardly possible to speak about any even distribution of stress in a seed under impact, and determination of stress values resulting from known impact forces using classical formulae yields only approximate, and not true, values. This is one of the reasons for which we have decided not to try to determine the values of stress, and to concentrate on calculating the energy (work) necessary to destroy a sample.

Impact phenomena are fairly extensively described in literature as far as crystalline and isotropic bodies are concerned, but considerable difficulties are encountered in plant material (especially in seeds), due to the variability of the physical properties of such materials, related to the morphological structure, moisture, stage of ripeness, and genetic features.

Most studies concerned with mechanical damage to seeds are conducted in the function of seed moisture [5]. This is true of both laboratory and field experiments. Most

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frequently, the authors of such publications also relate the extent of seed damage with the operation of certain working elements of the combines. Also the size of the seeds, their structure, position at the moment of impact, and the manner of damage infliction (static, dynamic) affect the resistance of seeds to damage [1-3].

The study presented herein is an attempt at providing an answer to the question of how rape seeds behave under impact loading.

MATERIAL AND METHOD

The study of the strength properties of rape seeds was carried out on a test stand, the design and methodological criteria of which allow for the simulation of dynamic loading encountered in practice in threshing, diminuting, and transporting agricultural machines.

Figure 1 presents schematically seed hitting by a beater installed in a rotating body, meeting the following test requirements: possibility of stepless control of beater r.p.m. and possibility of any required orientation of seed with relation to the hitting surface of the beater.

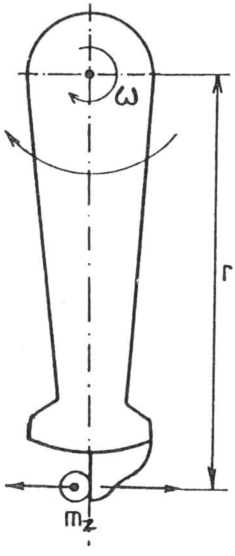

Fig. 1. Schematic diagram of the dynamic seed damage apparatus. m_z-seed mass, r-beater web, ω-angular velocity of the beater.

Considering the seed-beater impact with the assumptions that the angular velocity of the beater remains constant during the impact, and there is no deformation of the beater we obtain an expression describing the energy of permanent seed deformation, as follows:

$$E_{\mathrm{pl}} = (1-k^2)\frac{m_z u^2}{2} \qquad (1)$$

where $u=\omega\ r$, ω - angular velocity of the beater, k - coefficient of restitution determining the degree of impact elasticity.

In the theoretical analysis of the probability of grain damage we assume the relation of the probability to E_{pl}.

Formula (1), however, justifies an analysis of the relation of the probability of grain damage to energy:

$$E = \frac{m_z \cdot u^2}{2} \qquad (2)$$

which is energy of grain corresponding to its velocity equal to the velocity of the beater-grain contact point.

The required value of energy E is obtained by selecting an angular velocity of the beater ω for a specific seed mass m_z.

Simulation studies were conducted with two rape seed orientations: A - at the moment of contact with the seed the beater surface plane was parallel to the cotyledon division plane; B - at the moment of contact with the seed the beater surface plane was perpendicular to the cotyledon division plane.

The studies were conducted on the following rape varieties: Liporta, Ceres, Bolko, and Mar, harvested at the stage of full ripeness, and additionally on seeds of the Liporta variety harvested 5 days before full ripeness. Seeds of the particular varieties were separated into three fractions of the following diameters: I - 1.8 mm, II - 2.0 mm, III - 2.3 mm.

Estimation of seed macro- and microdamage was performed according to methods described earlier [4].

For the Ceres variety, at seed orientation A, a probabilistic analysis of seed damage occurrence was carried out on the basis of the Wiebull model of reliability of nonreproducible objects. The determined functional characteristics of the model allow to forecast the probability of seed damage for every value of impact energy. The probabilistic analysis is considered here as a presentation of the proposed method for statistical studies of seed damage under impact basing on results of experimental studies.

Probabilistic model of seed damage

Adopting seeds as the object, and damaged seeds as irreversible failure, we can transpose the probabilistic methods used in the theory of reliability of nonreproducible processes onto the determination of the probability of the occurrence of seed damage during impact. This is based on the fact that for a given value of energy E the occurrence of seed damage will be accidental in character, and the seed will remain undamaged up to a certain value of energy at which seed damage occurs. The range of energy values $E \leq E_u$ is the range of nondamageability of the object. Energy assumes random values, so it can be treated statistically, i.e., we can adopt a random variable ε denoting the energy of nondamageability of objects in a certain population.

For the analysis of experimental data, we will apply the Weibull mathematical model of objects, for which the extent of damage is defined by the function:

$$\lambda(E) = \alpha \beta^{\alpha-1}. \qquad (3)$$

The remaining function-type characteristics are defined by the relations:

$$R(E) = \exp(-\beta E^{\alpha}) \qquad (4)$$

$$F(E) = 1-\exp(-\beta E^{\alpha}) \qquad (5)$$

$$f(E) = \alpha \beta E^{\alpha-1} \exp(-\beta E^{\alpha}) \qquad (6)$$

where $R(E)$ - function of nondamageability (reliability), which is the probability of not damaging a seed at least up to a random variable value - E, $f(E)$ - density of probability of damage, $F(E)$ - probability of damage (unreliability function). In the case of $F(E=0) = 0$ it is the distribution function of the random variable; α, β - distribution parameters.

Transforming Eq. (5) we obtain a linear relation of variable $Y = \ln\ln\frac{1}{1-F}$ to variable $X = \ln E$ in the form:

$$\ln\ln\frac{1}{1-F} = \alpha \ln E + \ln\beta. \qquad (7)$$

Plotting the curves of relation $Y = f(X)$ on linear grids, or the functions of the relation of F to E on Weibull grids, we can determine coefficients α and β, and thus determine the function characteristics of the reliability of the process of seed damage.

STATISTICAL ANALYSIS OF EXPERIMENTAL RESULTS

The results of the experimental studies are presented according to increasing energy values within ranges of $\Delta E = 100$ mJ. The size of each range is $N_1 = 100$ seeds (Table 1).

Table 2 presents the values of the experimental distribution function F^* in the function of the values of E, corresponding to the centres of ranges ΔE and to the values of the experimental variables $X = \ln E$ and $\ln\ln\frac{1}{1-F*}$.

On the basis of the data in Tables 1 and 2 curves of the empirical density of probability and of the empirical distribution functions were plotted in Figs 2-5.

In order to estimate the values of coefficients α and β, the points of the experimental distribution function were plotted on the Weibull distribution grids. Next, using the method of the smallest squares, straight lines were matched to the experimental points (Fig. 6), and coefficients α_1 and β_2 were determined for those lines (Table 3). Comparing the forms of the curves of co-ordinates

Table 1. Experimental point and range results (sample size N=700, range size N_1=100)

Range ΔE (μJ)	Probability of damage Δ F* (%) in range ΔE			Range limit 0 - E_u (μJ)	Probability of damage F* in (%) for E ≤ E_u		
	macro	micro	Σ damage		macro	micro	Σ damage
190 - 290	0.57	0.29	0.86	290	0.57	0.29	0.86
290 - 390	0.76	0.53	1.29	390	1.33	0.81	2.14
390 - 490	2.00	0.86	2.86	490	3.33	1.67	5.00
490 - 590	0.86	0.64	1.50	590	4.19	2.31	6.50
590 - 690	1.86	1.71	3.57	690	6.04	4.03	10.07
690 - 790	3.43	3.29	6.71	790	9.47	7.31	16.78
790 - 890	3.86	5.00	8.86	890	13.33	12.31	25.64

F* - experimental distribution function.

Table 2. Data for the experimental distribution function and for the Weibull distribution

Eu (μJ)	Probability of damage F* for E ≤ E_u			ln Eu (μJ)	$\ln\ln\frac{1}{1-F^*}$		
	macro	micro	Σ damage		macro	micro	Σ damage
240	0.0057	0.0029	0.0086	5.481	-5.164	-5.842	-4.752
340	0.0133	0.0081	0.0214	5.829	-4.313	-4.812	-3.834
440	0.0333	0.0167	0.0500	6.087	-3.385	-4.084	-2.970
540	0.0419	0.0231	0.0650	6.292	-3.151	-3.756	-2.700
640	0.0604	0.0403	0.1007	6.461	-2.776	-3.191	-2.243
740	0.0947	0.0731	0.1678	6.607	-2.308	-2.578	-1.695
840	0.1333	0.1231	0.2564	6.733	-1.945	-2.030	-1.217

Table 3. Values of coefficients α_1 and $\ln\beta_1$ for the estimation of the form of curves of Eq. (6) and of the median E_m

Curve	Curve section	α $(\frac{1}{\mu J})$	$\ln\beta$	$\eta=\frac{1}{\beta}\frac{1}{\alpha}$	E_m (μJ)	Type of damage E_m (μJ)
I	a	2.904	-21.752	1791.0		micro-damage
	b	1.598	-13.811	5669.3		
	c	4.267	-30.760	1352.3		
IIz	a	2.640	-20.254	2149.6	1871	
	b	3.927	-28.504	1420.7	1294	
III	-	2.915	-21.863	1810.9		
I	a	2.923	-20.801	1232.5		Σ damage
	b	1.318	-10.993	4190.1		
	c	3.773	-26.623	1159.0		
IIz	a	2.562	-18.749	1507.1	1306	
	b	3.386	-24.053	1215.8	1091	
III	a	2.540	-18.662	1552.1		
	b	3.773	-26.623	1159.0		
- Z -	-	2.517	-18.929	1854.7	1596	macro-damage

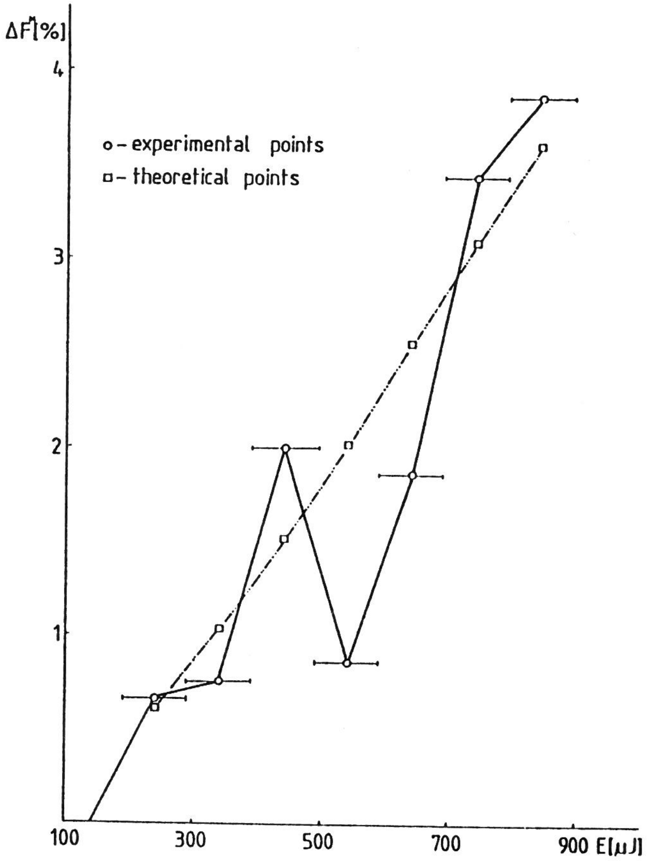

Fig. 2. Experimental graph of the function of probability density (ΔF*) and damage energy (E) for macro-damage.

calculated for the matched lines with the forms of the experimental curves, such curves were selected whose forms were the closest to the experimental results. In Table 3, coefficients α and β for those curves are identified by the symbol z.

Basing on the values of coefficients α and $\ln \beta$, the co-ordinates of the points of the functional characteristics of non-damageability for seed macro-damage are presented (Table 4). Figure 7 presents graphs of functions $f(E)$ and $F(E)$ for macro-damage. Corresponding curves can also be obtained for micro-damage and for Σ damage.

The coefficients α and β determined, moreover, allow for the determination of the numeric characteristics of the stochastic process of seed damage which assume the following values:

- expected value

$$\bar{E} = E_0 + \eta \, \Gamma\left(\frac{1}{\alpha} + 1\right) \tag{8}$$

- standard deviation of variable

$$\sigma = \beta^{\frac{-1}{\alpha}} \left[F\left(\frac{2}{\alpha} + 1\right) - \Gamma^2\left(\frac{1}{\alpha} + 1\right)\right]^{\frac{1}{2}} \tag{9}$$

- median

$$E_m = Me\,(E) = E_0 + \eta\,(\ln 2)^{\frac{1}{\alpha}} \tag{10}$$

- mode:

$$Mo\,(E) = E + [\beta^{-1}\left(1 - \frac{1}{\alpha}\right)]^{\frac{1}{\alpha}} \tag{11}$$

where Γ-gamma function, E_0-threshold parameter of the distribution.

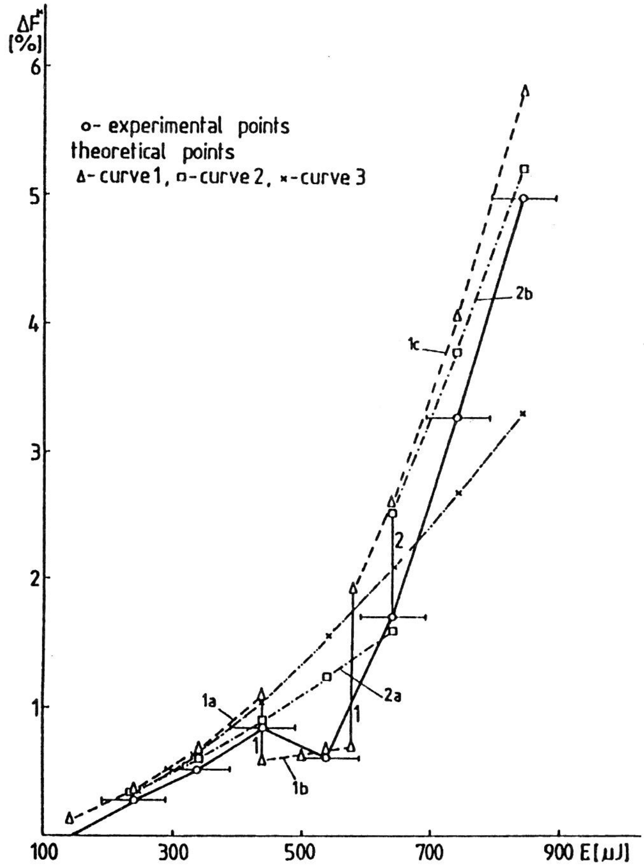

Fig. 3. Experimental graph of the function of probability density (ΔF*) and damage energy (E) for micro damage. (a, b, c - curve section as in Table 3).

Coefficients α and β determine also the numeric measures of the asymmetry and flattening of the random variable distribution.

To sum up the foregoing, we can state that the presented method for the study of seed damage under impact may find an extensive application in statistical studies on damage. It allows also to forecast damage for high values of energy *E*-beyond the scope of experimental studies. It allows for the determination of all the characteristics of random variable distribution, with a specific interval of credibility.

Knowledge of the distribution characteristics allows the comparison of the resistance to impact of various varieties of seeds under a variety of conditions, and the forecasting of a safe - from the viewpoint of seed damage - value of energy *E*.

Table 3 presents the values of median E_m of the random variable for the distributions finally accepted.

The distributions for the particular sections of the assigned curves correspond to various internal mechanisms of seed damage. The distributions presented are related to the total number of seeds in a sample. The application of the Weibull distribution allows the percentage estimation of the number of seeds subject to specific damage mechanisms, and thus the determination of partial characteristics corresponding to those particular damage mechanisms.

The simulation study of seed damage carried out has a significant value in the process of estimation of seed resistance to dynamic da-

Table 4. Numeric values for the distribution functions determined (macro-damage)

E (μj)	F (E)	R (E)	$10^4 \lambda (E) (\frac{1}{\mu J})$	$10^4 f(E) (\frac{1}{\mu J})$
140	0	1.00	0	0
240	0.0059	0.9941	0.6177	6.1402
340	0.0141	0.9859	1.0477	1.0329
440	0.0267	0.9733	1.5491	1.5077
540	0.0443	0.9557	2.1136	2.0199
640	0.0672	0.9328	2.7349	2.5512
740	0.0954	0.9046	3.4088	3.0836
840	0.1288	0.9712	4.1315	3.5994
1000	0.1925	0.8075	5.3824	4.3461
1200	0.2871	0.7129	7.0973	5.0599
1500	0.4475	0.5525	9.9564	5.5006
1800	0.6089	0.3911	13.1287	5.1342
2000	0.7890	0.2940	15.404	4.5295
2200	0.7060	0.2120	17.800	3.7560
2500	0.8831	0.1169	21.700	2.5263
2700	0.9261	0.0739	24.286	1.7945
3000	0.9665	0.0335	28.495	0.9545
4000	0.9999	0.0001	44.086	0.0400

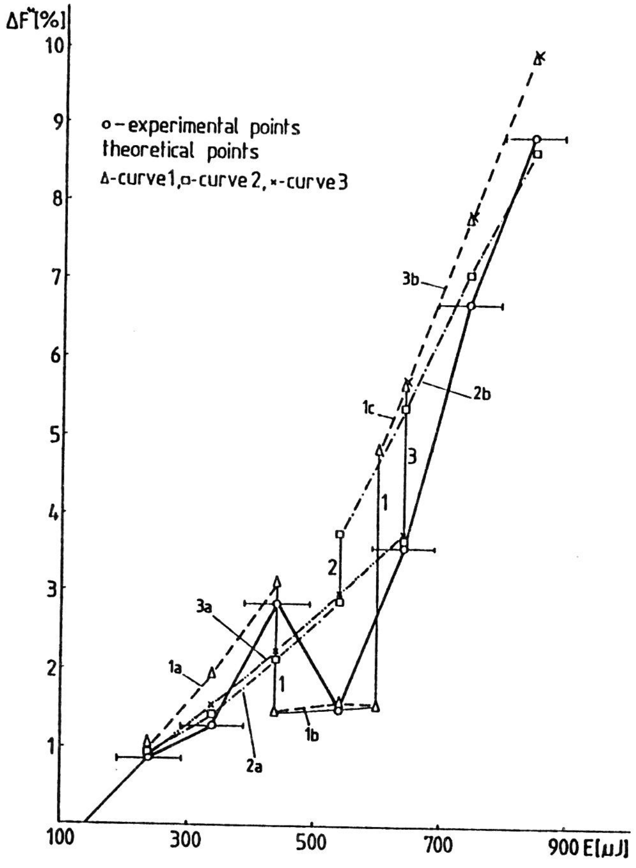

Fig. 4. Experimental graph of the function of probability density (ΔF*) and damage energy (E) for total damage. (a, b, c - curve section as in Table 3).

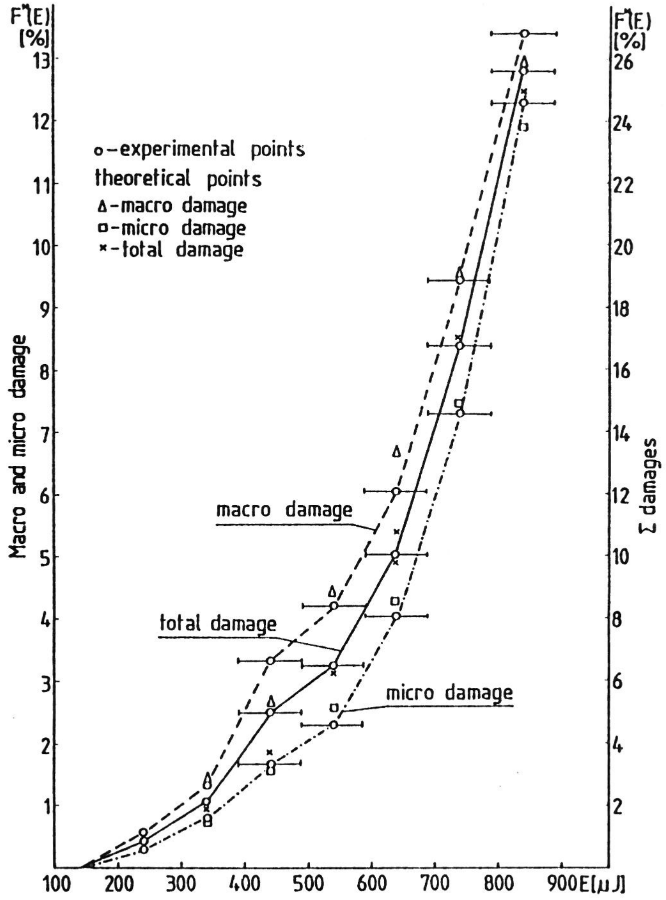

Fig. 5. Graph of the experimental distribution functions. Explanations as in Figs 2-4.

mage. This concerns the resistance features of a single variety (seed size, moisture, stage of ripeness), as well as comparisons of various varieties. This study has also a significant value for further studies on the process of seed diminution in the agricultural and food industry (energy requirements, efficiency, etc.).

The preliminary results obtained (Fig. 8) indicate that there is a distinct difference in the resistance of rape seeds to damage, related to the impact point. The beater hitting a point located in the plane of cotyledon division (orientation B) appears to be the most vulnerable position of the seed, and this is true for all the varieties under study. The phenomenon is the most pronounced in the case of the smallest seeds (1.8 mm fraction). In larger seeds, the difference (between orientations A and B) is less notable, nevertheless in the case of the Liporta variety it reaches up to 300 %. The largest proportion of damaged seeds was observed in the smallest fractions (1.8 and 2.0 mm fractions) - such seeds are distinctly less resistant to damage. This is especially true of such varieties as Mar and Liporta. One can suppose that the determining factor here is the biological conditions (degree of development, ripeness). Also significant, to a degree, is in this case the smaller radius of the seed curvature, and hence the seed-beater contact

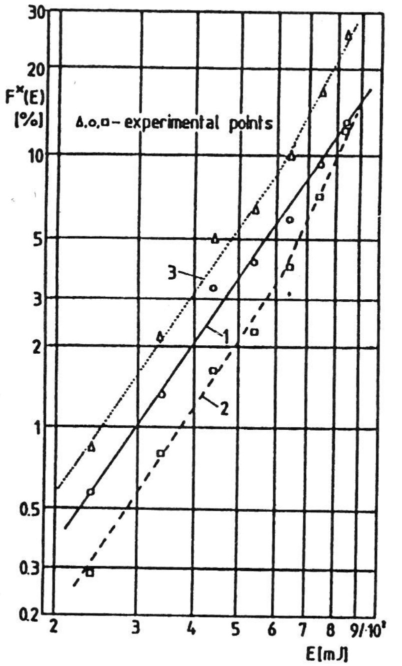

Fig. 6. Graph for function Y=f(X) determined from the Eq. (6) for macro-damage (1), micro-damage (2) and total-damage (3).

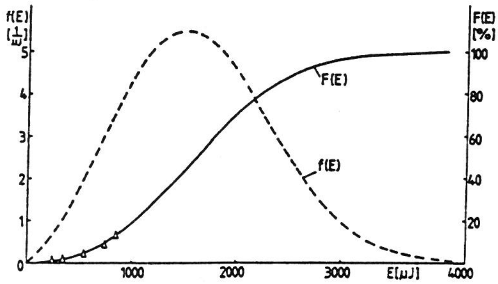

Fig. 7. Theoretical curves of the density of probability distribution f(E) and of the distribution function F(E) for seed macro-damage.

area is much smaller, with higher local stress.

CONCLUSIONS

1. Considerable differences were found in the resistance of rape seeds to dynamic loading. This is affected by the seed size, seed orientation at the moment of impact, varieties, and the stage of ripeness.

2. The statistical method presented above allows for seed damage estimation within a

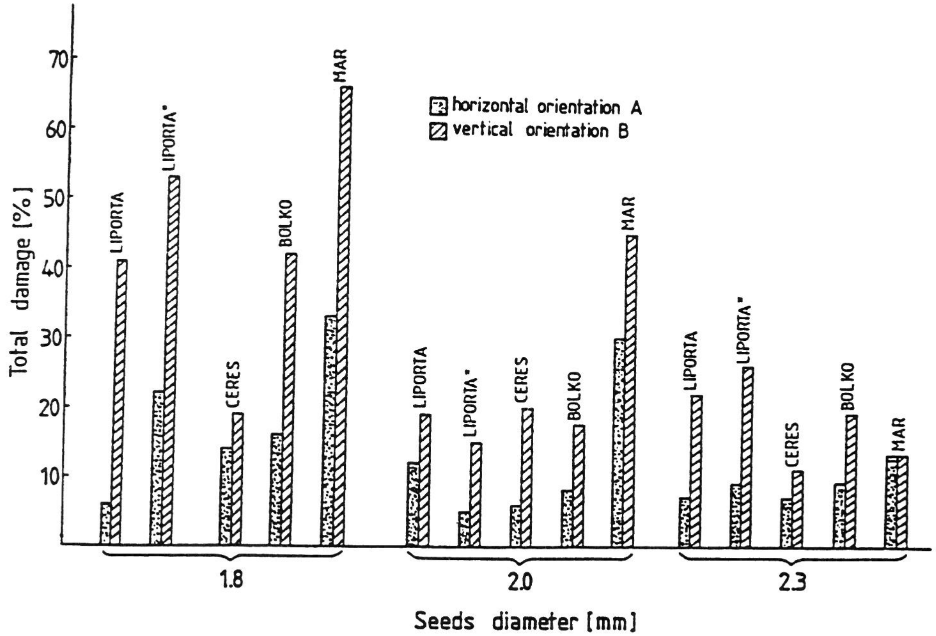

Fig. 8. Graphic presentation of the extent of seed damage for the varieties under study (E=400 μJ).

broad range of energy values.

3. Linear regression of the experimental results of the X and Y variables allows for the determination of the percentage of seeds which are subject to various mechanisms of damage occurrence, as well as for the determination of component distribution characteristics.

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