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RAPESEED DAMAGE AS INFLUENCED BY THE DYNAMIC LOAD

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A b s t r a c t. Studies were conducted on the resistance of individual rapeseeds to dynamic loading. The material consisted of three German varieties (Akela, Arabella, Emerald) and three varieties grown in Poland (Beryl, Jantar, Jupiter). Factors such as: two seed size fractions (1.6-2.0 and 2.1-2.5 mm); differentiated moisture content (4, 6, 9, 12, 15, 18, 21 %); and differentiated tangential velocity of the striker (4, 6, 8, 10, 12, 14 m/s) were used for determining the variability of seed resistance properties. The effects of dynamic forces were compared with the control. Macro- and micro-damage were evaluated for all the 756 combinations in the experiment (each combination consisted of 100 individual seeds). The statistically elaborated results showed that moisture content and the tangential velocity of the element striking the seeds exerted the greatest influence on the type and size of seed damage. The relations observed in the experiment were described by means of an exponential function. A very good agreement between the experimental results and the results of approximation was obtained.

INTRODUCTION

With increasing grain yield, quality is becoming an increasingly important factor in the grain market. Grain often subject to physical damage from the mechanical facilities used in harvesting, cleaning, drying and conveying operations. This damage leads to a decrease in the quality of grain and, as a result, to lower prices and greater storage problems.

A knowledge of the type and magnitude of force causing damage to various grains enables grain-handling equipment to be designed that minimizes the decrease in grain quality.

A lot of researchers have studied the problems connected with some aspects of grains damage from mechanical causes. Corn breakage susceptibility with respect to its moisture content was examined by Jindal *et al.* [5], Pulsen [8], Nguyen *et al.* [7] and Salter and Pierce [9]. Jindal *et al.* [5] also studied the influence of temperature on corn mechanical resistance. They confirmed that impact damage to corn increases with decreasing temperature but sustains the smallest for 25 % moisture content, increasing rapidly as the moisture content increases or decreases from this value. Bilanski [1] reported that size, moisture content and grain position all influenced its damage resistance. Fiscus *et al.* [4], by studying the physical damage caused by various handling techniques for corn, soybeans, wheat, barley and oats, proved that dropping grain from hights greater than 40 ft caused more breakage than any other handling method tested and that corn incurred more breakage than soybeans, and soybeans more breakage than wheat. Breakage was greater at low grain moisture and temperature. The dependence between Young's modulus and deformation velocity for corn kernels was checked by Kusterman and Kutzbach [6].

However, only a few researchers have conducted similar investigations on rape. Davison *et al.* [2] studied the maximum compressive strength of rapeseed, the apparent modulus of elasticity at various moisture contents, and estimated Young's modulus of rapeseed shell from its stress characteristics. Davison *et al.* [3] developed a stress-strain model for compressed rapeseed. Szot [11] estimated the mechanical properties and the susceptibility to damage of many winter rapeseed varieties. The influence of temperature on rapeseed strength was reported by Szot *et al.* [12].

The objective of this research was to estimate the mechanical resistance of rapeseed in a dynamic test with respect to the moisture content and the size of kernels in the wide range of the deformation velocities.

MATERIALS AND METHODS

Six rape varieties were taken as study material, i.e., three varieties grown in Germany (Akela, Arabella, Emerald), and three varieties grown in Poland (Beryl, Jantar, Jupiter), (Fig. 1). Firstly, seeds were fractionated by means of a set of sieves in order to divide them into two fractions, viz. 1.6-2.0 mm, and 2.1-2.5 mm in order to establish whether the seed size influences the type and character of seed damage. The weight of a 1 000 kernels was measured for each of the fractions as well as for the seeds with the natural granulometric composition as this is an index of the shapeliness of the individual varieties.

The most numerous fraction (2.1-2.5 mm) was then moistened in closed containers in order to arrive at differentiated moisture contents of 4, 6, 12, 15, 18, and 21% before the measurements were started. Seed samples of all the studied varieties were treated in that way only if they belonged to this bigger fraction. Each moisture content was checked immediately before the measurements in a special dryer 'System Gronert Ultra X'. The differences that appeared in three replications at each of the applied moisture contents ranged between the limits of 0.26 %.

Dynamic measurements of rapeseeds were conducted at the Hohenheim University on a prototype apparatus constructed at the University in Bonn [10] (Fig. 1).

The idea consists in a gyrating element that hits the sample with an electronically controlled tangential velocity that can be read on a meter. The apparatus has already been used for dynamic studies on corn seeds, and after some minor adaptations could be used for rapeseeds as well. The diameter of the striking element was slightly bigger, that is 2.7 mm, than the size of the biggest seeds (2.5 mm). The tangential velocity levels of the striker were the following: 0 (control), 4, 6, 10, 12, 14 m/s. The automatic feeder (synchronized with the rotations of the striker) allowed for placing 10 individual seeds at a time. A hundred seeds were applied as one of the experimental combinations. There was a 10-fold filling of the feeder by seeds of the same size, variety and moisture content. After they had been struck the seeds fell into a special container made of very soft cloth, and after each series of measurements they were submitted to further analyses. At first, the macro-damage of each of 100 seed samples was determined (i.e., visible cracking of the seed, seed cover or cotyledon decrements). Those seeds that were seemingly untouchted were placed on a Petri dish covered with soft tissue, moisturized with distilled water, and covered for 3 h. The micro-damage of these seeds could than be seen under the magnifying glass. Undamaged seeds did not show any changes - similarly to control samples.

The total number of experimental combinations analysed was 756. The combinations included size of seeds, their different moisture contents, and the different tangential velocities of the striker.

An attempt was made to estimate the effects of impact at a specific positioning of the seed. The first variant included striking

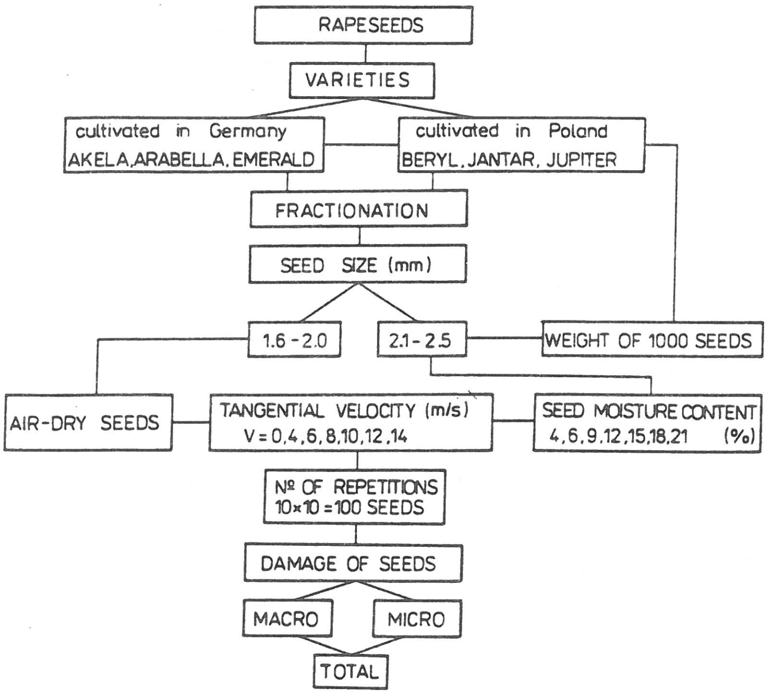

Fig. 1. Scheme of the dynamic investigations of rapeseeds.

at the vertical positioning of the cotyledons, and the second at their horizontal position. This part of the experiment included 16 combinations for the air-dry seeds (6 %) of the Arabella variety, and a tangential velocity of the striker of 8, 10, 12, and 14 m/s.

Seed shapeliness, as measured by the weight of 1 000 seeds, ranged from 3.667 g (Emerald) to 4.971 (Jupiter), (Table 1). This index did not exceed 4.5 g for most of the studied varieties. Slight differences were observed in the individual seed size fractions and these values increased in proportion to the weight of 1 000 seeds determined in the natural state (before fractionation). Hence, the greatest differences for the 1.6-2.0 fraction were 0.9 g, and for the 2.1-2.5 mm fraction these differences were about 0.7 g.

Table 1. A 1 000 rapeseed weight (g) studied at the conditional moisture content of 6 %

Rapeseed size	Varieties					
	Akela	Arabella	Emerald	Beryl	Jantar	Jupiter
In mass	3.850	4.816	3.667	4.870	4.532	4.971
1.6 - 2.0 mm	3.333	3.767	3.330	3.700	3.766	4.233
2.1 - 2.5 mm	4.403	4.933	4.433	4.966	4.903	5.166

RESULTS

All the results were statistically worked out, and the analyses proved a high variability of the resistance of the studied rapeseeds to dynamic loading in relation to the given factors.

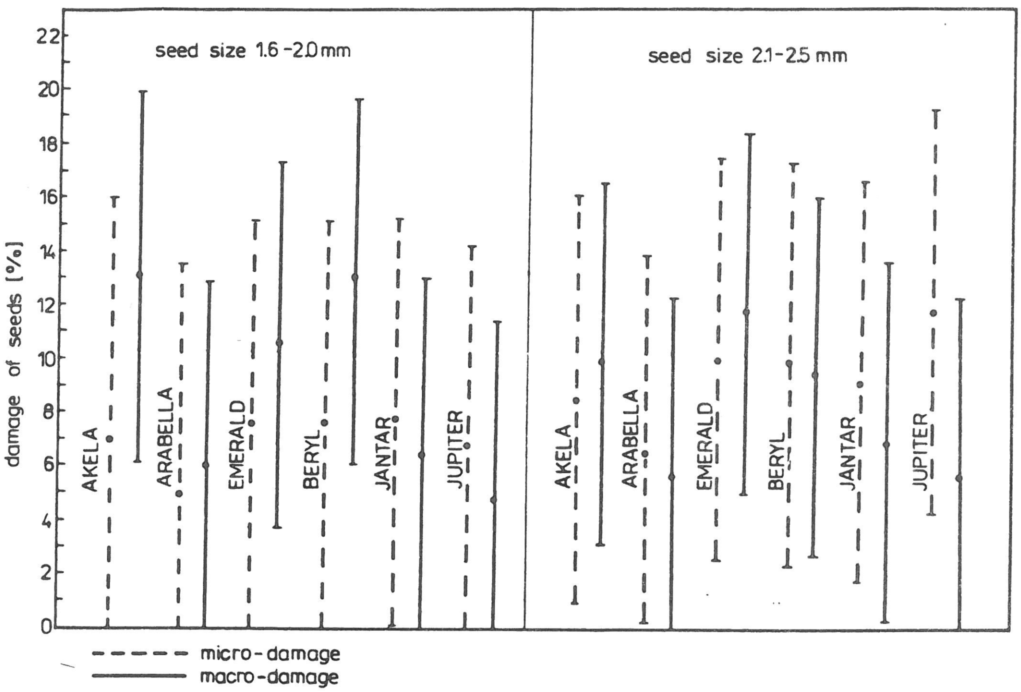

Fig. 2. Confidence intervals for the experimental combinations including comparison of the two fractions and six rape varieties in their macro- and micro-damage regardless of the level of dynamic loading.

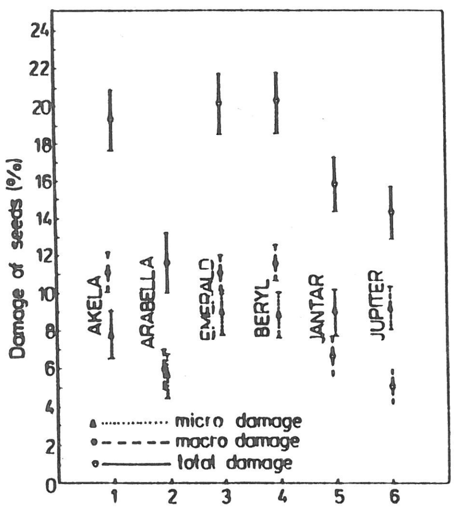

Fig. 3. Confidence intervals for the experimental combinations including the size and type of damage of air-dry samples from the six rape varieties regardless of the level of dynamic loading.

The analyses of variance showed that there were no significant differences in the size and character of damage between the two fractions (i.e., 1.6-2.01 and 2.1-2.5), (Fig. 2). The intervals of confidence that are given cover the whole range of dynamic loading. There was only a tendency towards a greater amount of micro-damage in seeds with greater diameter than in the smaller ones, which may result from their greater mass. It was also noticed that the amount of macro-damage was higher than the amount of micro-damage in per cent.

The results allow for the conclusion that rapeseed size does not play any significant role in the estimation of the damage, and any seed fraction may be taken as representative when estimating the effects of dynamic loading. For that reason only the most representative fraction of 2.1-2.5 mm was studied.

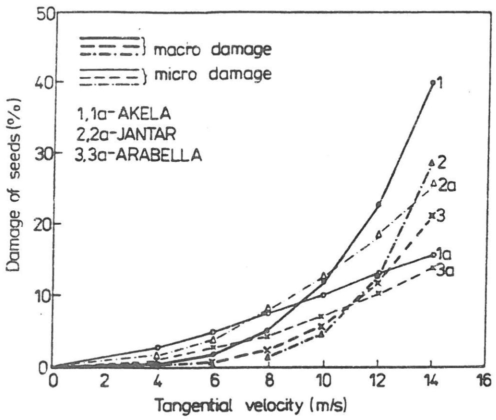

Fig. 4. The relationship between tangential velocity and the amount of macro- and micro-damage of rapeseed for three rape varieties.

Considerable differences among varieties were noticed when studying the influence of dynamic loading on the size and character of damage of air-dry samples of rapeseeds (6%), (Fig. 3). Two groups of varieties may be distinguished when analysing macro-damage: the least resistant ones - Akela, Emerald and Beryl, and much more resistant to dynamic loading - Arabella, Jantar, Jupiter. The most resistant to dynamic loading in terms of micro-damage were the seeds of Arabella. No statistically proved differences were noticed among other varieties when analysing micro-damage. However, when both macro- and micro-damage were estimated as total resistance of rapeseeds to dynamic loading, three statistically differentiated groups might be observed: Akela, Emerald, and Beryl were the least resistant; Jantar and Jupiter may be placed in the middle group; and Arabella belonged to the most resistant group. The above described differentiation points to a considerable varietal differentiation caused by genetic features.

The increasing tangential velocity of the striker increased the number of damaged seeds (Figs 2-4). The correlation between these two values was calculated in order to establish the relationship between them (Table 2). The correlation is highly significant at the level of significance above 0.01. The values so obtained pointed to the existence of a curvilinear relationship. A regression function of the type:

$$d(v) = a\,v^{b} \tag{1}$$

proved to describe it in the most suitable way, where d is the character of damage (macro-, micro-, total), v is the tangential velocity, a and b are the parameters of the regression function.

The values of the parameters and the coefficients of determination (R^2) are presented in Table 3.

Some examples of the graphs illustrating this relation are presented in Fig. 4. The figure shows an increase in the amount of macro-damage in the range of 8-10 m/s, and a very rapid increase above this value. On the other hand, micro-damage increased

Table 2. Values of the coefficients of correlation between the tangential velocity of the hitting element and seed damage

Rapeseed variety	Type of damage		
	Macro	Micro	Total
Akela	0.82281	0.86871	0.88341
Arabella	0.84160	0.87180	0.87576
Emerald	0.82802	0.85191	0.89017
Beryl	0.83821	0.84556	0.88109
Jantar	0.78276	0.85143	0.87084
Jupiter	0.80251	0.80069	0.81443

For $\alpha = 0.05$ $r_{crit} = 0.5324$.
For $\alpha = 0.01$ $r_{crit} = 0.6614$.

Table 3. Values of parameters (a, b) and the determination coefficients (R^2) for the regression function d(v)

Rapeseed variety	Parameter	Type of damage		
		Macro	Micro	Total
Akela	a	0.00299987	0.45929934	0.06020599
	b	3.60044505	1.34454081	2.58305168
	R^2	0.945104	0.914551	0.964332
Arabella	a	0.00075787	0.0605306	0.01193908
	b	3.88498397	2.07087024	3.03372905
	R^2	0.986484	0.933481	0.980753
Emerald	a	0.00033493	0.28459683	0.3471679
	b	4.44580838	1.61745106	2.82350922
	R^2	0.996265	0.888064	0.980388
Beryl	a	0.000256112	0.08651746	0.02931346
	b	3.66421786	2.11566030	2.90714162
	R^2	0.96634	0.887714	0.973072
Jantar	a	0.00003806	0.10143504	0.01934863
	b	5.12668198	2.10528791	3.00049967
	R^2	0.979221	0.886324	0.964495
Jupiter	a	0.00014708	0.02467535	0.00666215
	b	4.47839689	2.62527636	3.34421355
	R^2	0.970033	0.896086	0.937228
All the varieties	a	0.00079107	0.13468490	0.02594627
	b	4.018634	1.89717790	2.87557912
	R^2	0.891048	0.848003	0.932652

Table 4. Values of the correlation coefficients between seed moisture content (m), tangential velocity (v), and the type of damage (macro-, micro-, total) for the individual varieties

Rapeseed variety	Type of damage					
	Macro		Micro		Total	
	m	v	m	v	m	v
Akela	-0.46825	0.57602	-0.42189	0.57253	-0.48441	0.62086
Arabella	-0.41376	0.49365	-0.60907	0.37732	-0.53456	0.46623
Emerald	-0.37885	0.52733	-0.56537	0.40556	-0.51268	0.52454
Beryl	-0.43073	0.45391	-0.56828	0.46350	-0.52010	0.48711
Jantar	-0.39604	0.37240	-0.59454	0.35229	-0.52503	0.40002
Jupiter	-0.40602	0.41603	-0.61720	-0.41361	-0.55743	0.44222
All the varieties	-0.42869	0.48284	-0.59809	0.45537	-0.53748	0.50173

For $\alpha = 0.05$ $r_{crit} = 0.2800$.
For $\alpha = 0.01$ $r_{crit} = 0.3700$.

only slightly when compared to macro-damage.

Great changes in the resistance of rapeseeds to dynamic loading occur when the differentiated seed moisture content was combined with the increasing tangential velocity of the striker. The number of damaged seeds increased rapidly along with the decrease in seed moisture content, and with the increase of tangential velocity - though the effects were different for different varieties in individual combinations. To establish the relationship between seed moisture content, tangential velocity and the amount and type of damage in individual varieties, coefficients of correlation were calculated (Table 4). They appeared to be highly significant at the level of significance higher than $\alpha = 0.01$. The correlation coefficients between damage and moisture content were always negative, and between damage and tangential velocity always positive. The level of these coefficients points to the existence of a non-linear relationship between the studied features. The most suitable function of regression was sought to describe the type of changes in the studied features. The following function seemed the most suitable to meet this end:

$$D(v, m) = a \exp (bv + cv^2 + dm + em^2 + fmv) \quad (2)$$

where D is the type of damage (macro-, micro-, total), v is tangential velocity, m is seed moisture content and $a, b, ..., f$ are the parameters of the regression function.

The values of the function parameters together with the coefficients of determination are given in Table 5.

Preservation of the variation type of the studied features together with very high coefficients of determination prove the suitable choice of the function. Fig. 5 shows a graph made on the basis of experimental measurements (a), and a graph after the approximation by means of the regression function (b) for the seed macro-damage for the Jupiter variety.

All the varieties were characterized by means of the function $D(v, m)$, and for each variety the amount of macro-, micro-, and total damage was established as a general index of rapeseed resistance to mechanical dynamic loading. Some examples of the graphic representation of these regression functions for some of the studied varieties are given in Figs 6 and 7.

Considerable intervarietal differences were observed while analysing the character of macro-damage. The Akela seeds already became damaged at the 18 % moisture content and tangential velocity of 8 m/s. With decreasing moisture content and increasing velocity the number of macro-damaged seeds increased rapidly. The reaction of the

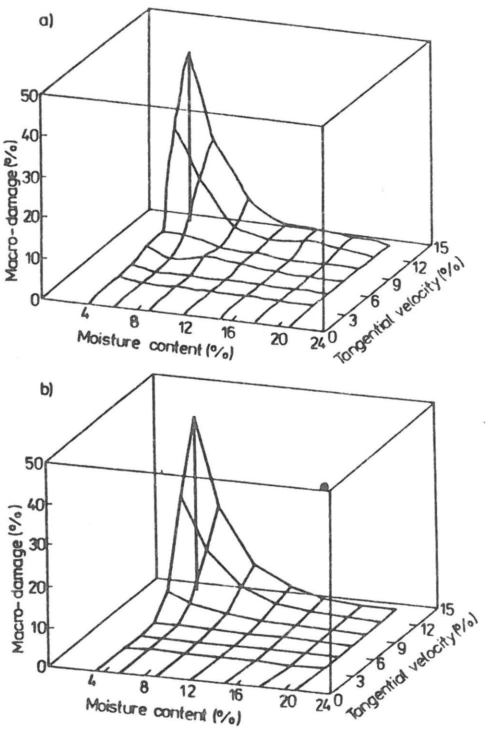

Fig. 5. Macro-damage of Jupiter rapeseeds in relation to their moisture content and tangential velocity on the basis of experiment results (a), and after approximation by means of the regression function (b).

Table 5. Values of parameters (a,b, ..., f) and the coefficients of determination (R^2) for the regression function D(v, m)

Rapeseed variety	Parameter	Type of damage		
		Macro	Micro	Total
Akela	a	0.066053	0.67519	0.41838
	b	0.56544	0.60411	0.60815
	c	-0.0086576	-0.023814	-0.018618
	d	0.28747	-0.077696	0.069441
	e	0.014055	0.00031634	0.0086694
	f	0.013709	0.00082868	0.0018515
	R^2	0.9667	0.8351	0.9442
Arabella	a	0.0018396	37.0421	8.2427
	b	1.50728	0.15164	0.38132
	c	-0.05103	-0.014515	-0.013370
	d	-0.45965	-0.66200	-0.55043
	e	-0.0074356	0.018112	0.00048187
	f	-0.0069362	-0.052559	-0.023526
	R^2	0.9771	0.9287	0.9665
Emerald	a	0.070368	0.10350	0.99273
	b	0.57090	1.42465	0.62934
	c	-0.015197	-0.08999	-0.031748
	d	0.21594	-0.81778	-0.18595
	e	0.057947	0.057660	0.051136
	f	-0.025829	-0.11517	-0.052897
	R^2	0.9372	0.9471	0.9550
Beryl	a	0.0032855	1.14976	0.44423
	b	1.36590	0.87385	0.88168
	c	-0.044348	-0.057295	-0.038377
	d	-0.30387	-0.79447	-0.48439
	e	0.013402	0.051649	0.027846
	f	-0.014359	-0.10367	-0.048024
	R^2	0.9919	0.9431	0.9802
Jantar	a	0.00011840	0.71531	1.20945
	b	2.86708	0.56954	0.65526
	c	-0.13322	-0.043411	-0.26724
	d	-2.73942	0.22992	-0.24372
	e	0.019594	0.13296	0.049215
	f	0.9938	-0.088342	-0.036828
	R^2	$1.0068\ 10^{-10}$	0.9649	0.9898
Jupiter	a	4.04718	51.0062	16.8214
	b	-0.14546	0.25182	0.35577
	c	-0.28873	-0.027777	-0.017218
	d	-0.00005148	-0.81113	-0.64325
	e	0.00046244	0.055964	0.022424
	f	0.9914	-0.098232	-0.049452
	R^2	0.00020952	0.9630	0.9768
All the varieties	a	1.78270	3.70461	1.97287
	b	-0.060280	0.69912	0.644142
	c	-0.060280	-0.044991	-0.026635
	d	-0.27891	-0.77584	-0.48732
	e	0.0041181	0.025565	0.011108
	f	-0.0062943	-0.074616	-0.032692
	R^2	0.9891	0.9663	0.9844

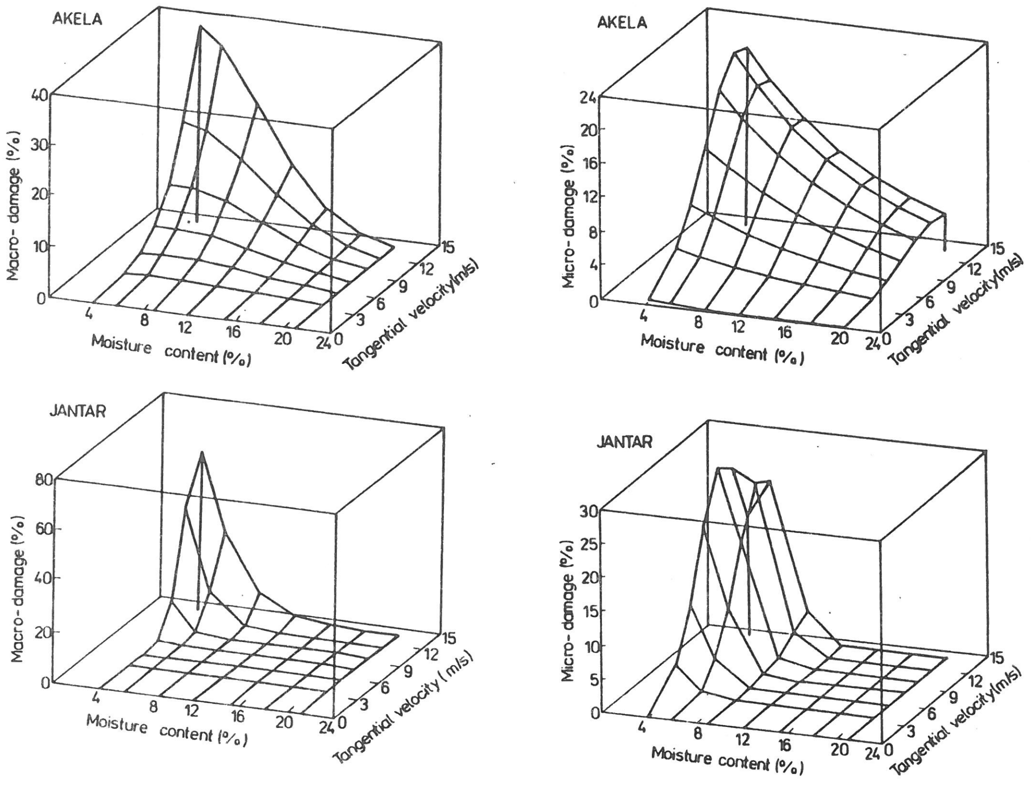

Fig. 6. The regression function for the macro- and micro-damage of Akela and Jantar rapeseeds in relation to their moisture content and the tangential velocity of the striker.

Jantar seeds was slightly different. The first macro-damages appeared at the 12 % moisture content and the tangential velocity of 14 m/s; and when the seeds were very dry (4%) at a velocity of 8 m/s. However, at the lower moisture content levels (4 and 6 %) and high levels of tangential velocity (12 and 14 m/s) more macro-damage was observed in Jantar than in Akela. When the micro-damage of these two varieties was analysed it could be noticed that the Akela seeds underwent micro-damage at almost all the moisture content levels and at any tangential velocity level, whereas in the case of Jantar the micro-damage could be observed only below the moisture content level of 12%.

To evaluate the resistance of rapeseed varieties to dynamic loading, a sum of macro- and micro-damage was established as an index of the resistance to damage of the individual varieties. As information of this type may have a practical value as well, a graphic representation of the results allowing one to predict the appearance of damage for any moisture content level and tangential velocity was worked out (Fig. 8).

The computer plotted levels characterize the course of seed damage increase along with the decrease of moisture content and the decrease of tangential velocity. The percentage of damage given at these levels enables the determination of any critical value for a specific variety, and both of the studied factors (moisture content, and velocity). Clearly seen intervarietal differences show the great influence of genetic features. In particular, Akela seems to be different from the other varieties. This variety seems to be especially susceptible to mechanical damage both at high moisture content level and low

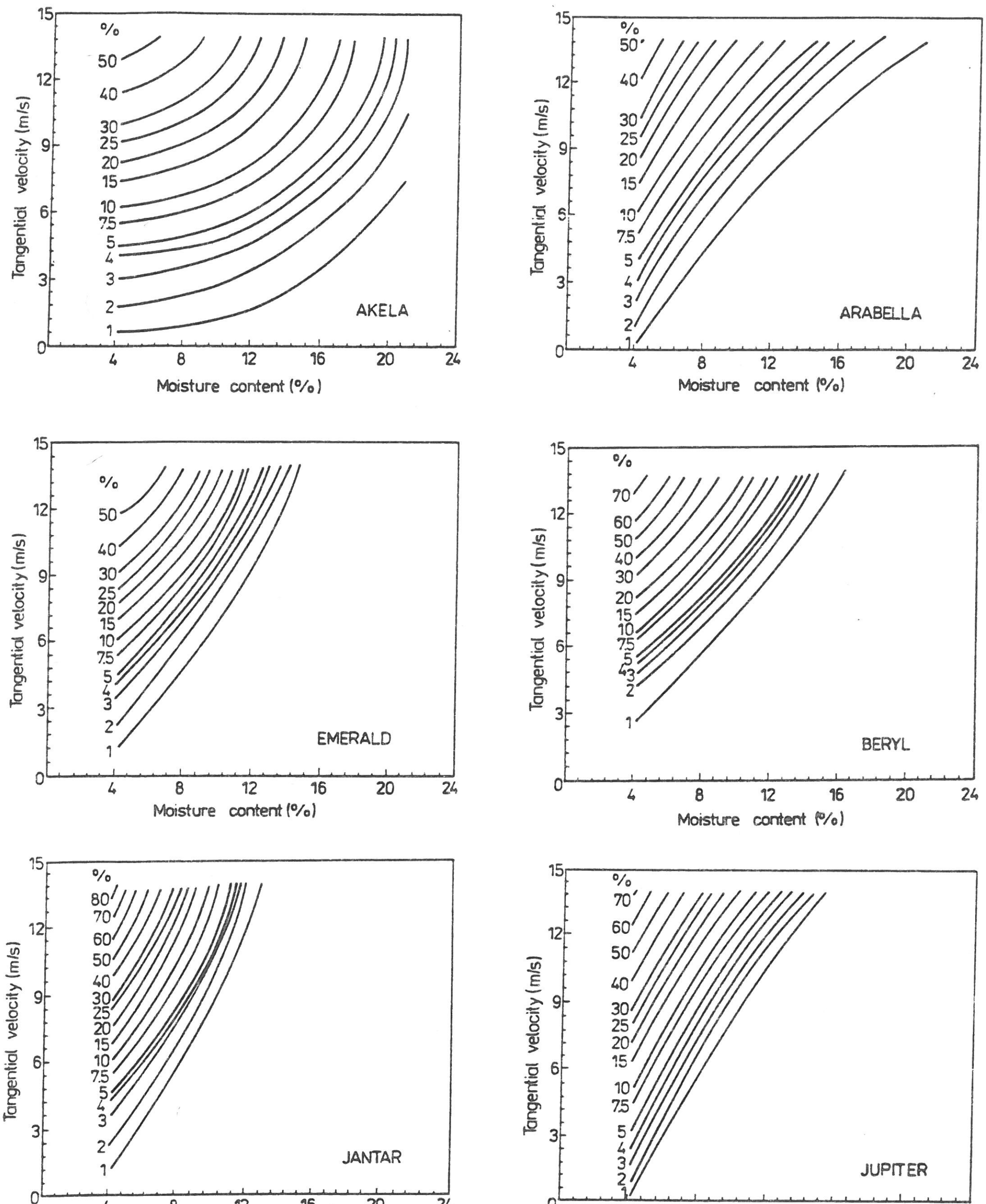

Fig. 7. Total rapeseed damage (macro- and micro-) for different seed moisture contents and tangential velocity of the striker.

tangential velocity level. On the other hand, Jantar seems to be the most resistant to mechanical loading since it shows no damage above 12% moisture content level and in the full range of the tangential velocities. However, below this moisture content level the amount of seed damage increases rapidly. At the least favourable level of moisture

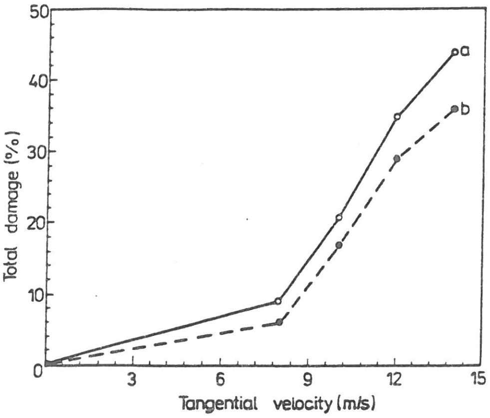

Fig. 8. Arabella rapeseeds damage at the horizontal (a) and vertical (b) positioning of the cotyledons in relation to the direction of impact of dynamic forces.

content (4 %) and the highest tangential velocity (14 m/s) the maximum percentage of damage for the German varieties was about 50-60 %, and for the Polish varieties 70-80 %.

The preliminary investigations on the influence of seed positioning at the time of impact showed that the horizontal position of the cotyledon is connected with more damage than the vertical one (Fig. 8). At the lower tangential velocity levels (8-10 m/s) the curves characterizing this experiment run parallely, and at the higher velocities (12-14 m/s) they clearly diverge. It may be concluded that when the seed position is horizontal the striker causes greater damage of the coherence of cotyledons than in the vertical position, when one of these cotyledons receives the effects of the impact. Therefore these effects were greater when the position of the seed was horizontal.

DISCUSSION

The method proved the great variability of the resistance properties of rapeseeds both under the influence of genetic as well as environmental factors. The macro- and micro-damage, together with the way in which they were estimated allow for the conclusion that the method fulfills all the conditions required for this type of investigation. The relationships concerning the influence of the studied factors enable the effects of dynamic loading of individual rapeseeds to be estimated. Literature on the subject shows that in the studies conducted so far static loading was used to estimate the mechanical properties of individual seeds and the seed mass. The application of dynamic loading was technically difficult; this steemed from the need to design an apparatus suitable for an object whose diameter does not exceed 2.5 mm. On the other hand, when studying the mechanical properties of rape one must determine the variability of its resistance features for the individual seeds, as their anatomy, genetic features and moisture content create the physical status of the single object, and hence of the whole sample, i.e., seeds in their bulk mass.

The range of moisture content levels (4-21 %) and tangential velocity levels (4-14 m/s) represents parameters appearing in agricultural practice and encompassing the whole rape production cycle form harvest, through transportation, cleaning, drying, to storage. Dynamic loading appears at each stage of this technological cycle and it influences the size and character of seed damage as well as the quality of the raw material and, in turn, the quality of oil and other related products.

Though the tangential velocity of the combine-harvester treshing drum is usually higher (17-25 m/s depending on the silique moisture content and seed moisture content) than those applied in the present investigations, even so the effects of mechanical dynamic loadings observed (up to 80 % of damaged seeds) entitle us to say that in the applied range there could also be negative effects from the threshing unit of combine-harvesters.

The problem is to find a suitable coefficient that would enable one to take into consideration the effects of attenuation, shock absorption, and lost motion that appear in the threshing unit of combine-harvesters. Such a coefficient would enable laboratory results to be applied in actual farming practice. It is to be hoped that investigations now being carried out in this field will bring us closer to solving this important problem.

CONCLUSIONS

1. The method utilized to estimate the mechanical resistance properties of individual rapeseeds to dynamic loading enables the evaluation of both macro- and micro-damage in the full range of variability.

2. The size of rapeseeds (division into size fractions) does not have any significant statistical influence on the estimation of the damage level. It is, then, possible to take any fraction or seed size as representative in order to estimate the effects of dynamic loading.

3. A significant variation in relation to macro- and micro-damage appeared among the studied varieties. Considering the total damage it was possible to distinguish three statistically distinct groups. Akela, Emerald, and Beryl belonged to the most susceptible to mechanical damage, Jantar and Jupiter took the medial position, and Arabella was the most resistant one.

4. The amount of macro-damage increased significantly in the velocity range 8-10 m/s, and a rapid increase was observed above this velocity. However, micro-damage increased slowly in the whole range of velocities of the striker.

5. Differentiated rapeseed moisture levels connected with the increasing velocity of the striker caused greater variability in the seed resistance to dynamic loading.

Along with a decrease of moisture content and an increase in the number of rotations the number of damaged seeds increased rapidly. Considering the full range of seed moisture contents we may say that Akela is the variety most susceptible to mechanical damage (no matter what the tangential velocity), and Jantar is the most resistant one as its seeds were not damaged above the 12 % moisture content level.

6. At the least favourable moisture content (4 %) and the highest tangential velocity (14 m/s) the maximum number of damaged seeds for the German varieties was 50-60 % and for the Polish ones 70-80 %.

7. The chosen regression functions $d(v)$ and $D(v, m)$ fully preserve the character of variability and accurately describe the influence of the individual factors that determine the size and type of damage.

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