DETERMINATION OF SOME MECHANICAL PROPERTIES FOR OILSEEDS USING UNIAXIAL COMPRESSION TESTS
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DETERMINAREA UNOR CARACTERISTICI MECANICE ALE SEMINŢELOR OLEAGINOASE UTILIZÂND TESTELE DE COMPRESIUNE UNIAXIALĂ

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ABSTRACT
Basic knowledge of the behavior of agricultural products to the mechanical forces application is essential for determination of necessary power for various work processes and for the design of machinery, equipment and agricultural installations. This paper presents the results obtained from uniaxial compression tests of sunflower seeds, rapeseeds and safflower seeds. Thus, data for the mechanical characteristics of the three types of oilseeds (force-deformation curve, forces, deformations and energy consumption at the point of shell rupture) were obtained.

REZUMAT
Cunoaşterea fundamentală a comportamentului produselor agricole la solicitările forţelor mecanice este esenţială pentru determinarea necesarului de putere pentru diferite procese de lucru, precum şi pentru proiectarea maşinilor, echipamentelor şi instalaţiilor agricole. Lucrarea de faţă prezintă rezultatele obţinute în urma testelor de compresiune uniaxială a seminţelor de floarea-soarelui, rapiţă şi şofrănel. Astfel, au fost obţinute date cu privire la caracteristicile mecanice ale celor trei tipuri de seminţe oleaginoase (curba forţă-deformaţie, forţele, deformaţiile şi consumul de energie în punctul de rupere a cojii).

INTRODUCTION
Oilseeds represent the main raw material for vegetable oils extraction. Among the most important oilseed grown in our country there are included sunflower seeds, rapeseeds and safflower seeds.

Oil raw materials are subjected to mechanical forces during the oil extraction process, those forces leading to the seeds deformation. Therefore, the mechanical behavior of oil seeds has an important role in the process of oil extraction, *(Ozumba I.C., Obiakor S.I., 2011).*

Compression test represents an objective method for determining the mechanical properties of cereal seed and one of the best techniques for determining the modulus of elasticity by studying their behavior to compression load using force-deformation curve, *(ASAE Standards 2000; Khodabakhshian R., Emadi B., 2011).*

Numerous works have been carried out by researchers in the field in order to highlight the physical and mechanical properties of oilseeds,*(Bagvand A., Lorestani A.N., 2013; Jafari S., Khazaei J. et al, 2011; Khodabakhshian R. et al, 2010).*

Thus, numerous works in the literature have been carried out on various oil seeds (sunflower, Moringa, safflower, jatropha, rapeseeds) in order to determine various physical properties (weight, size, average diameter, surface area, sphericity, coefficient of static friction, moisture content) *(Babić Lj., Radojčin M., Pavkov I., Babić M., 2012)* and mechanical properties (elasticity modulus, hardness, rupture force, deformation at the rupture point, consumed energy at rupture) thereof, *(Ajav E.A., Fakayode O.A., 2013; Gupta R.K., Das S.K., 2000; Herak D. et al, 2010; Herak D. et al, 2012; Jafari S., et al, 2011).*

Some researchers have studied the dependence of physical and mechanical properties of safflower seeds *(Feyzallahzadeh M., et al, 2013).* Thus, it was observed that there is a significant dependency between seed mass, mean diameter, sphericity and surface area and the mechanical properties of seeds. However, an insignificant dependence was observed between the mass, the sphericity and the average diameter with the safflower seeds deformation.

Other researchers*, (Gupta R.K., Das S.K., 2000),* studied the influence of the moisture content of sunflower seeds (and for the sunflower kernel) on the seeds behavior during compression tests and, also, the influence of seed position during compression. Thus, it was observed that the rupture force of the seeds and kernels decreased with increasing the moisture content and the force value was higher for the seed in vertical position compared to tests carried out with seeds in horizontal position. Another paper, *(Khodabakhshian R. et al, 2010),* studied the influence of moisture content on the physical and mechanical properties of sunflower seeds and kernels.

Knowing the importance of the mechanical properties of oilseeds, this paper presents the results obtained from uniaxial compression tests of sunflower seeds, rapeseeds and safflower seeds.

MATERIAL AND METHOD

For conducting the experiments were used sunflower, rape and safflower oilseeds. For the three types of seeds were carried out measurements on samples of 10 seeds in order to determine moisture content, oil content, the principal dimensions and mass of the seed. The moisture content of the seeds was determined by MAC 110 thermo-balance and had values from 4.65 to 4.77% for sunflower, 4.75 to 5.05% for rape or 5.19 to 5.49 % to safflower.

Using solvent extraction method was determined oil content of the seed and the following values were obtained: from 46.90 to 47.70% for sunflower, from 41.10 to 41.40 and from 34.23 to 37% for rapeseed, 0.1% for safflower. Measurement of the three main dimensions of seed (length, width and thickness), was performed using a digital caliper with precision of 0.01 mm, and then determined the individual seeds mass with Kern 572 electronic scales, having the accuracy of 10^{-3} g.

To determine the mechanical properties of oilseeds (sunflower, rapeseed and safflower) was used the Hounsfield/Tinius Olsen mechanical tests machine, model H1 KS, which enables the mechanical properties for a wide range of materials (wood, vegetable products, metal, plastic, textile, leather, ceramics, etc.). The main components of the machine are: support columns; a fixed flat plate to support material sample; pressing head with movable flat plate parallel to the base plate; display, adjustment and control panel; force cell; data acquisition system (computer) with QMAT software (fig. 1).

The seeds subjected to uniaxial compression are arranged between two parallel planes plate of the device, and on the movable plate is placed the 1 kN force cell that is fixed to the movable traverse for registering the displacement. Resistant force of the tested material sample is measured by a force cell, which can be changed easily and quickly by means of a special mechanism, depending on the material being tested. For the displacement measuring, the device has an accuracy of ± 0.0001 mm, and the movement speed can take values between 0.001 mm/min and 1000 mm/min. From the research in the studied field, it was concluded that for the compression test on oilseed the movement speed has to be constant at the value of 1 mm·min^{-1}.

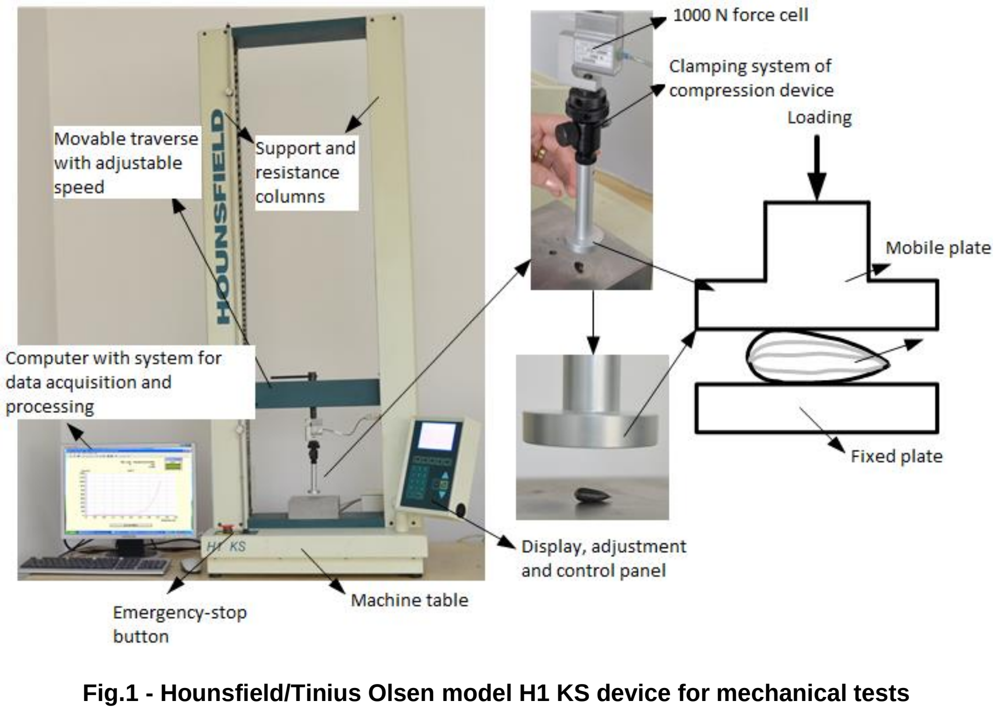

Fig.1 - Hounsfield/Tinius Olsen model H1 KS device for mechanical tests

After the compression tests on the 30 oilseeds (10 sunflower seeds, 10 rapeseeds and 10 safflower seeds) for which has been previously determined dimensional characteristics, the characteristic force-displacement curves were obtained, on which has been read the deformation values, force and energy consumed at different moments of compression and, also, the curve slope to shell rupture point (fig. 2).

The seeds were placed on the fixed plate of the machine in stable horizontal position and the speed of the mobile plate was set at 1 mm/min. The force and displacement values are obtained and saved by Qmat software of the mechanical testing device used in the compression test. Point "1" on the force-displacement curve (fig. 2) is the point where the oilseeds shell rupture occurred, here being observed a sharp drop of the force. Beyond that point, the seed kernel started to be compressed, this process taking place until the point "2" where the maximum force has been reached (about 1030 N), since the force cell was of 1 kN.

From the obtained graph the characteristic forces for the two points could be read, as well as the displacements and consumed energy at those moments. The energy consumption for each of the two points is determined by calculating the area under the curve, starting from the point where the force increases to the desired point. The curve slope up to the rupture force was traced starting from the point where the force begins to increase and to the point "1" when the shell rupture occurs.

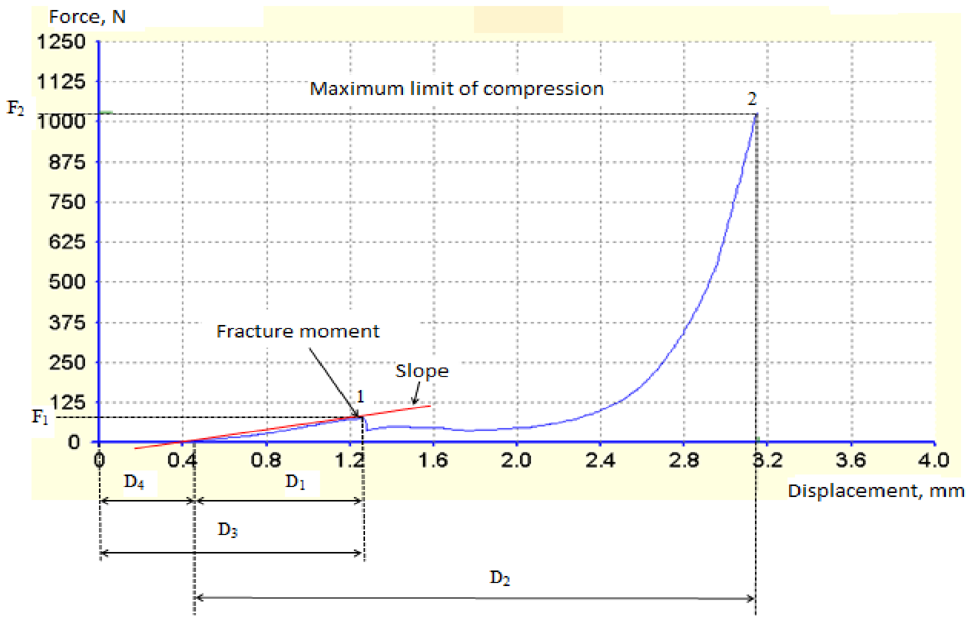

Fig. 2 – The force-strain curve and its characteristic points

RESULTS

In Tables 1, 2 and 3 are presented the values of force, deformation, consumed energy and slope read from the force-deformation curves for sunflower seeds, rapeseeds and safflower seeds.

Table 1

Measured and calculated values for sunflower seeds from the compression tests

Den. No.	F_1, (N)	F_2, (N)	Deformation, (mm)					Slope, (N/mm)	Energy, (J)	
			D_{max}	D_1	D_2	D_3	D_4		E_1	E_2
1	51.3	1030	3.272	1.121	2.909	1.484	0.363	43.18	0.0201	0.4610
2	47.5	1027	3.060	0.945	2.720	1.285	0.340	48.58	0.0155	0.4140
3	58.8	1030	3.420	0.856	3.156	1.120	0.264	66.60	0.0205	0.3374
4	75.0	1029	3.312	0.944	2.964	1.292	0.348	77.50	0.0269	0.5260
5	46.3	1026	3.780	0.996	3.416	1.360	0.364	43.84	0.0175	0.4930
6	53.8	1030	2.860	0.779	2.520	1.119	0.340	72.20	0.0203	0.4228
7	60.0	1028	3.352	0.960	2.980	1.332	0.372	60.10	0.0217	0.4927
8	45.0	1029	3.752	1.056	3.388	1.420	0.364	40.13	0.0144	0.5390
9	51.3	1026	3.240	0.956	2.924	1.272	0.316	52.00	0.0202	0.4774
10	57.5	1030	3.832	1.144	3.424	1.552	0.408	48.80	0.0219	0.5200

Table2

Measured and calculated values for rapeseeds from the compression tests

Den. No.	F_1. (N)	F_2. (N)	Deformation. (mm)					Slope. (N/mm)	Energy. (J)	
			D_{max}	D_1	D_2	D_3	D_4		E_1	E_2
1	11.25	1029	1.88	0.336	1.550	0.662	0.326	26.04	0.0031	0.3524
2	7.50	1028	1.98	0.340	1.624	0.696	0.356	14.71	0.0022	0.3467
3	10.00	1030	1.93	0.462	1.594	0.798	0.336	16.23	0.0027	0.3395
4	8.75	1028	2.11	0.365	1.785	0.690	0.325	17.12	0.0020	0.3450
5	16.25	1026	2.30	0.621	1.993	0.928	0.3075	22.16	0.0039	0.3407
6	12.50	1026	2.13	0.363	1.823	0.670	0.3075	27.59	0.0037	0.3368
7	7.50	1026	2.30	0.298	1.945	0.653	0.355	16.78	0.0023	0.3358
8	11.25	1029	2.26	0.408	1.925	0.743	0.335	21.45	0.0030	0.3341
9	16.25	1029	2.17	0.611	1.883	0.893	0.2825	24.57	0.0036	0.3358
10	11.25	1030	1.97	0.336	1.614	0.692	0.356	26.04	0.0032	0.3355

Table3

Measured and calculated values for safflower seeds from the compression tests

Den. No.	F_1. (N)	F_2. (N)	Deformation. (mm)					Slope. (N/mm)	Energy. (J)	
			D_{max}	D_1	D_2	D_3	D_4		E_1	E_2
1	42.5	1024	3.128	0.5	2.84	0.788	0.288	80	0.0168	0.3924
2	26.3	1029	2.86	0.332	2.572	0.62	0.288	71.5	0.0155	0.3303
3	45	1024	3.208	0.628	2.876	0.96	0.332	67.7	0.0159	0.4167
4	42	737	2.800	0.74	2.536	1.004	0.264	53.7	0.0145	0.2805
5	36.3	1027	3.472	0.788	3.072	1.188	0.4	60.5	0.0168	0.4044
6	53.8	1029	2.940	0.596	2.584	0.952	0.356	83.9	0.0197	0.397
7	78.8	1030	3.152	0.856	2.752	1.256	0.4	87.6	0.0212	0.3966
8	52.5	1025	3.120	0.764	2.788	1.096	0.332	63.8	0.0187	0.3626
9	61.3	1027	3.328	0.504	3.024	0.808	0.304	114.1	0.0218	0.4538
10	45	1027	3.088	0.58	2.792	0.876	0.296	71.1	0.0202	0.4465

After analyzing force-deformation curves obtained on the computer for the 30 oleaginous seeds, 10 from each seed type it was found that not all had the same point of origin for the displacement. In order to start from zero all the curves, both for horizontally and vertically positions the acquired data were processed in Excel and experimental curves were redrawn.

Further, there are presented the mean values force-deformation curves for the three types of seeds used in the experiments. Thus, in fig. 3 can be seen that the shell rupture for sunflower occurs between 1.112 and 1.504 mm for deformation and between 40.6 to 62 N for force, values which were read on the mean force-deformation curves.

As for the rapeseeds, the mean values of deformation and force at rupture point were between 0.271 and 0.561 mm. respectively 8.75 and 9.88 N. values that are much lower than those for the of sunflower seeds. It also notes that the mean deformation and force values at shell rupture for safflower seeds have higher values than those for rapeseeds i.e. 0.512 to 0.944 mm. respectively 34.65 to 39.28 N.

The slope of force-deformation curve till the rupture point of the shell represents the elasticity of the shell, but it must take into account that under the shell is the kernel (in contact with the shell) that also opposes resistance to crushing (or shell rupture). For this reason we cannot express a direct relation between the curve slope and the shell or kernel elasticity.

To establish a correlation between slope and rupture energy E_1 was performed in Microsoft Excel a regression analysis using linear variation law. Fig. 4 presents the variation of rupture energy depending on the slope for the three types of oilseeds. As a result of the regression analysis, it was found that the best correlation between slope and rupture energy is shown by rapeseeds (R^2=0.647) and the lowest correlation was obtained for sunflower seeds (R^2=0.528).

In fig. 4 is also shown another regression analysis using linear variation law in Microsoft Excel which has been made to establish a correlation between the force and the energy to the shell rupture point. F_1 and E_1. obtained from the compression tests on which the three types of oilseeds have been subject to. Analyzing the figure can be seen that the best correlation was obtained for sunflower seeds with R^2=0.873. while safflower seeds had the lowest correlation with R^2=0.605.

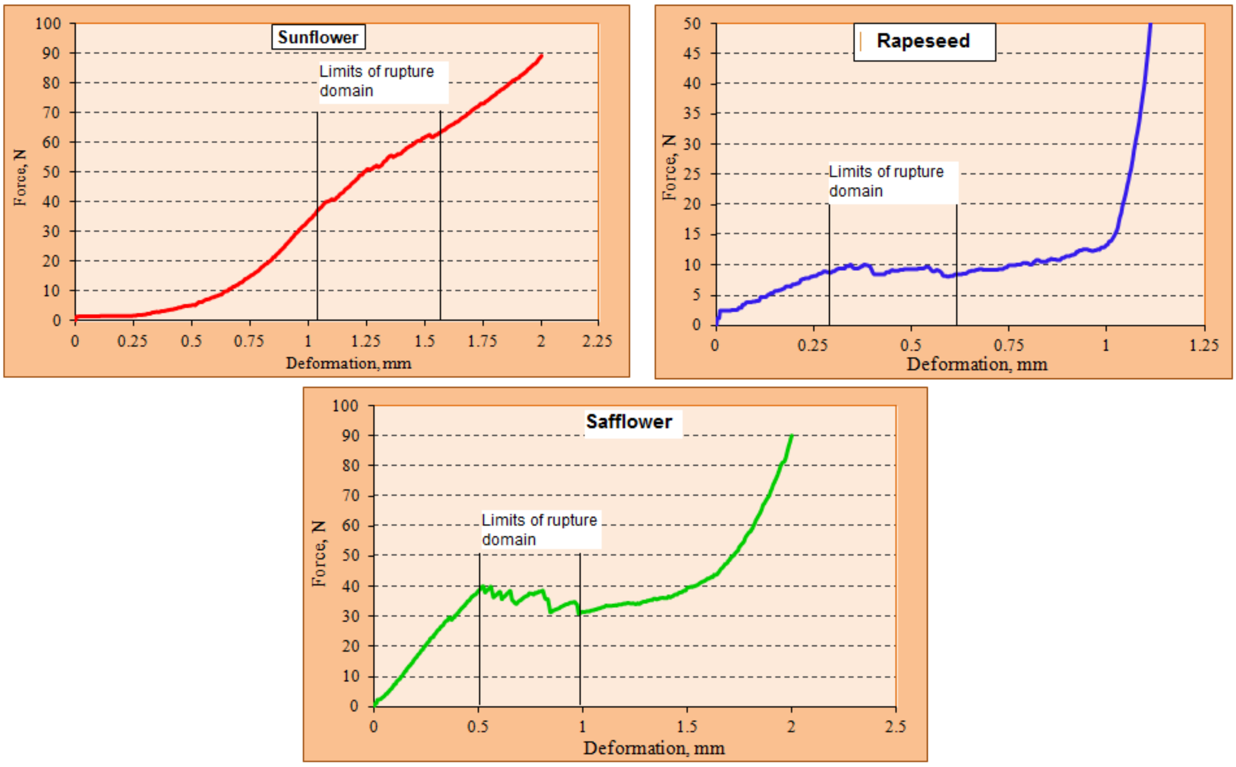

Fig. 3 - Average force-deformation curve for the three types of oilseeds

Relatively low values of correlation coefficients show the dispersion of experimental data points (curve slope-consumed energy) which are distributed in a very wide area. It is obvious.Therefore, not all culture seeds are developed the same and the different climatic conditions are affecting this phenomenon. It is further said that at the same plant the seeds are not developed equally, which is closely related to seeds position on stalk capitulum or on circular rows of the capitulum.

For this reason, the seeds do not have similar dimensions or mechanical characteristics in a narrow range of values.

A real image of these ranges of values could be obtained on a large number of experiments (on the same seeds culture) without a selection of them. However, the obtained values can be helpful for processors in order to achieve a proper adjustment of the machine, but also for designers and builders to optimally establish the actuators.

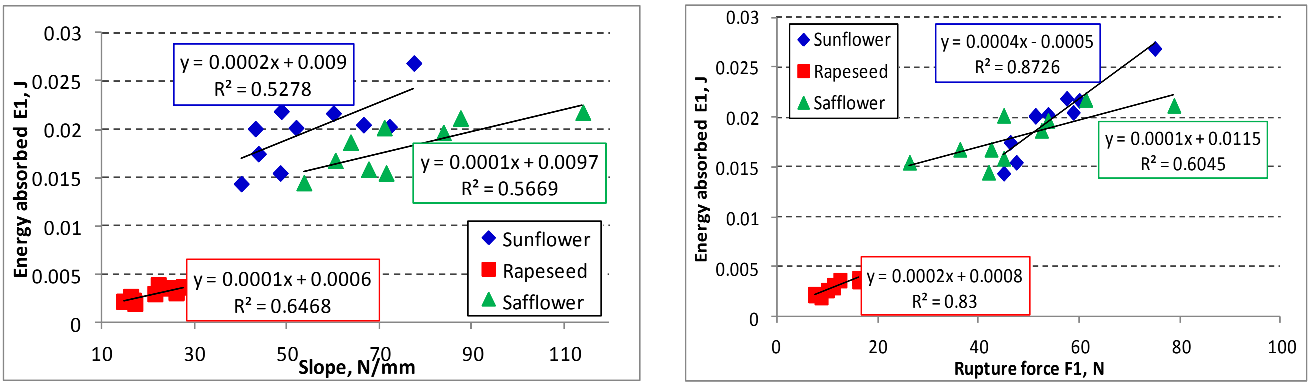

Fig.4 - Variations of the energy absorbed E1 with the slope/rupture force for the three types of oleaginous seeds

CONCLUSIONS

Using the force-deformation curves of the uniaxial compressive tests (performed on the thickness of the sunflower and safflower seeds) may be obtained precious information on the mechanical characteristics of seeds regarding the shell rupture force (taking into account the influence of kernel resistance), total deformation until rupture, the necessary energy (or consumed to deformation), seeds elasticity (in assembly), deformation limits and shell rupture forces for a mixture of seeds etc.

Thus, the necessary force for sunflower seeds shell rupture was within the limits of 45-75 N. while for safflower seed was in the range of 26.3-78.8 N and for rapeseed was from 7.5 to 6.3 N.

For these rupture forces registered by the device, total seeds deformation was 2.9-3.8 mm for sunflower, 2.8 to 3.5 mm for safflower and 1.9-2.3 mm in the case of rapeseeds.

Energy consumed for seeds rupture shows a linear correlation with the rupture force (with a high degree of correlation especially for rapeseed and sunflower) falls in the ranges $(1.4\text{-}2.7)\cdot 10^{-2}$ J for sunflower. $(1.5\text{-}2.2)\cdot 10^{-2}$ J for safflower and $(0.2\text{-}0.4)\cdot 10^{-2}$ J for rapeseeds.

The elasticity of the seed as a whole, expressed by the value of the curve slope until the moment of breakage (rupture) of the shell shown also values in relatively wide limits. Thus, the sunflower seeds showed elasticity values within the limits of 40.1-77.5 N/mm. 53.7- 114.1 N/mm for safflower and between 14.7 and 27.6 N/mm for rapeseeds.

Knowing the values of the mechanical characteristics of oilseeds are really useful both for manufacturers but especially for operators of equipment used for oil extraction from oilseeds.

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