Moisture-dependent physical and mechanical properties of cumin (*Cuminum cyminum* L.) seed

Kaveh Mollazade[1], Hojat Ahmadi[1], Jalal Khorshidi[2], Ali Rajabipour[1], Seyed Saeid Mohtasebi[1]

(1. *Department of Agricultural Machinery Engineering*, *Faculty of Biosystems Engineering*, *University of Tehran*, *P.O. Box* 4111, *Karaj* 31587-77871, *Iran*;
2. *Department of Horticulture Science*, *Faculty of Horticulture and Plant Protection*, *University of Tehran*, *Karaj*, *Iran*)

Abstract: Some physical and mechanical properties of cumin seed were obtained as moisture content changed from 7.24% to 21.38% d.b. Increasing of moisture content was found to increase the seed length (5.14−5.58 mm), width (1.33−1.55 mm), thickness (0.97−1.05 mm), arithmetic mean diameter (2.48−2.73), geometric mean diameter (1.88−2.09 mm), surface area (10.34−12.66 mm^2), thousand seed weight (2.9−3.9 g), porosity (51.22%−64.11%), true density (917.8−1030.6 kg/m^3), static angle of repose (43−49 deg), dynamic angle of repose (47−56.6 deg), and coefficient of static friction on the three surfaces: glass (0.48−0.77), galvanized iron sheet (0.36−0.73), and plywood (0.57−0.69). However, bulk density was found to decrease from 447.66−369.88 kg/m^3, and rupture force and rupture energy along with seed length and width were found to decrease from 83.74−56.17 N, 132.95−84.47 N, 50.66−27.52 mJ, and 67.8 to 33.36 mJ, respectively. The sphericity increased from 36.63% to 37.5% with increasing in moisture content from 7.24% to 14.5% d.b. and then reduced to 37.5% with further increase in moisture content to 21.38% d.b.

Keywords: seed, engineering properties, moisture, porosity, density, medical plant
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1 Introduction

Cumin (*Cuminum cyminum* L.) seed has been a part of the people diet and is usually used as a spice or a flavoring material. Iran, Egypt, India, and Morocco are the main producers of cumin seed in the world. Reduction of blood glucose levels in rats with induced diabetes, and reductions in plasma and blood cholesterol, phospholipids, free fatty acids, and triglycerides by cumin seed and also its oil antimicrobial property have been reported by different researchers. Chemical composition of cumin seed essential oil has been studied by a number

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Biographies: Kaveh Mollazade, MSc student in Department of Agricultural Machinery Engineering, University of Tehran, Karaj, Iran. His research fields include Application of Neural Network and Fuzzy Logic in Mechanical Systems, Artificial Intelligence, Machine Vision and Programming, Condition Monitoring, Application of Mechatronic in Agricultural Engineering, Design of Agricultural Machinery, and NDT. Tel: +98-918-972-0639. Email: kaveh.mollazade@gmail.com, mollazade@ut.ac.ir
Hojat Ahmadi, associate professor in University of Tehran. His current research interests are Machinery Fault Detection, Vibration & Oil Monitoring, Signal Processing, Precision Agriculture and System Maintenance. Email: hjahmadi@ut.ac.ir
Jalal Khorshidi, MSc student in Department of Horticulture Science, Faculty of Horticulture and Plant Protection, University of Tehran, Karaj, Iran. Email: jalal_khorshidi2006@yahoo.com
Ali Rajabipour, associate professor in University of Tehran. His current research interest is Engineering Properties of Agricultural Products. Email: rajabipour@ut.ac.ir
Seyed Saeid Mohtasebi, associate professor in University of Tehran. His current research interests are Mechanical Systems and Dynamic of Machines. Email: mohtaseb@ut.ac.ir

of researchers. Cuminaldehyde, *β*-pinene, *γ*-terpinene, *p*-mentha-1,3-dien-7-al, *p*-mentha-1,4-dien-7-al and *p*-cymene have been usually reported as main constituents. Cuminaldehyde has been introduced as the main characteristic constituent of the seed which acts as an aldose reductase and *α*-glycosidase inhibitor with intimate activities[1].

Proper design of machines and processes in order to harvest, handle and store agricultural materials and convert these materials into food and feed requires an understanding of their physical and mechanical properties. Shape and physical dimensions are important in screening solids to separate foreign materials and to sort and to size fruits and vegetables. Quality differences in fruits, vegetables, grains and seeds can often be detected by differences in densities. Volumes and surface areas of seeds must be known for accurate modeling of heat and mass transfer during cooling and drying. The porosity affects the resistance to airflow through bulk solids. The static coefficient of friction and angle of repose are necessary to design conveying machine and hopers which are used in planter machines. When cereal grains and seeds are ground in mills, the rupture force and energy must be known in order to achieve desirable properties without unnecessary expenditure of energy[2,3].

In view of this, several similar studies have been conducted on the physical and mechanical properties of different cereals and seeds such as size, shape, bulk density, true density, porosity, angle of repose, rupture force and coefficients of static and dynamic friction in relation to moisture content. Moisture-dependent physical and mechanical properties of sorghum seeds[4], chick pea seeds[5], lentil seeds[6], Pumpkin seeds[7], Sunflower seeds[8], green gram[9], wheat seed[10,11], grass pea seed[12], and soybean grains[13] had been reported by a number of researchers due to their importance.

Hence, current study was conducted to investigate the moisture-dependence of some physical and mechanical properties of cumin seed including size, thousand seed weight (TSW), sphericity, bulk density, true density, surface area, porosity, angle of repose, coefficient of static friction, rupture force, and rupture energy.

2 Materials and methods

The dry seeds of cumin were used in all the experiments in this study. The seeds were cleaned manually to remove all foreign matters such as dust, dirt, stones and chaff as well as immature and broken seeds. The initial moisture content of the seeds was determined by oven drying at (105±1)℃ for 24 h[14]. The initial moisture content of the seeds was 7.78% d.b. The samples of the desired moisture contents were prepared by adding the amount of distilled water as calculated from the following relation[15]:

$$Q = \frac{W_i(M_f - M_i)}{(100 - M_f)}$$

The samples were transferred into separate polyethylene bags and then the bags sealed tightly. The samples were kept at 5℃ in a refrigerator for a week to enable the moisture to distribute uniformly throughout the samples. Before starting an experiment, the required quantity of the seeds were taken out of the refrigerator and allowed to equilibrate to the room temperature for about 2 h[16]. All the physical and mechanical properties of the seeds were determined at five moisture contents in the range of 7.24%−21.38% d.b. with four replications at each moisture content.

A Vernire caliper was used to measure the axial dimensions of randomly selected of 100 seeds including length, width, and thickness. From the average of axial dimensions, the arithmetic mean diameter D_a and geometric mean diameter D_g in mm were determined by using the following formula[2, 5]:

$$D_a = \frac{L + W + T}{3}$$

$$D_g = (LWT)^{1/3}$$

The sphericity was determined using[2]:

$$\psi = \frac{(LWT)^{1/3}}{L}$$

The surface area of seeds was calculated from the following formula presented by Jain and Bal[17]:

$$S = \frac{\pi L^2 \sqrt{WT}}{(2L - \sqrt{WT})}$$

Thousand seed weight (TSW) was measured by counting 100 seeds and weighing them by an electronic balance having an accuracy of 0.001 g and then multiplied by 10 to give mass of 1000 seeds. The bulk density was determined by filling an empty 250 mL scaled cylinder with the seed and weighed[2]. The weight of the seeds was obtained by subtracting the weight of the cylinder from the weight of the cylinder and seed. To achieve uniformity in bulk density, the scaled cylinder was shaken 10 times. The volume occupied was then recorded. The process was replicated four times and the bulk density for each replication was calculated from the following relation[2]:

$$\rho_b = \frac{W_s}{V_s}$$

The true density was defined as the ratio between the mass of cumin seeds and the true volume of the seeds, using the toluene (C_7H_8) displacement method. Toluene was used instead of water because it is absorbed by seeds to a lesser extent. The volume of toluene displaced was found by immersing a weighted quantity of cumin seeds in the measured toluene[13].

Porosity was calculated from the values of bulk and true densities using the following relationship[2]:

$$\varepsilon = (1 - \frac{\rho_b}{\rho_t}) \times 100$$

The static angle of repose (θ_s) was determined using the apparatus shown in Figure 1 consisting of a plywood box of 140 cm×160 cm×35 cm and two plates: fixed and adjustable. The box was filled with the sample and then the adjustable plate was inclined gradually allowing the seeds to follow assuming a natural slope[18,19]. The dynamic angle of repose was determined using a hollow cylinder and also trigonometry rules[12].

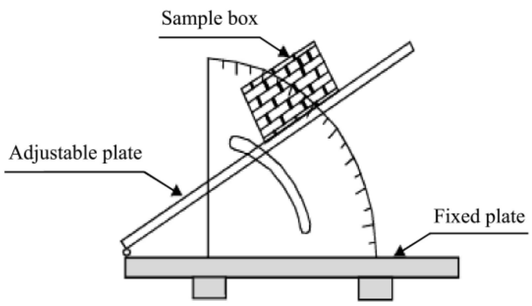


Figure 1 Apparatus to determine angle of repose

Coefficients of static friction of cumin seeds on three surface including wood, galvanized steel, and glass were determined. In order to achieving this end, cumin seeds were put on the surface with variable slip (see Figure 2). When seeds were started to motion, tangent of slip angle indicated the coefficient of friction[19].

Figure 2 Device for determining the coefficient of static friction

Rupture strength for cumin seed was determined from forces acting along with seed length and width with load speed 5 mm/min. For doing the test along with seed width, samples were prepared as a cubic shape. Method of test was to put the seed on desired section and selecting speed of loading and after that applying force till seed fractured. Instron Universal Testing Machine (Model Santam STM-5), which is equipped with a 25 kg compression load cell and integrator, was used for this test. The measurement accuracy was 0.001 N in force and 0.001 mm in deformation[2,20]. The individual seed was loaded between two parallel plates of the machine and compressed at the present condition until rupture occurred as is denoted by a rupture point in the force-deformation curve. Energy absorbed by the sample at rupture was determined by calculating the area under the force–deformation curve from the following relationship[13,21]:

$$E = \frac{F \cdot D}{2}$$

3 Results and discussion

The length, width and thickness of seeds increased from 5.14 to 5.58 mm, 1.33 to 1.55 mm, and 0.97 to 1.06 mm, respectively with an increase in moisture content from 7.24% to 21.38% d.b. Similarly, the arithmetic and geometric mean diameter increased from

2.48 to 7.73 mm and 1.88 to 2.09 mm, respectively, in the same moisture content range indicating that the moisture content significantly influences these properties (see Figure 3). Reason for these phenomena is cellules inflation and penetration water in the porous area. The relationship between these dimensions of cumin seeds and their moisture contents, except seed length, was found to be linear in the moisture content considered as described by the following equations:

$$L = 0.0025M^2 - 0.0414M + 5.3115,\ R^2 = 0.971$$

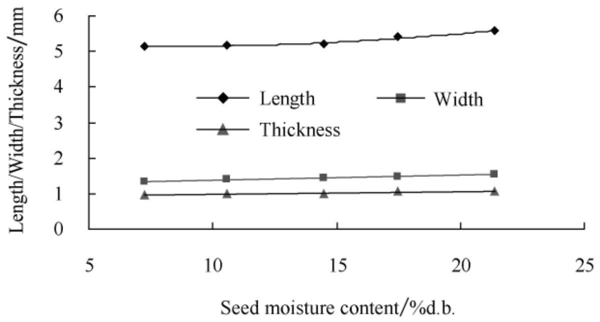
$$W = 0.0146M + 1.2266,\ R^2 = 0.975$$

$$T = 0.0061M + 0.929,\ R^2 = 0.885$$

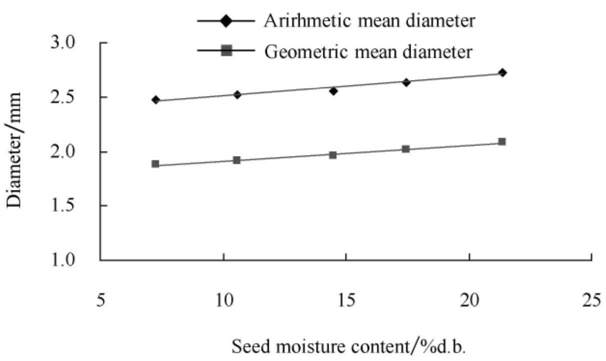
$$D_a = 0.0176M + 2.33,\ R^2 = 0.944$$

$$D_g = 0.0148M + 0.9811,\ R^2 = 0.981$$

Similar trend of increase was reported by Tavakkoli et al.[13] for soybean grains and Al-Mahasneh and Rababah[22] for green wheat.



a. Seed dimension



b. Seed diameters

Figure 3 Effects of moisture content on seed dimension and seed diameters

Figure 4 shows the variation of sphericity with moisture content. The sphericity of seeds calculated at different moisture content increased from 36.63% to 37.5% with the increase in moisture content from 7.24% to 14.5% d.b. and reduced to 37.5% with further increase in moisture content to 21.38% d.b. The relationship between sphericity and moisture content is described by a second-degree polynomial equation as below:

$$\psi = -0.0097M^2 + 0.3354M + 34.73,\ R^2 = 0.954$$

Former researches showed that sphericity could be affected by moisture content in different ways. A decrease in the sphericity with increase in moisture content was observed for pigeon pea[23]. Cuskun et al.[16] showed that sphericity of sweet corn seed is proportional to the moisture content.

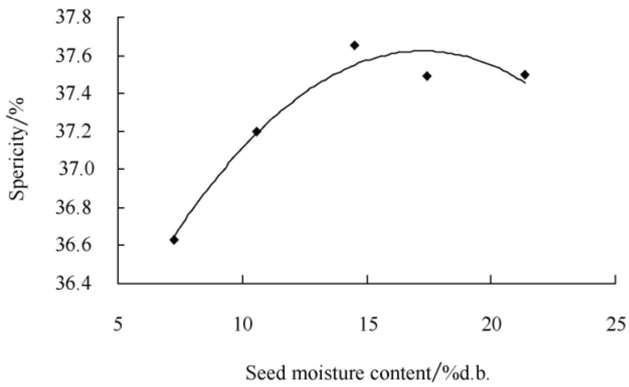


Figure 4 Variation of the sphericity with seed moisture content

The surface area of cumin seeds increased nonlinearly from 10.36 to 12.66 mm^2, as the moisture content of seeds increased from 7.24% to 21.38% d.b. Following equation shows the relationship between cumin seed surface area and the moisture content:

$$S = 0.0066M^2 - 0.0248M + 10.213,\ R^2 = 0.987$$

Kheiralipour et al.[10] reported an increase in surface area of wheat seeds at different moisture contents in the range of 8% to 18% d.b.

Thousand seed weight was increased from 2.9 to 3.9 g as the moisture content increased from 7.24% to 21.38% d.b. Linear relationship for thousand seed weight based on moisture content, M, was determined as follows:

$$TSW = 0.0727M + 2.3936,\ R^2 = 0.955$$

The bulk density of cumin seeds decreased from 447.66 to 369.88 kg/mm^3 and the true density increased from 917.8 to 1030.64 kg/mm^3 for a corresponding change in the moisture content from 7.24% to 21.38% d.b. Tabatabaeefar[17] for wheat seed found that decreasing the bulk density is due to the fact that an increasing in mass owing to moisture seed in the seed sample was lower than the accompanying volumetric expansion of the bulk. The mathematical relationship between bulk and true densities with moisture content were found to be polynomial and linear, respectively, as below:

$$\rho_b = 3.1221M^2 - 39.062M + 486.6,\ R^2=0.969$$

$$\rho_t = 27.514M + 889.66,\ R^2=0.995$$

Linear increase of true density as the seed moisture content increases has been found by Gupta and Das[8] for sunflower seeds, Aviara et al.[24] for guna seeds, Chandrasekar and Visvanathan[25] for coffee. Carman[26], Gupta and Das[27], and Visvanathan et al.[28] found the bulk density of lentil seeds, sunflower seeds, neem nuts to be decreased as the seed moisture content increasesd.

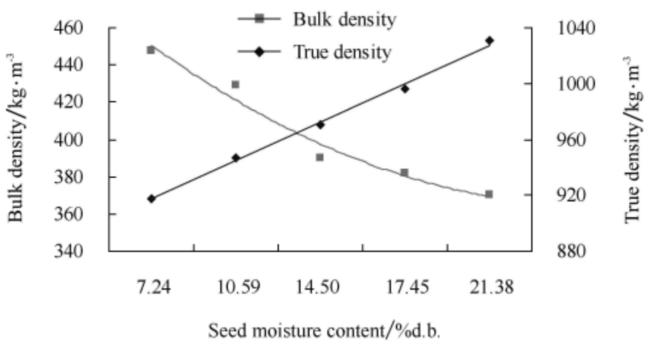


Figure 5 Effect of moisture content on seed bulk and true densities

Since the porosity depends on the bulk and true densities, variation in porosity depends on these factors only. Results showed that the porosity increased with increasing in seed moisture content from 51.22% porosity at 7.24% d.b. seed moisture content to 64.11% porosity at 21.38% seed moisture content. The relationship between porosity and seed moisture content was found to be linear and can be expressed using the following equation:

$$\varepsilon = 0.9351M + 44.976,\ R^2=0.974$$

An increase in porosity with moisture content was reported for chickpea seeds[7], and green gram[9].

Figure 6 shows the variation of both the static and dynamic angles of repose with seed moisture content. Results showed that the static and dynamic angles of repose increased linearly in the moisture range of 7.24 to 21.38 %d.b. from 43 to 49 and from 47 to 56.6 degree, respectively. The static and dynamic angles of repose and the moisture content of grain can be correlated as follows:

$$\theta_s = 0.4524M + 39.892,\ R^2=0.957$$

$$\theta_d = 0.7103M + 41.821,\ R^2=0.992$$

These results were similar to those reported by Garnayak et al.[29] for jatropha seed and Pradhan et al.[30] for karanja kernel.

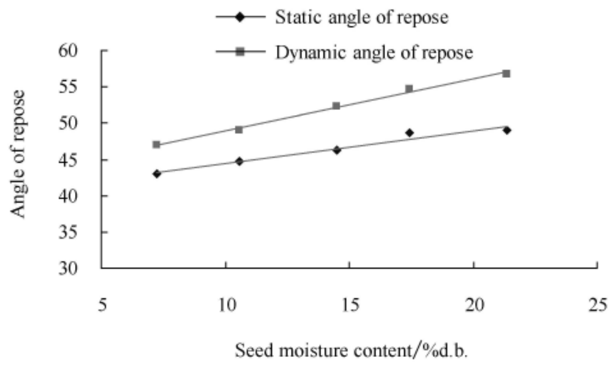


Figure 6 Effects of moisture content on static and dynamic angles of repose

The coefficient of static friction determined at different moisture levels on the three surfaces (glass, galvanized iron sheet, and plywood) shown in Figure 7 increased for all surfaces with increasing in moisture content from 7.24% to 21.38% d.b. Accordingly, coefficient of friction increased from 0.48 to 0.77, 0.36 to 0.73, and 0.57 to 0.69 for glass, galvanized iron sheet, and plywood, respectively. This increase is due to the increased adhesion between the seeds and the material surfaces at higher moisture values. The mathematical relationship of these coefficients with moisture content

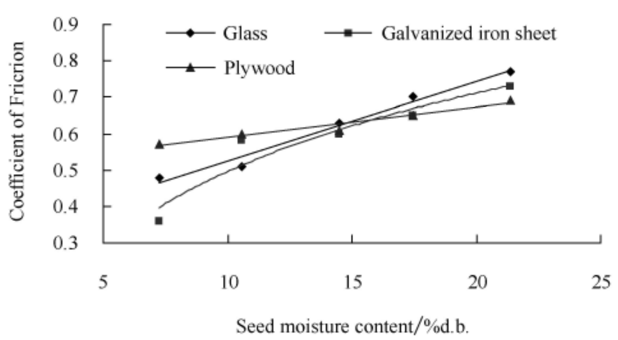


Figure 7 Coefficient of friction in variation with seed moisture content

can be expressed as below:

$$f_g = 0.0219M + 0.306, R^2=0.98$$

$$f_w = 0.0082M + 0.507, R^2=0.958$$

$$f_{gis} = 0.31Ln(M) - 0.2179, R^2=0.919$$

Similar findings were reported for millet[31], pumpkin seeds[5], and karingda seeds[32].

Figure 8 shows the effects of moisture content on the rupture force and the rupture energy. Rupture force along with both seed length and width decreased from 83.74 to 56.17 N and 132.95 to 84.47 N, respectively with moisture content in the moisture range of 7.24% to 21.38% d.b. Similarly the rupture energy along with both seed length and width decreased from 50.62 to 27.52 mJ and 67.8 to 33.36 mJ, respectively, in this moisture range. The obtained relationships between the both rupture force and rupture energy with moisture content can be expressed using the following equations:

$$F_l = 0.0854M^2 - 4.4779M + 112.32, R^2=0.993$$

$$F_w = -0.1211M^2 - 0.516M + 146.15, R^2=0.0.817$$

$$E_l = 0.0827M^2 - 3.965M + 74.77, R^2=0.997$$

$$E_w = -0.0944M^2 + 0.2106M + 71.391, R^2=0.99$$

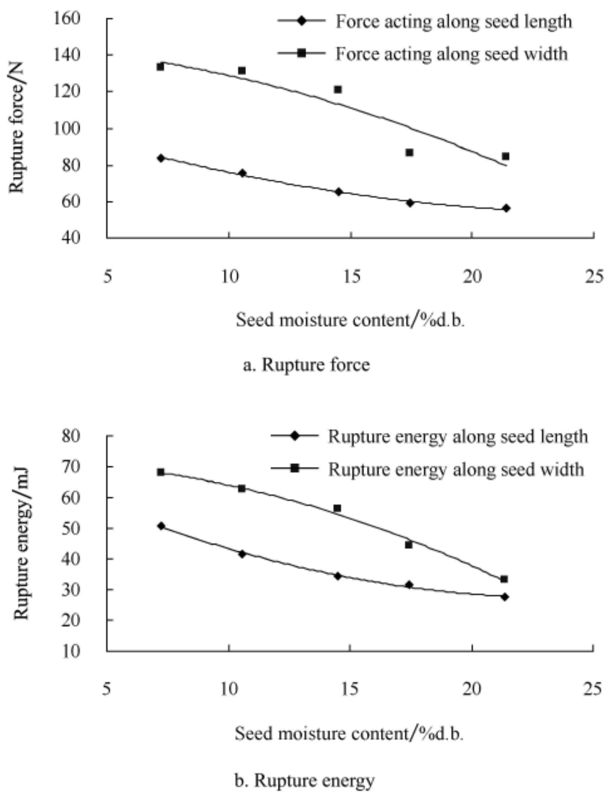


Figure 8 Effects of moisture content on rupture force and rupture energy

Tavakoli et al.[13] reported for soybean grain that the rupture force decreased whit increasing the moisture content whereas rupture energy increased at the same moisture content.

4 Conclusions

The moisture-dependence of various physical and mechanical properties of cumin (*Cuminum cyminum* L.) seed in the moisture content range of 7.24% to 21.38% d.b. was determined. The length, width, thickness, arithmetic and geometric mean diameters, surface area, thousand seed weight, porosity, static and dynamic angles of repose, true density, and coefficient of static friction of seeds increased with the increase of moisture content from 7.24% to 21.38% d.b. The bulk density and both the rupture force and rupture energy decreased with moisture content. Whereas the sphericity exhibited an initial increase followed by a decrease as the seed moisture content increased.

Acknowledgment

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Nomenclature	
L	Seed length, mm
W	Seed width, mm
T	Seed thickness, mm
D_a	Arithmetic mean diameter, mm
D_g	Geometric mean diameter, mm
S	Surface area, mm^2
TSW	Thousand seed weight, g
ρ_b	Bulk density, kg • m^{-3}
ρ_t	True density, kg • m^{-3}
ε	Porosity, %
ψ	Sphericity, %
W_i	Initial mass of sample, kg
M_i	Initial moisture content of sample, % d.b.
M_f	Final moisture content of sample, % d.b.
Q	Mass of required water, kg
d.b.	Dry basis
M	Moisture content, % d.b.
θ_s	Static angle of repose, deg

θ_d	Dynamic angle of repose, deg
f_g	coefficient of friction of seed on glass
f_w	coefficient of friction of seed on plywood
f_{gis}	coefficient of friction of seed on galvanized iron sheet
F_l	Rupture force along seed length, N
F_w	Rupture force along seed width, N
E_l	Rupture energy along seed length, mJ
E_w	Rupture energy along seed width, mJ
D	Deformation at rupture point, mm
W_s	Mass of the sample, kg
V_s	The volume occupied by the sample, m^3

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(By Wang Yingkuan)

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