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MECHANICAL PROPERTIES OF WHEAT GRAINS

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ABSTRACT

Mechanical properties of three new varieties of Egyptian wheat grains Giza-168, Sakha-93 and Banisuif-1 were investigated at different levels of moisture content ranged between 8 to 19 % w.b.

Mechanical tests including bulk and particle compression (stress-strain), particle shear and particle hardness were conducted to obtain grains properties. Statistical analysis was performed to obtain the regression coefficient between the studied properties and the moisture content of grains. Mechanical properties included hardness (kg), shear stress (MPa), initial elasticity modulus (MPa) for grains in bulk and in particle, elasticity modulus (MPa) for grains in bulk and in particle, maximum stress(MPa), bioyield point and breakage energy (kJ/m^3).

INTRODUCTION

Wheat processing to flour mainly consists of a mechanical treatment of the grain. This mechanical treatment during milling is eventually related to the external forces on each wheat kernel between rollers. Therefore, study of the relationship between the forces and single wheat kernel is needed for a better understanding of milling (**Kang, et. al.1995*)*.** Otherwise, grains are subjected to a series of static and dynamic loads during harvesting, handling, transport, processing and storage. These loadings include high speed impact loads, long-term static loads and small repeated loads of varying magnitude. It is therefore important to study the mechanical behavior of these grains, as affected by their physical condition, so that the process and equipment can be designed for maximum mechanical efficiency and highest quality of the final product.

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However, moisture content of the grains has been reported to be one of the critical factors influencing the mechanical behavior (**Bargal, et. al. 1995**).

In this regard, the physical properties of grains are essential for the design of equipment for handling, harvesting, aeration, drying, storing and processing. These properties are affected by numerous factors such as size, form, superficial characteristics and moisture content of the grain (**Erica Baumler et.al, 2005**).

The objectives of the present study are indicated as follow:

- Establishing a database on the mechanical properties related to handling and milling for different Egyptian varieties of wheat grains.
- Studying the relationship between the studied properties and grain moisture content.

MATERIALS AND METHODS

Raw materials

Three samples of the Egyptian wheat varieties Giza-168, Sakha-93 and Banisuif-1 with the initial moisture contents 14.5, 14.02 and 11.42% wet basis were selected for the present study. Each variety was divided into four samples each of 25 kilograms randomly in order to obtain four different levels of moisture content. The desired moisture content levels of grains (nominal as 9, 12, 14 and 18 w.b.%) were achieved by tow methods, by natural drying or by moistening the grains. The moisture levels were prepared as **Nelson, 1980 and Sacilik, 2003**.

Physical characteristics of wheat grains varieties under study were investigated and demonstrated as the first part of this work (Physical Characteristics of Wheat Grains, under publishing in Misr Journal of Agricultural Engineering).

The mechanical properties of wheat grains are included grain hardness, static shear stress, and compressive stress for one layer of grain and in bulk.

Hardness tester

Kiyo Seisakasho, LTD. Model No.3941 with maximum measurement 20 kg and accuracy of 200 mg was used to determine the particle hardness of grains. The procedure of work was done by putting a selected grain from a randomly sample on the platform of the hardness tester in thickness direction, and compressed by the cylindrical flat face plunger which move down and up by means of rotating bully by hand, meanwhile the graduated circular scale reading was increased with the increasing of the pressure on the grain until the grain has been cracked. At this point the reading of the scale pointer means the grain hardness. The particle hardness at each level of moisture content for each investigated variety was including twenty replicates.

Static Shear Stress:

Static shear cell as shown in figure (1) was designed and fabricated for this purpose. It was used to determine the shear stress of wheat grains at each level of moisture content for the investigated varieties.

A selected grain from a randomly sample was put inside the suitable hole of the tow discs. Then, the water was added slowly to the pail until the moving disc turned and the grain was cut.

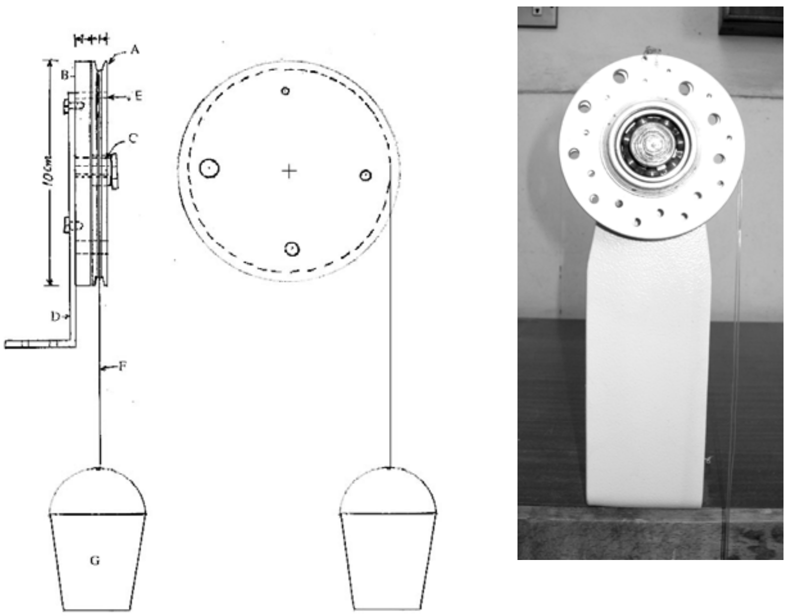


Figure (1): Static Shear Cell Apparatus.

A-Moving Disc B- Fixed Disc C- Ball Bearing D- Holder
E- Hole F- Rope G- Water Bucket

The pail with water was weighed and the shear force was calculated as follows:

$$F_2 = \frac{F_1 \times r_1}{r_2}$$

Where: F_2 = shear force, kg
F_1 = weight of the pail and water, kg
r_1 = the radius from disc center to groove bottom, cm
r_2 = the radius from disc center to hole center, cm

The cross section area (Csa) of the grain was calculated as follows:

$$Csa = (B \times T \times \pi)/4$$

Where: Csa = cross section area of grain, mm^2,
B = width of grain, mm ,
T = thickness of grain, mm.

The shear stress was calculated as follow:

$$Ss = \frac{F_2}{Csa}$$

Where: Ss = shear stress, kg/mm^2,
F_2 = shear force, kg,
Csa = cross section area of the grain, mm^2.

The particle shear stress at each level of moisture content for each wheat variety was including twenty five grains in four replicates.

Bulk and Particle Stress-Strain:

Bulk and particle stress-strain tests were carried out by using an Instron Machine Cole Parameter model (G-08232-28) as shown in Figure (2), with applied force ranges from 0 to1818 kilograms and crosshead speed ranges from 5 to 100 mm/min. The system was provided with digital controller and documentation system model CEDM, which was connected with an automatic recording unit for each of time, force and velocity by computerized reading, operating and controlling system. The tests in this study were carried out at crosshead speed of 20 mm/min.

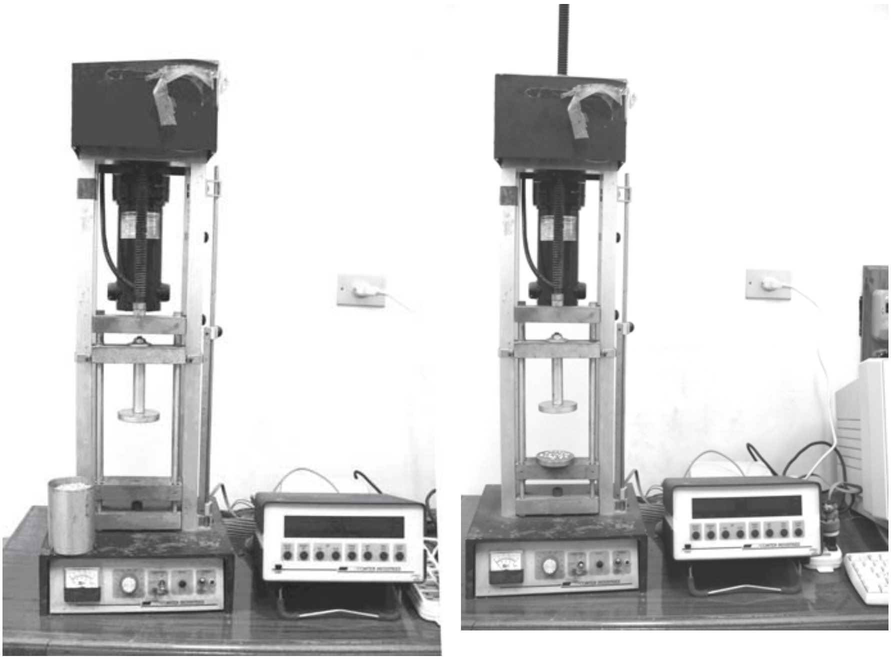


Figure (2): Instron machine with bulk and particle samples.

Both the crosshead speed and the force transducer of the Instron machine were calibrated.

Bulk Stress-Strain:

The bulk stress-strain tests of wheat grains were carried out by using a stainless-steel cylindrical compression cell with a dimensions of 100 mm in height with 70 and 80 mm inner and outer diameter and provided with two upper and lower circular parallel plates of 69 mm diameter and 10 mm thickness one for bottom and the other for top which was connected to the Instron crosshead using a steel bar of 2 cm diameter and 10 cm length as in figure (2). A randomly sample of about 300 ml of grains was placed inside the cylinder between the tow plates and the force was applied on the top plate by the press of the crosshead which was moved down at the selected speed (20 mm / min) deforming the sample until the failure was achieved.

The deformation of the sample under the press was considered equal to the change in the sample height. The strain was calculated by dividing the deformation of the sample by the initial height of the sample. The stress was calculated by dividing the force by the circular cross-section area of the cylinder as follows:

$$Stress = \frac{4F}{\pi D^2}$$

Where: F = force, kg and D = cylinder inner diameter, cm.

Particle Stress-Strain:

The particle stress-strain tests of wheat grains were carried out by placing 25 grains in one layer of the same thickness approximately between two parallel plates and the force was applied on the top plate by the press of the crosshead which was moved down at the selected speed deforming the sample until failure was achieved.

The force for one particle was calculated by dividing the total force by the number of the grains in the sample as illustrated in Figure (3).

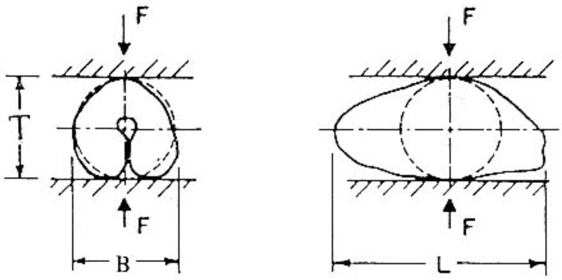


Figure (3): Grain of wheat loaded between the tow parallel plates

The deformation of the particle under the press considered equals to the changing in the particle thickness.

The average stress was calculated by dividing the force of one particle by the projected area of the particle as follows:

$$Stress = \frac{F}{A_P}$$

Where: F = force on one particle, kg,

A_p= particle projected area, cm^2.

The projected area of grain (A_p) was calculated as **Hindi and El-Tawil, 1998.**

The strain was calculated by dividing the deformation of the particle by the initial particle average thickness.

For each bulk and particle stress-strain tests, the initial modulus of elasticity (E_o) in (MPa) was calculated as the initial slope of the stress-strain curve before straight line. While, the modulus of elasticity (E) in (MPa) was calculated as the slope of the stress-strain curve at the stage appear to be straight line. Break energy (kJ/m^3) was calculated as the area between until rupture point and the horizontal axis **(Haddad, et. al, 2001).**

RESULTS AND DISCUSSION

Grain Hardness:

The hardness of several samples of wheat varieties Giza-168, Sakha-93 and Banisuief-1 was investigated as a function of moisture content by means of grain hardness tester SATAKE (KY-140). Hundred grains from each level of moisture sample were tested. The average values of hardness at each level of moisture content were demonstrated in the following table (1):

Table (1): The average values of hardness of wheat grains

Giza 168		Sakha 193		Banisuief 1	
M.C.%	H, kg	M.C.%	H, kg	M.C.%	H, kg
9.55	5.565	10.22	4.135	8.99	9.085
11.36	5.115	12.09	4.015	11.75	6.83
13.74	5.05	13.82	3.97	14.88	5.455
17.49	6.6	17.62	6.203	17.87	5.565

Hardness of different wheat varieties diminished regularly with increasing moisture content up to approximately 15 % and then hardness was increased with moisture content.

At the levels of moisture content range from about 9 to 14% (w.b), Banisuif-1 variety recorded the highest values of hardness; while Sakha-93 variety showed the lowest values of hardness. At moisture content of 17.5 % Giza-168 variety showed the highest values of hardness and Banisuif-1 variety recorded the lowest values. The results of hardness for different wheat grain varieties under investigation are shown in Figure (4).

Static Shear Stress

Static particle shear stress for wheat grains of the investigated varieties as shown in figure (5) appeared linearly with moisture content. The following linear regression equations described the relationships between static shear stress (Ss) in MPa and moisture content in percent (w.b):

For Giza-168 variety:

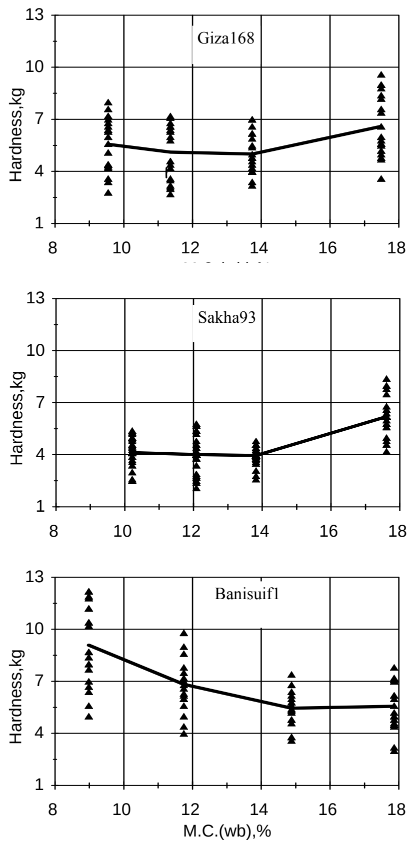
$$Ss=11.6355 - 0.38946\ Mc \ldots\ldots\ldots\ldots\ldots R^2=0.8704$$

For Sakha-93 variety:

$$Ss= 9.09191- 0.27272\ Mc \ldots\ldots\ldots\ldots\ldots R^2=0.9093$$

For Banisuif-1 variety:

$$Ss=10.9126 - 0.36003\ Mc \ldots\ldots\ldots\ldots\ldots R^2=0.7970$$



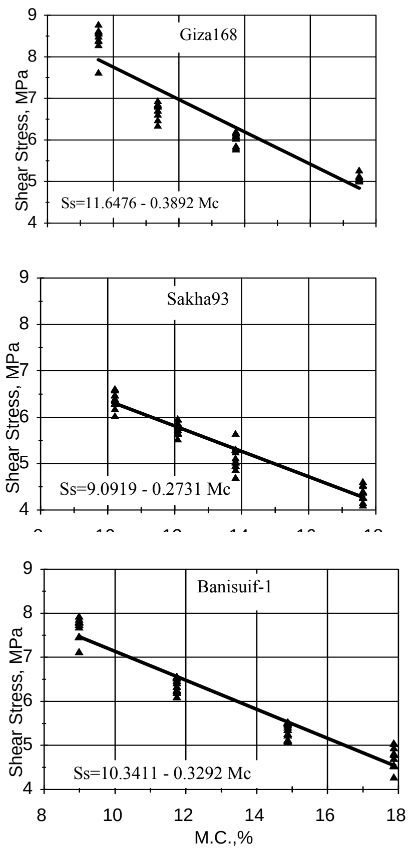


Figure (4) Figure (5)

Figures (4 & 5): Hardness and Static Shear Stress of Wheat Grains

As shown from the above equations, the static particle shear stress decreased with increasing the moisture content at the studied range.
Giza-168 variety recorded the highest values of static shear stress which decreased from 8.437 to 5.09 MPa with increasing of grains moisture content from 9.55 to 17.49 % (w.b). While, Sakha-93 variety showed the lowest values of static shear stress, which decreased from 6.415 to 4.395 MPa with increasing of grains moisture content from 10.22 to 17.62 % (w.b). The results indicated also that Giza-168 variety has the highest static particle shear stress followed by Banisuif-1 and the lowest static particle shear stress was for Sakha-93. Similar results were found by ***(Soliman and Korayem 1983)*** for paddy rice Giza-170 variety.

Stress-Strain Tests on Bulk and Particle Wheat Grains

The bulk and particle force-deformation compression experiments were carried out for each of the three investigated varieties at the four levels of moisture content. Figure (6) demonstrates the typical curves of bulk and particle stress-strain tests for Giza-168 as a sample for other wheat varieties.
The mechanical properties data of compressive stress strain tests for wheat varieties under study at different levels of moisture contents for bulk and particles case were analyzed to seven parameters including initial modulus of elasticity (MPa), modulus of elasticity (MPa), bioyield stress point (MPa), bioyield strain point, maximum compressive stress (MPa), maximum compressive strain and breakage energy (MJ/ m^3).
Results of average values of compressive stress-strain tests parameters in bulk and particles related to different levels of moisture contents are summarized in tables 2 and 3.
Figures 7, 8, 9 and 10 illustrate the seven parameters of stress-strain test. For the all studied varieties the initial modulus of elasticity for each of bulk and particle tests was decreased with increasing of moisture content in the studied range.
Bulk modulus of elasticity was decreased with increasing of moisture content in studied range for studied varieties. But particle modulus of elasticity was decreased with increasing of moisture content from about 10 to 14 %(w.b)

Table (2): Bulk Wheat Grains Average Mechanical Properties of
The Studied Varieties

Variety	M.C. %	Initial Elasticity MPa	Elasticity MPa	Bioyield point		Maximum		Break Energy MJ/m^3
				Stress MPa	Strain	Stress MPa	Strain	
Giza -168	9.55	4.154	46.603	3.000	0.111	3.743	0.135	0.2195
	11.36	3.889	31.069	3.166	0.150	3.673	0.184	0.2998
	13.74	3.536	28.959	3.222	0.163	3.596	0.191	0.3064
	17.49	3.093	20.426	3.500	0.225	3.764	0.247	0.4012
Sakha -93	10.22	4.949	36.810	2.778	0.110	3.666	0.155	0.2675
	12.09	4.508	28.129	2.889	0.138	3.603	0.175	0.2788
	13.82	3.093	27.869	2.944	0.150	3.652	0.194	0.3133
	17.62	2.917	24.649	3.000	0.168	3.883	0.226	0.4111
Banisuif -1	8.99	4.595	30.752	3.000	0.100	3.736	0.181	0.3373
	11.75	3.536	30.442	3.167	0.133	3.806	0.175	0.2908
	14.88	3.447	27.615	3.222	0.150	3.624	0.184	0.3005
	17.87	2.828	19.002	3.340	0.218	3.813	0.264	0.4394

Variety	M.C. %	Initial Elasticity MPa	Elasticity MPa	Bioyield point		Maximum		Break Energy kJ/m^3
				Stress MPa	Strain	Stress MPa	Strain	
Giza -168	9.55	16.57	25.81	3.733	0.160	5.181	0.297	0.915
	11.36	14.67	37.21	5.467	0.183	7.125	0.266	0.951
	13.74	14.47	33.76	5.000	0.170	7.018	0.298	1.133
	17.49	14.09	35.56	5.067	0.166	6.080	0.218	0.654
Sakha -93	10.22	22.86	53.33	5.733	0.132	7.586	0.195	0.734
	12.09	18.67	34.78	4.200	0.130	4.584	0.153	0.356
	13.82	18.28	27.90	3.333	0.133	4.047	0.196	0.415
	17.62	16.00	38.46	4.600	0.143	5.975	0.229	0.736
Banisuief -1	8.99	36.00	120.00	7.700	0.100	11.956	0.191	1.191
	11.75	34.29	73.17	9.800	0.162	11.869	0.219	1.325
	14.88	24.57	57.94	7.200	0.160	10.333	0.313	1.855
	17.87	20.00	54.55	4.700	0.157	6.355	0.190	0.696

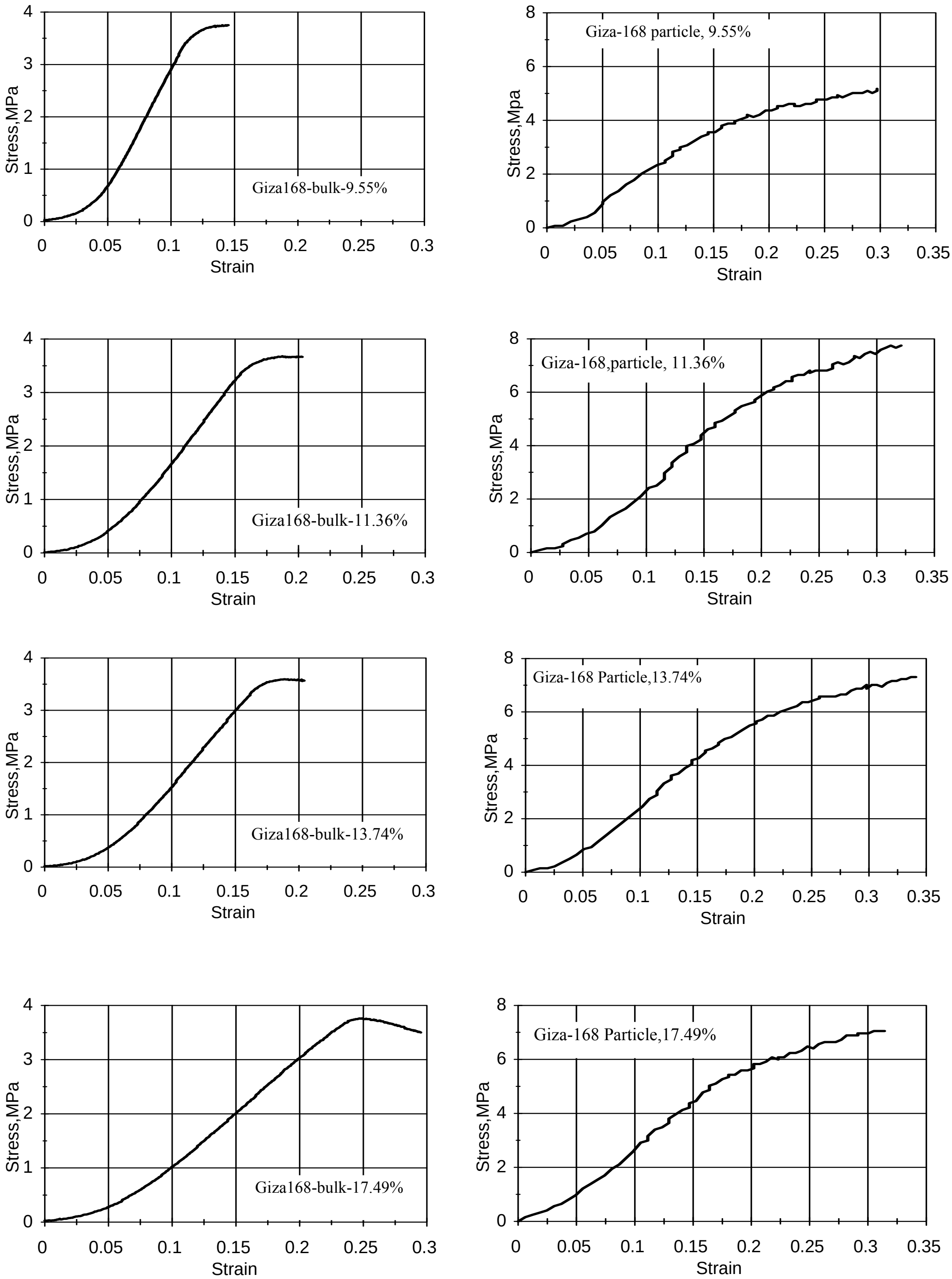


Figure (6): Typical Bulk and Particle Stress-Strain Curves of Giza-168 Variety of Wheat Grains at Different Levels of Moisture Content.

for Giza-168 and Sakha-93 varieties, then, increased with increasing of moisture content. While, it decreased with increasing of moisture content for Banisuif-1 variety in the studied range.

For Giza-168 variety each of stress and strain at bioyield point of bulk and particle tests were increased with increasing of moisture content.

For Sakha-93 variety bulk stress of bioyield point was increased with increasing of moisture content. While, bulk strain of Bioyield Point was decreased with increasing moisture content from 10.22 to 12.09%. Then, it was increased with increasing of moisture content to 17.62%.

Each of bioyield point stress and strain in bulk tests of wheat grains for the three studied varieties were increased with increasing of moisture content at the studied range.

For Giza-168 and Banisuif-1 varieties each of bioyield point stress and strain of particle wheat were increased with increasing of moisture content from about 9 to about 12% then, decreased with increasing of moisture content to about 18% (w.b). While, the Bioyield point stress of particle wheat for Sakha-93 variety was decreased with increasing of moisture content from 10.22 to13.82%, then, it was increased with increasing of moisture content to 17.62% (w.b), at the same time, the Bioyield strain of particle wheat for the same variety was decreased with increasing of moisture content from 10.22 to 12.09%, then it was increased with increasing of moisture content to 17.62% (w.b).

Bulk maximum compressive stress for each of Giza-168 and Sakha-93 varieties was decreased with increasing of moisture content from about 10 to 14% (w.b), then, it was increased with increasing of moisture content to about 18 %. While, it was decreased with increasing of moisture content from 8.99 to 11.75 %(w.b), then, increased with increasing of moisture content to 17.87 %(w.b) for Banisuif-1 variety. For each of Giza-168 and Sakha-93 varieties, the maximum strain of wheat grains in bulk tests was increased with increasing of moisture content at the studied range. While, for Banisuif-1 it was decreased with increasing of moisture content from 8.99 to 11.75%, then, it was increased with increasing of moisture content to 17.87% (w.b).

Particle maximum stress for Banisuif-1 variety was decreased with increasing of moisture content in studied range. While, it was decreased with an increasing of moisture content from about 10 to 12% (w.b) then, increased with increasing of moisture content to about 18% for each of Giza-168 and Sakha-93 varieties.

Particle maximum strain of Giza-168 variety was decreased with increasing of moisture content from 9.55 to 11.36%, then, it was increased with increasing of moisture content to 13.74%, after that, it was decreased with increasing of moisture content to 17.49% (w.b). While, for Sakha-93 variety it was decreased with increasing of moisture content from 10.22 to12.09%, then, it was increased with increasing of moisture content to17.62% (w.b). But, for Banisuif-1 variety it was increased with increasing of moisture content from 8.99 to 14.88%, then, it was decreased with increasing of moisture content to 17.87% (w.b).

The breakage energy in bulk tests for each of Giza-168 and Sakha-93 varieties was increased with increasing of moisture content at the studied range. While, for Banisuif-1 variety, it was decreased with increasing of moisture content from 8.99 to 11.75%, then, it was increased with increasing of moisture content to 17.87% (w.b).

The breakage energy of particle wheat for each of Giza-168 and Banisuif-1 varieties, was increased with increasing of moisture content from about 9% to about 14%, then, it was decreased with increasing of moisture content to about 17.50% (w.b). While, for Sakha-93 variety it was decreased with increasing of moisture content from 10.22 to 12.09%, then, it was increased with increasing of moisture content to 17.62% (w.b).

Statistical linear regression analysis were conducted for describing the relationship between the mechanical parameters related to bulk and particle compression tests and moisture content of the three studied wheat varieties. The resulted constants of linear equations are shown in table (4).

The results of each of elasticity modulus, maximum compressive stress and strain and breakage energy as a function of moisture content were suggested in trend with the results of ***(Delwiche, 2000)*** which work on endosperm specimens of soft and hard wheat.

The particle bioyield point strain of Sakha-93 variety related to moisture content was suggested in trend with the results of ***(Kang, et. al, 1995)***.

Table (4): Regression Equations of Compression Tests Parameters for Wheat Grains of Different Varieties.

Variety	Test	Parameter	A	B	R^2
Giza-168	Bulk	E_o, MPa	5.4096	– 0.1336	0.996
		E, MPa	69.8182	– 2.9144	0.842
		Yσ, MPa	2.4442	0.0597	0.968
		Yε	- 0.0147	0.0136	0.968
		MSσ, MPa	3.6544	0.0030	0.488
		MSε	0.0207	0.0129	0.935
		BE, MJ/m^3	0.0348	0.0209	0.926
	Particle	E_o, MPa	18.4018	– 0.2648	0.679
		E, MPa	22.0047	0.8884	0.488
		Yσ, MPa	3.3647	0.1114	0.586
		Yε	0.1715	-0.0001	0.522
		MSσ, MPa	5.5961	0.0579	0.476
		MSε	0.3803	-0.0085	0.597
		BE, MJ/m^3	1.3082	-0.0303	0.771
Sakha-93	Bulk	E_o, MPa	7.7510	– 0.2891	0.807
		E, MPa	48.5631	- 1.4288	0.747
		Yσ, MPa	2.5230	0.0283	0.884
		Yε	0.0423	0.0074	0.914
		MSσ, MPa	3.2560	0.0331	0.705
		MSε	0.0591	0.0096	0.995
		BE, MJ/m^3	0.0459	0.0202	0.954
	Particle	E_o, MPa	30.1315	– 0.8319	0.841
		E, MPa	59.7714	-1.5743	0.513
		Yσ, MPa	6.0854	-0.1205	0.543
		Yε	0.1124	0.0016	0.8003
		MSσ, MPa	7.3722	-0.1358	0.731
		MSε	0.1035	0.0067	0.4576
		BE, MJ/m^3	0.3847	0.0137	0.492
Banisuif-1	Bulk	E_o, MPa	6.0014	- 0.1795	0.885
		E, MPa	44.1663	– 1.2872	0.819
		Yσ, MPa	1.4974	0.1051	0.759
		Yε	- 0.0164	0.0125	0.929
		MSσ, MPa	3.7255	0.0014	0.455
		MSε	0.0841	0.0087	0.635
		BE, MJ/m^3	0.1975	0.0108	0.537
	Particle	E_o, MPa	54.7779	– 1.9490	0.950
		E, MPa	170.7816	– 7.0616	0.806
		Yσ, MPa	12.6743	-0.3982	0.553
		Yε	0.0705	0.0056	0.509
		MSσ, MPa	18.4210	– 0.6201	0.825
		MSε	0.1878	0.0030	0.400
		BE, MJ/m^3	1.7019	-0.0325	0.689

In general, the mechanical properties of wheat grains influenced by transparency ***(Haddad, et. al, 1999)*** and moisture content ***(Haddad, et. al, 2001)*** and by a compact uniform endosperm structure with starch granules firmly embedded in the surrounding protein matrix ***(Turnbull and Rahman, 2002).*** As shown in the results of the present study, each of hardness, shear force, particle maximum stress and particle breakage energy were the highest for Banisuif-1 variety with the highest transparency (tables 2, 3) and the lowest for Sakha-93 with zero transparency (tables 2, 3).

CONCLUSION

The obtained results can be summarized as follows:

1. Hardness of Giza-168 and Sakha-93 varieties was increased with increasing of moisture content. While, hardness of Banisuif-1 variety was decreased with increasing of moisture content at the studied range.
2. Shear stress was decreased linearly with increasing of moisture content in the studied range for the three studied varieties. Giza-168 variety showed the highest decrease values of static shear stress. While, Sakha-93 variety recorded the lowest decrease values.
3. Initial elasticity modulus in bulk and particle for the studied wheat varieties was decreased with increasing of moisture content in the studied range.
4. Elasticity modulus in bulk was decreased with increasing of moisture content at the studied range for the three varieties. While, elasticity modulus in particle for Banisuif-1 variety was taken the same trend of that in bulk, but for each of Giza-168 and Sakha-93 varieties it was decreased with increasing of moisture content from about 10 to 14%, then, it was increased with increasing of moisture content to about 18%(w.b).
5. Each of the three studied varieties was appeared different behavior in each of maximum compressive stress, bioyield point and breaking energy with increasing of moisture content in the studied range.

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الملخص العربي

الخواص الميكانيكية لحبوب القمح

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تهدف هذه الدراسة إلى توفير قاعدة معلومات للخواص الميكانيكية المرتبطة بعمليات التداول والطحن لحبوب القمح وعلاقة كل منها بالمحتوى الرطوبي للحبوب لثلاثة أصناف من أصناف القمح المصرية الجديدة وهي: جيزة١٦٨- سخا٩٣ و بني سويف-١.

وتم اختيار هذه الأصناف لكونها من أكثر أصناف القمح المزروعة في مصر مساحة وأعلاها إنتاجية وتمثل أصناف القمح المستخدمة في صناعة الخبز والبسكويت(جيزة-١٦٨،سخا-٩٣) وقمح الديورم المستخدم في صناعة المكرونة(بني سويف-١). وتمت الدراسة للأصناف المذكورة عند أربعة مستويات رطوبية مختلفة (حوالي ٩و١٢و١٤و١٨%) على أساس الوزن الرطب. أما الاختبا رات المدروسة فكانت كما يلي: اختبار إجهاد قص الحبة و اختبار صلابة الحبة و اختبار الإجهاد-الانفعال للحبة الواحدة و اختبار الإجهاد - الانفعال الكمي للحبوب باستخدام ماكينة الاختبارات العامة.

ويمكن تلخيص النتائج التي توصل إليها البحث فيما يلي:

<u>إختبارصلابة الحبة:</u>

صلابة الحبة للصنفين جيزة-١٦٨ و سخا-٩٣ زادت بزيادة المحتوى الرطوبي للحبوب في حين انخفضت بزيادة المحتوى الرطوبي للحبوب للصنف بني سويف-١. في المدى الرطوبي من٩ إلى ١٥% سجل صنف بني سويف-١ أكبر مقادير في صلابة الحبة، في حين أظهر صنف جيزة-١٦٨ أقل انخفاض في صلابة الحبة في المدى الرطوبي المذكور. عند المحتوى الرطوبي ١٨% أظهر صنف جيزة-١٦٨ أعلى متوسط لمقدار الصلابة (٦.٦٠ كجم)، في حين سجل صنف بني سويف-١ أقل مقدار للصلابة(٥.٥٦٥كجم) عند نفس المحتوى الرطوبي.

١- أستاذ هندسة التصنيع الزراعي بكلية الزراعة جامعة الإسكندرية.
٢- أستاذ مساعد الهندسة الزراعية بكلية الزراعة جامعة المنوفية - شبين الكوم.
٣- طالب دراسات عليا بقسم الهندسة الزراعية بكلية الزراعة جامعة المنوفية - شبين الكوم.

إختبار إجهاد القص الاستاتيكي:

أظهر تحليل الارتباط الخطي للنتائج أن إجهاد القص الاستاتيكي للحبة الواحدة ينخفض خطيا مع زيادة المحتوى الرطوبي للحبة للأصناف الثلاثة المدروسة. وقد سجل صنف جيزة-١٦٨ أعلى انخفاض في متوسط إجهاد القص الاستاتيكي(٨.٤٣٦- ٥.٠٩ ميجا باسكال) بزيادة المحتوى الرطوبي من ٩,٥٥ إلى ١٧.٤٩%، فيما سجل صنف سخا-٩٣ أقل انخفاض في إجهاد القص الاستاتيكي(٦.٤١٥ – ٤.٣٩٥ ميجا باسكال) بزيادة المحتوى الرطوبي من ١٠.٢٢ إلى ١٧.٦٢ % على أساس الوزن الرطب.

اختبار الإجهاد- الانفعال:

معاملات المرونة الكمية وللحبة الواحدة تتناسب تناسبا عكسيا مع المحتوى الرطوبي للحبوب للأصناف الثلاثة المدروسة في المدى الرطوبي المدروس. فمعامل المرونة للحبة الواحدة للصنف بني سويف- ١ انخفض بزيادة المحتوى الرطوبي في المدى المدروس. ولقد أظهر صنفي جيزة-١٦٨ وسخا -٩٣ انخفاض بمعامل المرونة للحبة الواحدة بزيادة المحتوى الرطوبي من حوالي ١٠- ١٤% ، ثم ازداد بزيادة المحتوى الرطوبي إلى حوالي ١٨% على أساس الوزن الرطب.

أقصى إجهاد كمي للصنفين جيزة- ١٦٨ وسخا- ٩٣ انخفض بزيادة المحتوى الرطوبي من حوالي ١٠-١٤% ثم ازداد بزيادة المحتوى الرطوبي إلى حوالي ١٨%. في حين أظهر صنف بني سويف- ١ انخفاض لأقصى إجهاد كمي بزيادة المحتوى الرطوبي من٩-١٢%، ثم بزيادة المحتوى الرطوبي إلى حوالي١٨% على أساس الوزن الرطب.

أقصى إجهاد للحبة الواحدة للصنف بني سويف-١ انخفض بزيادة المحتوى الرطوبي في المدى المدروس. في حين سجل كل من صنف جيزة-١٦٨ وسخا-٩٣ انخفاض في أقصى إجهاد للحبة الواحدة بزيادة المحتوى الرطوبي من حوالي ١٠-١٢ %، ثم ازداد بزيادة المحتوى الرطوبي إلى حوالي ١٨.٥.

طاقة التحطيم الكمي للصنفين بني سويف-١ وسخا-٩٣ انخفضت بزيادة المحتوى الرطوبي للحبوب من حوالي ٩-١٤ %، ثم ازدادت بزيادة المحتوى الرطوبي إلى حوالي ١٨%. بينما ازدادت للصنف جيزة- ١٦٨ بزيادة المحتوى الرطوبي من ٩.٥٥ % إلى ١١.٣٦% ثم انخفضت بزيادة المحتوى الرطوبي إلى ١٣.٧٤%، ثم ازدادت بزيادة المحتوى الرطوبي إلى ١٧.٤٩%.

طاقة التحطيم للحبة الواحدة لكل من صنفي جيزة-١٦٨ وسخا-٩٣ انخفضت بزيادة المحتوى الرطوبي من حوالي ١٠- ١٢% ثم ازدادت بزيادة المحتوى الرطوبي إلى حوالي ١٨%. بينما أظهر صنف بني سويف-١ انخفاض في طاقة تحطيم الحبة الواحدة بزيادة المحتوى الرطوبي من ٨.٩٩% إلى ٨٨. ١٤%، ثم ازدادت بزيادة المحتوى الرطوبي إلى ١٧.٨٧% على أساس الوزن الرطب.

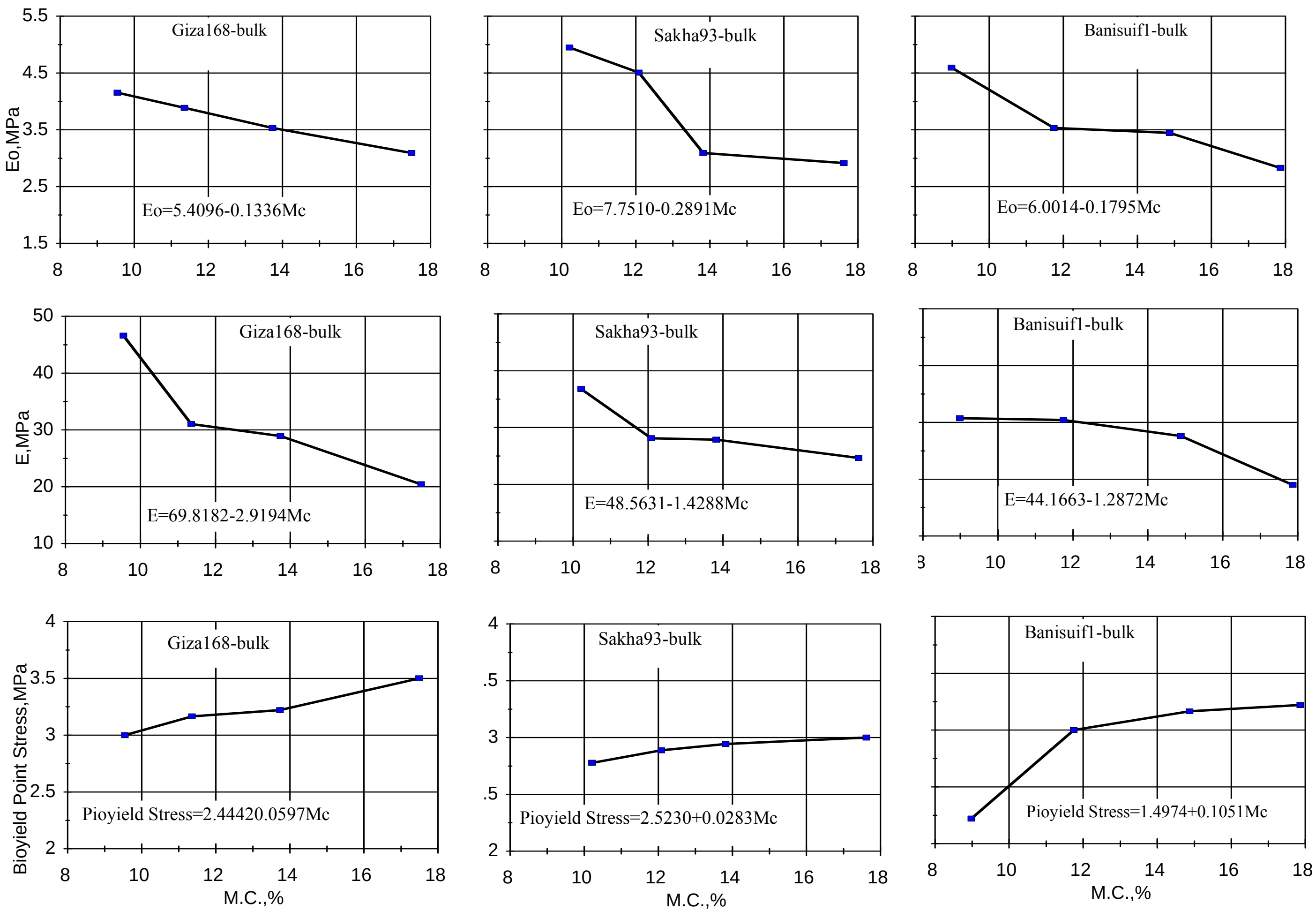

Figure (6): Initial Modulus of Elasticity, Modulus of Elasticity and Bioyield Point Stress of Wheat Grains In Bulk

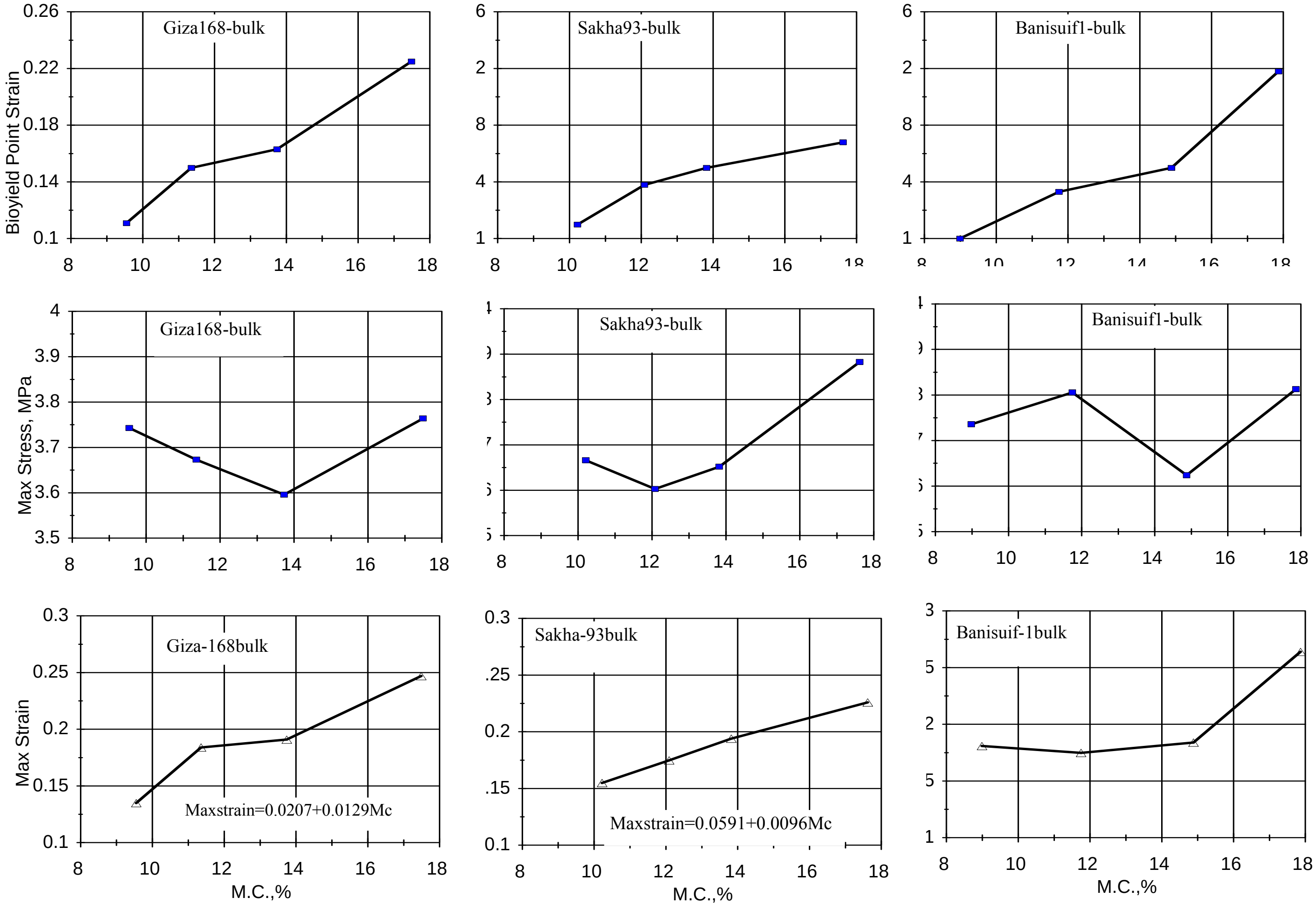

Figure (7): Bioyield Point Strain, Maximum Compressive Stress and Maximum Compressive Strain of Wheat Grains In Bulk

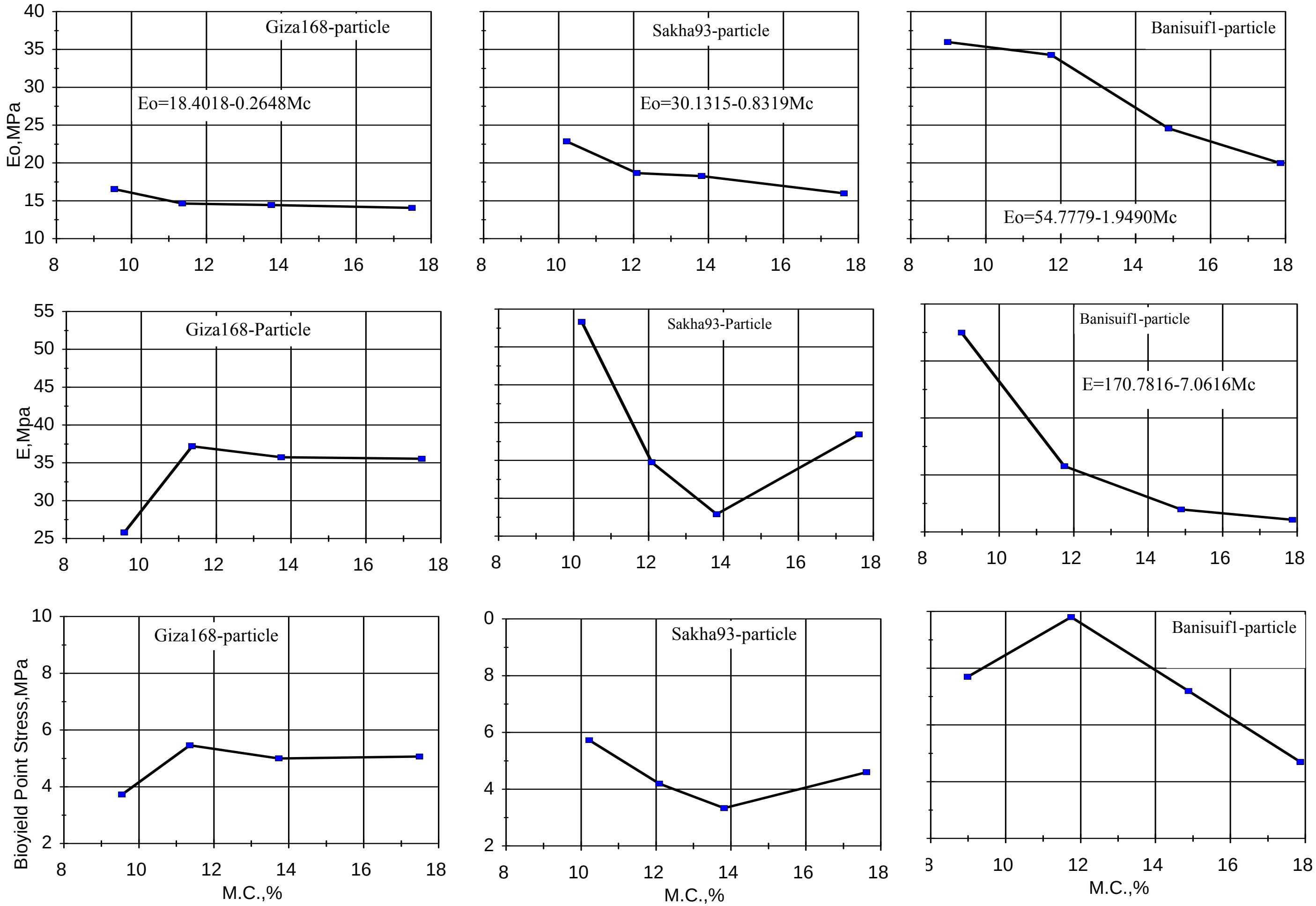

Figure (8): Initial Modulus of Elasticity, Modulus of Elasticity and Bioyield Point Stress of Wheat Grains In Particle

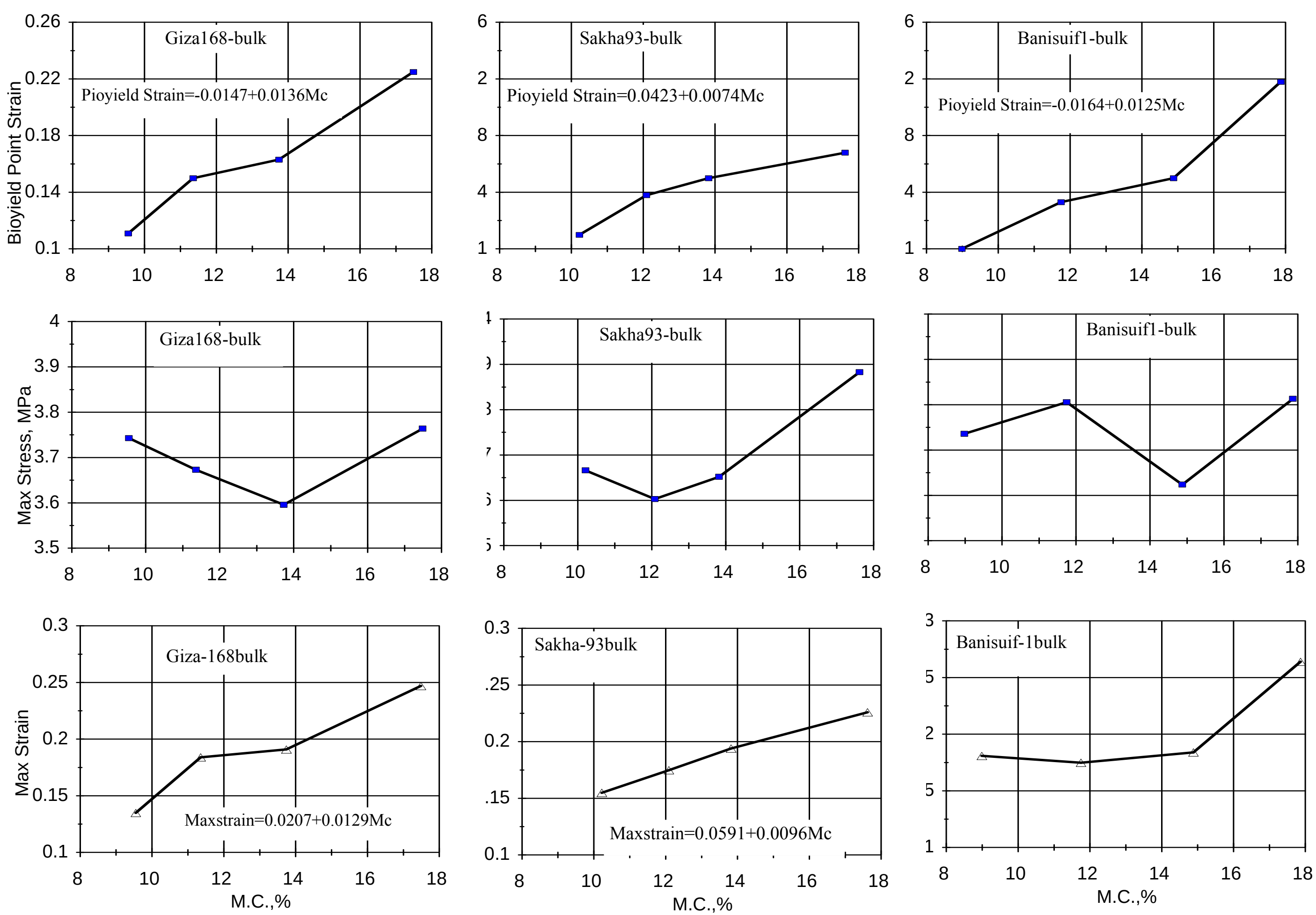

Figure (9): Bioyield Point Strain, Maximum Compressive Stress and Maximum Compressive Strain of Wheat Grains In Particle

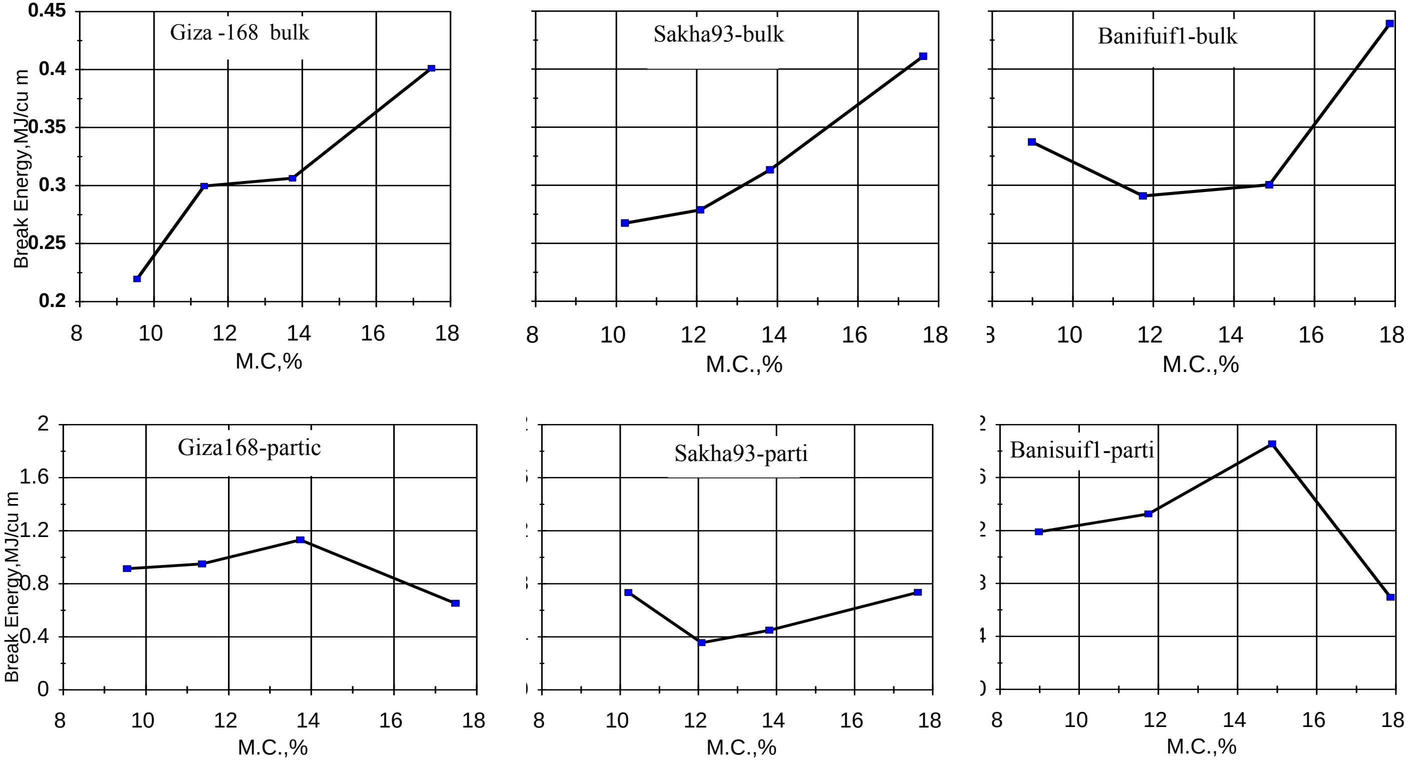

Figure (10): Break Energy of Wheat Grains In Bulk and Particles Under Different Levels of Moisture Contents