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EFFECT OF MOISTURE CONTENT ON MECHANICAL PROPERTIES OF SOME CEREAL GRAIN

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ABSTRACT

The effect of five different levels of moisture content on grain hardness, shear force and shear stress at both longitudinal and lateral directions was determined for some varieties of rice, wheat, corn and barely.

The results showed that for all studied crops, hardness, shear force and shear stress showed an opposite linier dependence on moisture content. The values of grain hardness within the investigated range of moisture content were ranged from [(21.76-37.50), (88.07-173.20), (24.012-50.44), and (40.35-81.54) N] for rice, corn, wheat, and barley, respectively.

Meanwhile, shear force at the longitudinal direction was higher than lateral direction for the investigated varieties of rice and barely, while it was lower at longitudinal direction than lateral direction for corn and very close at both directions for wheat. Also, the values of shear stress in lateral direction were higher than longitudinal direction for all varieties of the investigated crops

INTRODUCTION

Mechanical properties such as compressive strength, impact and shear resistance are important and in some cases necessary engineering data in studying size reduction of cereal grains as well as seed resistance to cracking under harvesting and handling conditions. From an energy stand point, this information can be used to determine the best method (shear, impact or static crushing) to breakup or grind grain.

Hardness of grains has been a subject of interest to millers, livestock feeders, breeders and other agricultural scientists. Bitting or cutting the grain has provided a qualitative evaluation of grain hardness.A number of attempts have been made to find an objective and qualitative measure of the hardness of individual kernels or the average of a collection of kernels, (Mohsenin, 1987).

Oloso and Clarke (1993) discovered that failure force, failure deformation and the energy absorbed increased with the increases of moisture

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content while the failure force decreased. Pre-damage to grain resulted in a decrease in all failure parameters.

Okuno and Adachi (1992) examined the relationship between the water content, volume, specific gravity, grain hardness and water absorption characteristics during the soaking process of milled grain of different rice cultivars. They found that, grain hardness was the characteristics most affected by cultivar. Grain hardness was highly positively correlated with water absorption rate and with final water content.

Kirleis and Stroshine (1990) mentioned that, severity of stress cracking was directly related to hardness of different maize hybrids, stein breakage was greatest for the soft hybrid and least for the hard hybrid, whereas Wisconsin breakage was greatest for the hard hybrid and least for the hybrid of intermediate hardness. Stein breakage susceptibility was primarily influenced by hardness, while Wisconsin breakage susceptibility was correlated with stress cracking.

Martin *et al*., (1997) determined the breakage, susceptibility and hardness of corn kernels of various sizes and shapes. They found that mechanical breakage at harvest was influenced by kernel size, shape and structure characteristics then by kernel hardness properties. There were high correlation between and among physical properties, composition, hardness and stein Breakage Tester (SBT) values.

Bamrung *et al*., (1988) determined the required force for breakage of two different rice varieties representing short and long grains. The results show that, the force required for breaking long grain variety was less than short grain variety. The recorded force for breaking of long grain variety was ranged from 16-40 N. in comparison with 28-68 N. for short grain variety.

Owies (1995) determined the hardness of different varieties of wheat, paddy and corn. The results clear that, the hardness of grain ranged from 7.06 to 32.08 N. for wheat, from 25.60 to 36.20 N., for paddy and for corn varieties they ranged from 25.60 to 36.20 N. for the endosperm and from 4.02 to 13.34 N. for the germ.

The present study was conducted to determine grain hardness, shear force and shear stress for different varieties of rice wheat, corn and barley at different levels of grain moisture content. Also, to develop a mathematical relationships relating these properties with the changes in grain moisture content.

MATERIALS AND TEST PROCEDURE

Materials:

Different varieties of rice, corn, wheat and barely were selected based on their recent coverage area and the expected future expansion of each variety.

For the experimental work, samples of the selected varieties were procured from the experimental farm of Agricultural Research Center at Sakha Station, Kafr EL-Sheikh Gov. The selected samples were cleaned from foreign matters, broken and immature grain.

To obtain different levels of grain moisture content, the grains of each variety were carefully mixed and the initial moisture content was determined according to (Matouk *et al.*, 2002). The five desired levels of grain moisture content of each variety were attained by adding calculated amount of tap water to the grain sample and mixing them in a grain conditioning apparatus for 72 hours as proceeded by (Matouk *et al.*, 2004).

The conditioned samples of each level of grain moisture content were sealed in poly-ethylene bags and stored in a freezing unit adjusted at temperature of -5±1 ^oC to prevent moisture loss and fungal growth throughout the storage period. Before each test, the required quantity of grain was taken out from the freezing unit and allowed to reach the normal room temperature. The moisture content was determined just before each test.

Measurements and test procedure :

Grain moisture content :

The oven drying method at 130 ^oC for 16 h. proceeded by Matouk *et al.*, (2002) was used for determining the grain moisture contents for different studied varieties of each crop.

Grain hardness :

Hardness and shear force, meter model FGN-50 with an accuracy of 0.01 N. and a digital LCD was used for measuring grain hardness and shear force.

For measuring grain hardness, a grain was pressed by the conical end of the meter, while the digital reading was increased with the increasing of the pressure on the grain until it has been cracked. At this point the displayed reading means grain hardness. It should be mentioned here that, each tested sample was represented by 100 grains and only one reading was recorded for each grain for all samples of different varieties of each crop.

Grain shear force and shear stress :

Shear force was measured at both longitudinal and lateral grain axis. The conical end of the meter was changed to a shearing end and the previously mentioned procedure was used for measuring the shear force at both grain axis.

The average of 100 readings of shear force at the longitudinal axis was used for calculating, the shear stress at this axis using the following equation :

$$S_w = \frac{F_L}{A_L} \quad \text{.....................................} \quad (1)$$

Where :

S_w = shear stress at grain longitudinal axis.

F_L= shear force at grain longitudinal axis.

A_L= cross section area of shear at grain longitudinal axis.

The value of A_L for rice, wheat and barley could be calculated using the following relation ship:

$$A_L = \frac{\pi}{4} L.Th \quad \text{..} (2)$$

Also, for corn the following relation could be used:

$$A_L = L.Th \quad \text{..} (3)$$

While, the average of 100 readings of shear force at lateral axis was used for calculating the shear stress at this axis using the following equation:

$$S_w = \frac{F_w}{A_w} \quad \text{...} \quad (4)$$

Where :

S_W = shear stress at lateral grain axis.

F_W = shear force at lateral grain axis.

A_W = cross section area of shear at grain lateral axis.

The value of A_W for rice, wheat and barely could be calculated using the following relationship:

$$A_W = \frac{\pi}{4} W.Th \quad \text{.......................................} (5)$$

While for corn the following relationship could be used:

$$A_W = W.Th \quad \text{...................................} (6)$$

Where :

L = grain length, cm.

W = grain width, cm.

Th = grain thickness, cm.

Figure (1) presents a schematic diagrams for measuring procedure of shear force at both longitudinal and lateral positions of grain.

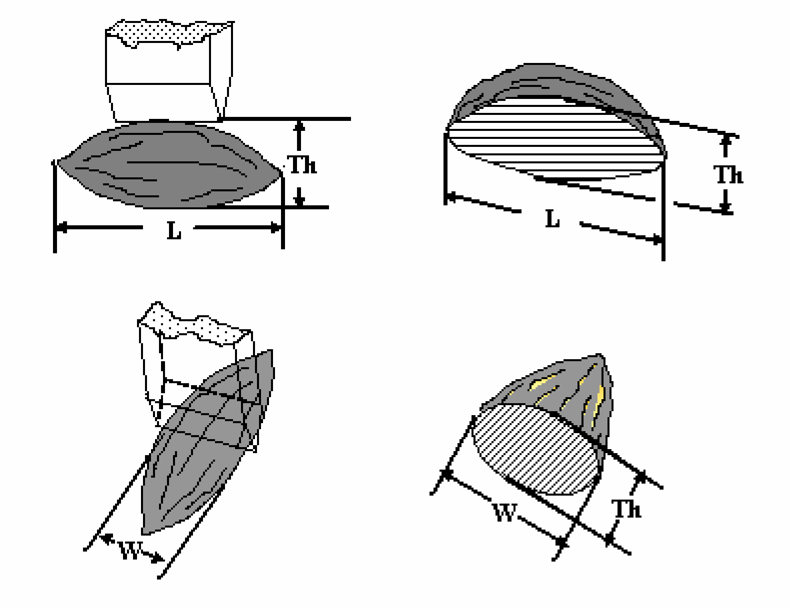

Figure (1): Measurement procedure for shear force at both longitudinal and lateral direction.

RESULTS AND DISCUSSION

Grain hardness :

Figures (2) to (5) illustrate the change in grain hardness as related to moisture content for different varieties of rice, corn, wheat and barely. In general, the results show that, grain hardness decreased with the increase of moisture content for all varieties.

As shown in Fig. (2), for rice crop, the recorded grain hardness was ranged from 21.76 to 37.5 N. and the long grain varieties recorded higher grain hardness in comparison with short grain varieties. The figure also shows that, Jasmin variety recorded the highest grain hardness which increased from 33.46 to 37.50 N. with the decrease of moisture contents from 25.11 to 12.80 % w.b. followed by varieties G. 181, Sakha 101 and Giza 137. While, variety Giza 178 recorded the lowest grain hardness.

For corn crop, Fig. (3) shows that, the grain hardness for different varieties was ranged from 71.07 to 173.20 N. and the variety triple hybrid 310 recorded the highest hardness which increased from 71.07 to 173.2 N. with the decrease of grain moisture content from 27.74 to 9.95 % w.b. followed by varieties triple hybrid 321 and single hybrid 10. While variety Balady recorded the lowest grain hardness which increased from 90.09 to 147.85 N. with the decrease of grain moisture content from 25.93 to 10.40 % w.b. respectively.

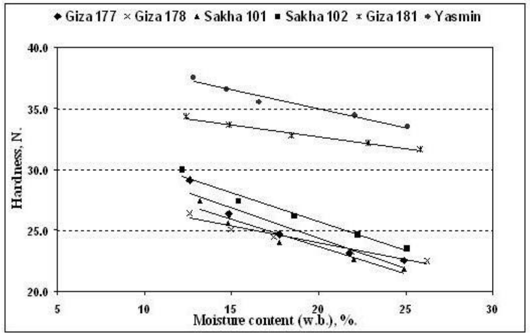

Fig. (2) : Effect of moisture content on grain hardness for the investigated rice

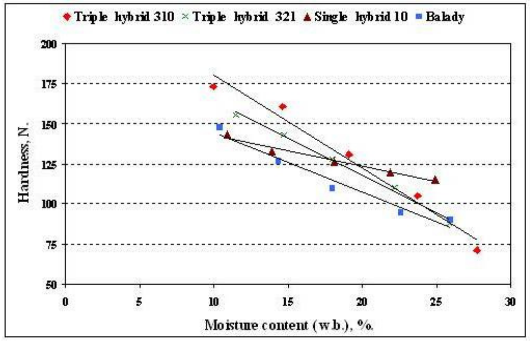

Fig. (3) : Effect of moisture content on grain hardness for the investigated corn varieties.

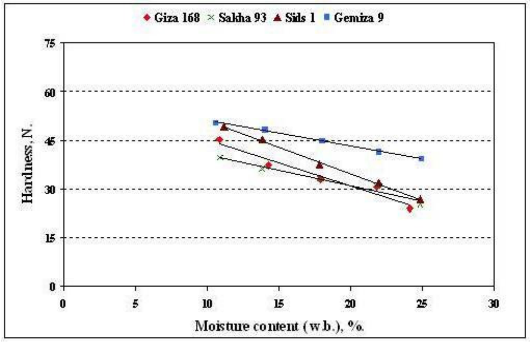

Fig. (4) : Effect of moisture content on grain hardness for the investigated

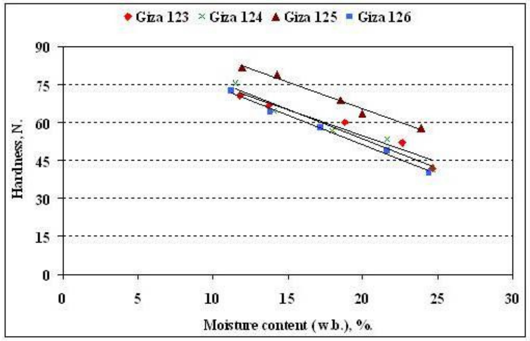

Fig. (5) : Effect of moisture content on grain hardness for the investigated barely varieties.

For wheat crop, Fig. (4) shows that, the grain hardness was ranged from 24.012 to 50.44 N and variety Gimmeza (9) recorded the highest hardness values which increased from 39.15 and 50.44 with the decrease of moisture content from 24.92 to 10.60 % w.b. followed by varieties Sids 1 and Giza (168), while variety Sakha 93 recorded the lowest hardness values which increased from 25.182 to 39.65 with the decrease of grain moisture contents from 24.06 to 10.97 % w.b. respectively.

For barely crop, Fig. (5) shows that the grain hardness was ranged from 37.349 to 81.538 N. and the variety Giza 125 recorded the highest hardness degree which increased from 57.598 to 81.538 N. with the decrease of grain moisture contents from 23.87 to 11.95 % w.b. followed by the varieties Giza 124 and Giza 123. While the variety Giza 126 recorded the lowest hardness values which increased from 40.349 to 72.551 N. with the decrease of grain moisture contents from 24.41 to 11.22 % w.b. respectively.

Shear Force :

Shear force at both lateral and longitudinal directions were measured as a function of grain moisture content. In general, shear force at both directions was decreased with the increase of grain moisture content for all studied crops.

As shown in Figs (6 and 7) the grain shear forces for different rice varieties were increased from 28.43 to 69.80 N. at longitudinal direction and from 20.51 to 45.91 N. at lateral direction. The higher grain shear force at longitudinal direction in comparison with lateral direction could be attributed to the nature of grain structure and also the difference in shearing area at both directions.

For corn varieties Figs (8 and 9) shows that, in contrast of rice grain the grain shear force at longitudinal direction was lower than lateral direction and the recorded shear force was ranged from 80.81 to 193.47 N. at longitudinal direction and from 128.69 to 266 N. at lateral direction. Also, variety triple hybrid 310 shows the highest values of shear force while variety Balady shows the lowest values at both directions.

Figures (10 and 11) also show that, for wheat crop, the values of grain shear force was very close at both longitudinal and lateral directions and it was ranged from 25.398 to 50.49 N. at longitudinal direction and from 26.314 to 46.838 N. at lateral direction.

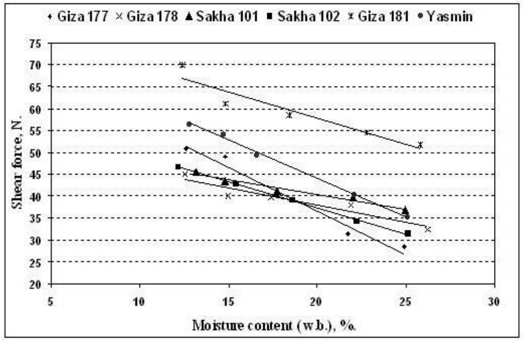

Fig. (6) : Effect of moisture content on grain shear force in longitudinal direction for the

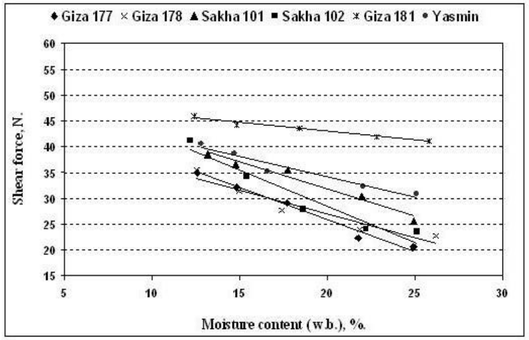

Fig. (7) : Effect of moisture content on grain shear force in lateral direction for the investigated rice

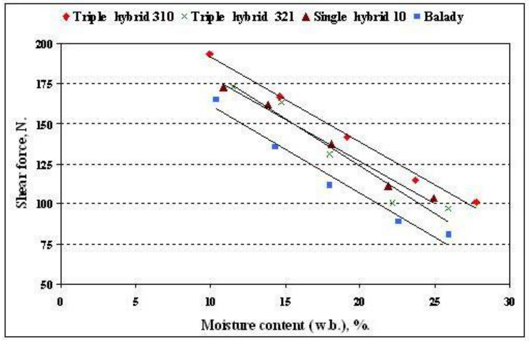

Fig. (8) : Effect of moisture content on grain shear force in longitudinal direction for the investigated

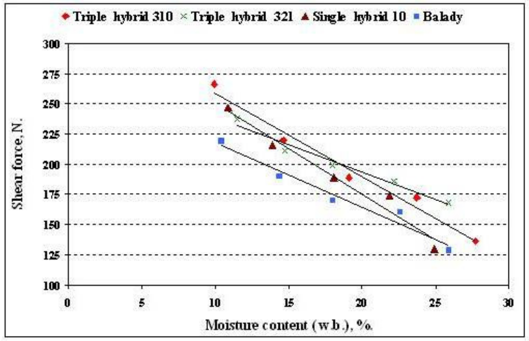

Fig. (9) : Effect of moisture content on grain shear force in lateral direction for the investigated corn

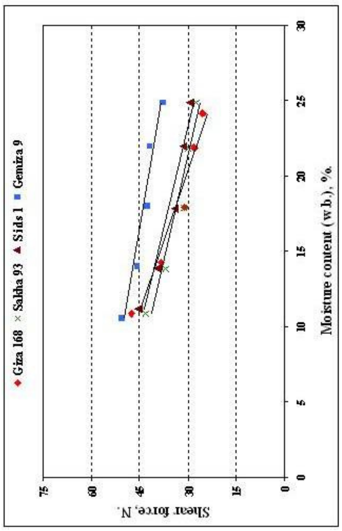

Fig. (10) : Effect of moisture content on grain shear force in longitudinal direction for the

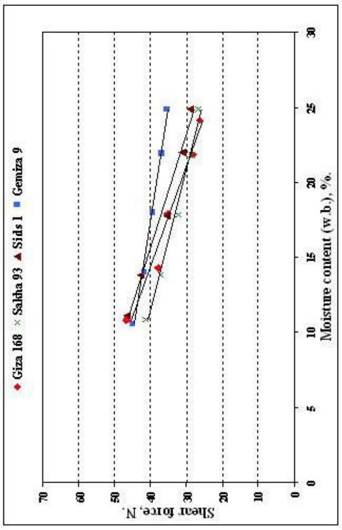

Fig. (11) : Effect of moisture content on grain shear force in lateral direction for the investigated

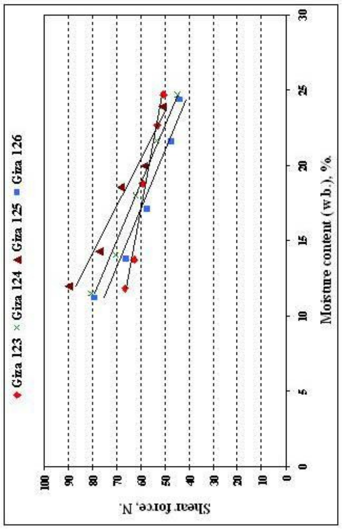

Fig. (12) : Effect of moisture content on grain shear force in longitudinal direction for the

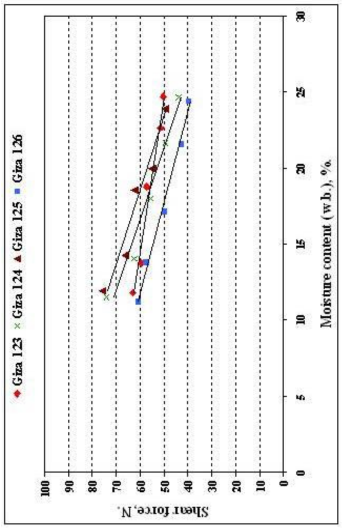

Fig. (13) : Effect of moisture content on grain shear force in lateral direction for the investigated

For barely crop Figs (12 and 13) show that, similar to rice grain the shear force was higher at longitudinal direction in comparison with lateral direction. The recorded shear force was ranged from 43.914 to 89.738 N. at longitudinal direction and from 39.314 to 75.596 N. at lateral direction. Also, the variety Giza 125 recorded the highest values of shear force while variety Giza 123 recorded the lowest values.

Shear Stress:

Figures (14) to (21) illustrate the change in grain shear force as related to moisture content. In general, for all studied crops the shear stress was decreased with the increase of grain moisture content.

For rice crop, Figs (14 and 15) show that, grain shear stress was lower at longitudinal direction in comparison with lateral direction. The recorded shear stress at longitudinal direction was ranged from 2.01 to 4.95 N/mm^2 while it was ranged from 3.99 to 10.17 N/mm^2 at lateral direction. These results are in contrast with that of shear force which means and assure the effect of grain structure and cross section area on the values of both shear force and shear stress.

For corn crop, Figs (16 and 17) show that, the shear stress was lower at the longitudinal direction in comparison with lateral direction. The recorded shear stress values at longitudinal direction was ranged from 1.363 to 3.446 N/mm^2 in comparison with 2.165 to 7.162 N/mm^2 at lateral direction.

On the other hands, for wheat crop Figs (18 and 19) show that, the grain shear stress was also lower at the longitudinal direction in comparison with lateral direction. The recorded shear stress values at the longitudinal direction were ranged from 1.47 to 3.1421 N/mm^2 in comparison with 2.723 to 6.036 N/mm^2 at lateral direction. Also, variety Sids 1 showed the highest shear stress values while variety Sakha 93 showed the lowest values at both directions.

Meanwhile, for barely crop, Figs (20 and 21) show that, grain shear stress at longitudinal direction was lower than that of lateral direction. The recorded shear stress values at longitudinal direction were ranged from 1.672 to 3.344 N/mm^2 in comparison with 4.170 to 8.732 N/mm^2 at lateral direction. This means that, the results obtained for wheat crop were similar to that of rice crop.

Statistical regression analysis:

In general, a simple regression analysis was applied to relate the change in grain hardness, shear force and shear stress with the change in grain moisture content. The results of analysis show that, for all varieties of the studied crops, grain hardness, shear force and shear stress were decreased with the increase of grain moisture content. The general equation represented this relationship was in the following form :

$$\mathbf{y = a - bx}$$

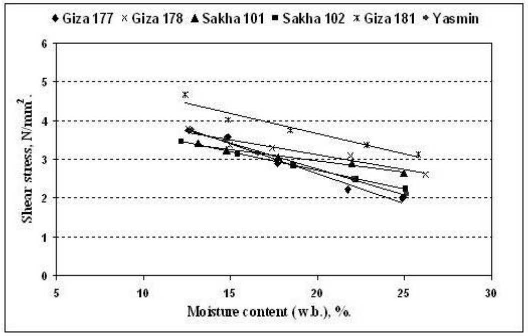

Fig. (14) : Effect of moisture content on grain shear stress in longitudinal direction for the

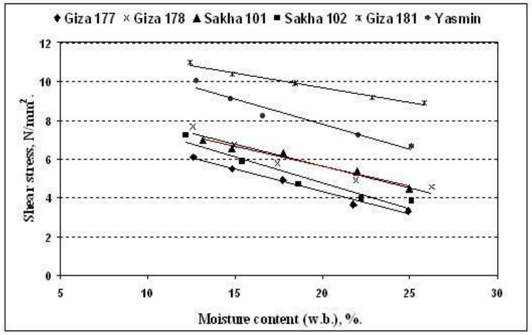

Fig. (15) : Effect of moisture content on grain shear stress in lateral direction for the investigated

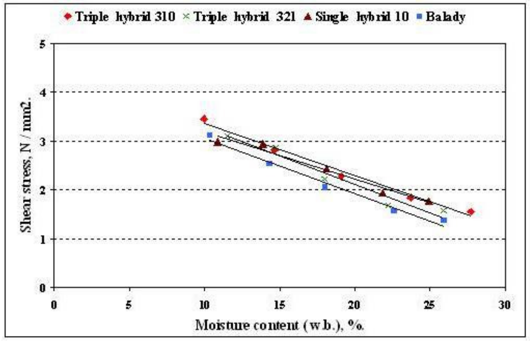

Fig. (16) : Effect of moisture content on grain shear stress in longitudinal direction for the

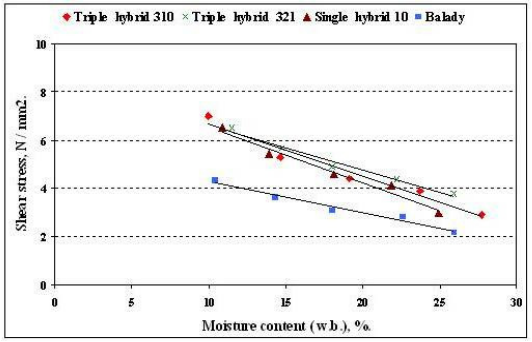

Fig. (17) : Effect of moisture content on grain shear stress in lateral direction for the investigated

The regression parameters (a and b) for all regression equations are tabulated in tables (1) through (3) respectively.

Table (1): Regression parameters of equations relating the change in moisture content with grain hardness.

Crop	Variety	Grain M.C % w.b.	Regression parameters		
			a	b	R^2
Rice	Giza 177	12.581 - 24.900	34.358	0.5011	0.90
	Giza 178	12.567 - 26.220	29.468	0.276	0.96
	Sakha 101	13.185 - 24.950	32.535	0.447	0.94
	Sakha 102	12.174 - 25.090	35.320	0.480	0.97
	Giza 181	12.390 - 25.820	36.657	0.198	0.98
	Jasmin	12.800 - 25.110	41.075	0.306	0.96
Wheat	Giza 168	10.850 - 24.140	59.288	1.417	0.95
	Sakha 93	10.870 - 24.860	49.896	0.944	0.96
	Sids 1	11.170 - 24.850	67.292	1.629	0.99
	Gemiza 9	10.60 - 24.920	59.201	0.804	0.99
Corn	T.H 310	9.950 - 27.74	238.47	5.801	0.97
	T.H 321	11.500 - 25.906	210.180	4.617	0.99
	S.H 10	10.870 - 24.940	161.73	1.909	0.97
	Balady	10.400 - 25.930	181.93	3.741	0.96
Barely	Giza 123	11.805 - 24.680	95.528	2.036	0.95
	Giza 124	11.512 - 24.670	100.040	2.324	0.95
	Giza 125	11.952 - 23.870	107.360	2.125	0.98
	Giza 126	11.224 - 24.410	97.524	2.310	0.99

Table (2): Regression parameters of equations relating the change in moisture content with shear force at longitudinal and lateral directions.

Crop	Variety	Grain M.C % w.b.	Regression parameters at longitudinal direction			Regression parameters at lateral direction		
			a	b	R2	a	b	R2
Rice	Giza 177	12.58 - 24.9	76.466	1.989	0.97	50.431	1.231	0.98
	Giza 178	12.567 - 26.22	53.962	0.796	0.90	45.324	0.915	0.91
	Sakha 101	13.185 - 24.95	53.877	0.676	0.96	52.896	1.055	0.96
	Sakha 102	12.174 - 25.09	61.143	1.193	0.99	56.46	1.403	0.92
	Giza 181	12.39 - 25.82	81.683	1.197	0.90	49.717	0.336	0.97
	Jasmin	12.8 - 25.11	78.904	1.746	0.99	49.509	0.766	0.94
Wheat	Giza 168	10.85 - 24.14	4.048	0.110	0.94	7.851	0.213	0.97
	Sakha 93	10.87 - 24.86	3.283	0.076	0.93	6.482	0.157	0.96
	Sids 1	11.17 - 24.85	3.993	0.089	0.94	8.144	0.200	0.97
	Gemiza 9	10.6 - 24.92	3.742	0.072	0.97	6.780	0.140	0.98
Corn	T.H 310	9.95 - 27.74	244.59	5.313	0.99	328.02	6.900	0.97
	T.H 321	11.5 - 25.906	242.13	5.908	0.94	283.07	4.481	0.96
	S.H 10	10.87 - 24.94	231.68	5.258	0.98	326.71	7.573	0.96
	Balady	10.4 - 25.93	216.63	5.486	0.97	270.97	5.328	0.96
Barely	Giza 123	11.805 - 24.68	97.687	1.160	0.97	73.926	0.971	0.96
	Giza 124	11.51 - 24.67	108.730	2.586	0.99	95.612	2.148	0.96
	Giza 125	11.95 - 23.87	125.360	3.192	0.96	98.922	2.106	0.94
	Giza 126	11.22 - 24.41	104.220	2.576	0.95	79.520	1.681	0.98

Table (3): Regression parameters of equations relating the change in moisture content and shear stress at longitudinal and lateral equations.

Crop	Variety	Grain M.C % w.b.	Regression parameters at longitudinal direction			Regression parameters at lateral direction		
			a	b	R^2	a	b	R^2
Rice	Giza 177	12.58 - 24.9	76.466	1.989	0.97	50.431	1.231	0.98
	Giza 178	12.567 - 26.22	53.862	0.796	0.90	45.324	0.915	0.91
	Sakha 101	13.185 - 24.95	53.877	0.676	0.96	52.896	1.055	0.96
	Sakha 102	12.174 - 25.09	61.143	1.193	0.99	56.468	1.403	0.92
	Giza 181	12.39 - 25.82	81.683	1.197	0.90	49.717	0.336	0.97
	Jasmin	12.8 - 25.11	78.904	1.746	0.99	49.509	0.766	0.94
Wheat	Giza 168	10.85 - 24.14	62.509	1.601	0.94	61.486	1.494	0.96
	Sakha 93	10.87 - 24.86	52.72	1.068	0.92	52.042	1.058	0.98
	Sids 1	11.17 - 24.85	56.083	1.124	0.94	60.745	1.324	0.97
	Gemiza 9	10.6 - 24.92	58.096	0.803	0.94	51.491	0.656	0.98
Corn	T.H 310	9.95 - 27.74	4.423	0.107	0.98	8.797	0.215	0.96
	T.H 321	11.5 - 25.906	4.440	0.116	0.95	8.463	0.185	0.97
	S.H 10	10.87 - 24.94	4.135	0.096	0.96	8.863	0.230	0.97
	Balady	10.4 - 25.93	4.192	0.113	0.98	5.581	0.130	0.97
Barely	Giza 123	11.805 - 24.68	5.410	0.059	0.98	9.440	0.170	0.97
	Giza 124	11.51 - 24.67	4.383	0.109	0.99	11.699	0.288	0.97
	Giza 125	11.95 - 23.87	4.710	0.128	0.96	10.93	0.261	0.95
	Giza 126	11.22 - 24.41	4.549	0.122	0.96	10.348	0.256	0.99

CONCLUSSION

1- For all studied crops, hardness, shear force and shear stress were decreased with the increase of grain moisture content. This relationship could be represented as $y = a - bx$.

2- For different varieties of rice and barely, shear force at the longitudinal direction was higher than lateral direction while it was lower at longitudinal direction than lateral direction for corn and, it was very close in both directions for wheat.

3- Shear force and shear stress in lateral direction were higher than longitudinal direction for rice and barely. While, they were lower in lateral direction than longitudinal direction for corn and wheat.

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الملخص العربى

تأثير المحتوى الرطوبى على الخصائص الميكانيكية لبعض أصناف محاصيل الحبوب

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تم دراسة تأثير خمسة محتويات رطوبية مختلفة على كل من صلابة الحبوب، قوة القص وإجهاد القص فى الاتجاه الطولى والعمودى لبعض أصناف محاصيل الحبوب (الأرز، الذرة الشامى، القمح، والشعير).

أظهرت النتائج أن العلاقة بين التغير في المحتوى الرطوبي وكلاً من صلابة الحبوب وقوة القص وإجهاد القص فى الاتجاهين الطولى والعرضى لكافة أصناف الحبوب موضع الدراسة علاقة خطية عكسية. حيث تراوحت قيم الصلابة عند المستويات المختلفة للمحتويات الرطوبية بين [(٢١,٧٦ – ٣٧,٥٠)، (٨٨,٠٧ – ١٧٣,٢٠)، (٢٤,٠١٢ – ٥٠,٤٤)، (٤٠,٣٤٩ – ٨١,٥٣٨) نيوتن] لأصناف محاصيل الأرز، الذرة، القمح، والشعير على الترتيب.

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وتبين من النتائج أيضا أن قوة القص فى اتجاه المحور الطولى أعلى منها على المحور العرضى لأصناف الأرز والشعير، بينما كانت أقل فى المحور الطولى عنها فى المحور العرضى لأصناف الذرة بينما كانت متقاربة جداً لأصناف محصول القمح وربما يرجع ذلك إلى الاختلاف فى طبيعة المكونات فى مساحة القص لكلا المحورين،

ومن ثم فإن قيم إجهاد القص فى المحور العرضى كانت أعلى منها على المحور الطولى لجميع أصناف المحاصيل موضع الدراسة.

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