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EFFECT OF DRYING TEMPERATURES ON STRESS CRACKS AND BREAKAGE SUSEPTIBILITY OF CORN GRAINS

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ABSTRACT

Stress cracking of two corn hybrids (White, SC-10 and Yellow, SC-162) dried at various temperatures (35, 50, 60, 75 and 100^{o}C) from 21.2% to 13% moisture content and tempered for 24hr at ambient temperature (22 ± 1 ^{o}C with available relative humidity) were tested. A breakage tester (BT-drop tester) was manufactured and a single-grain breakage susceptibility of two corn hybrids at various grain temperatures and times after drying (0, 3 ,6 , 10, 20 and 30min) were evaluated. The results indicated that, the damage index significantly increased as the drying temperature increased for two corn hybrids except at 100^{o}C with SC-162, it was decreased. The SC-162 was more susceptible to cracking more than SC-10 hybrid especially at lower grain temperature. Also, the predicted models and observation showed that both hybrids were plastic and had minimal breakage susceptibility at high grain temperatures from 72 to 93^{o}C, while, decreasing grain temperature increased breakage exponentially. After drying at both 75 and 100^{o}C, the breakage of the two corn hybrids increased rapidly for the first 10min after drying and reached an asymptotic level after around 10min cooling after finishing drying at ambient temperature. At the same drying temperature (75^{o}C), the breakage susceptibility increased by 37.4% for SC-10 and by 51.5% for SC-162 with the average stress cracks (multiple and checked) kernels for two hybrids of about 20.2%.

INTRODUCTION

Recently, the government tends is expand the growing area of corn (***Zea Mays L***.) to limit the shortage of wheat production and to approach self-sufficiency for bread by mixing corn with

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wheat at a rate of 20%. However, increasing productivity of corn per unit area needs more advanced techniques to achieve better harvesting and processing***, Matouk et al. (1999).*** Stress cracking of corn is caused by excessive compressive or tensile stresses occurring during or after drying, cooling, or rehydration processes. Moisture and temperature gradients in a kernel cause expansion and contraction at different locations in the nonhomogeneous viscoelastic material of the kernel, ***Brooker et al. (1992)*** and ***Peplinski et al. (1994)*** Also, ***Kirleis and Storshine (1990)*** showed that stress cracking in maize, which are not visible externally, increased consistently with drying temperature up to 60^{o}C, it then decreased with drying temperature increases up to 93^{o}C. As a result, ***Davidson et al. (2000)*** reported that kernel stress cracks increase the susceptibility of maize kernels to breakage during mechanical handling, and the fines created increase material losses in all milling operations and promote mold growth during storage. ***Vyn and Moes (1988)*** reported that kernel breakage could be reduced by proper choice of hybrids, drying at low air temperature, and harvesting at low grain moisture content. The breakage susceptibility of maize grain is moisture dependent as reported by ***Paulsen (1983).*** Thus, it has been recommended that the moisture content of the sample around 12-13% should be consistent and reported together with the percentage breakage when grain is tested. It has increasingly important to find an optimum temperature of air for corn grain drying in order to minimize the development of stress cracks due to temperature gradients.

Several grain physical factors related to breakage susceptibility including grain moisture content and grain temperature have been studied, however, the effects of high grain temperatures on stress cracking and breakage susceptibility have not yet been studied. Also, data for the chronological change of physical characteristics of corn grain after high-temperature drying are not available. More data are crucial for understanding the viscoelastic characteristics of the grain in relation to high-temperature drying and may also provide important information for measurement of grain hardness and breakage susceptibility of local corn hybrids. This study was initiated to determine stress cracking and breakage susceptibility of two local corn hybrids at various grain temperature and times after drying.

MATERIALS AND METHODS

Corn hybrids and physical properties;

The samples of the corn used in these studies are: white dent corn ***Single Hybrid 10 (SH-10)*** and yellow dent corn ***single Hybrid 162 (Sc-162)***.obtained from the Sakha Research Farm, Corn Section, Kafr El-Sheikh Governorate after the 2008 summer harvesting season. These hybrids are the most spread cultivars in Egypt, where they are characterized with high yield and kernels quality. Ten kilograms of fresh ear corn from each hybrid at about 20,7 – 21.2% moisture content (wet basis) harvested by hand and sealed in closed plastic bag and transported to Rice Mechanization Center. The corn ears were shelled manually and the grains then divided into six categories based on their ability to pass through sieves of different sizes, i.e. small round, medium round, large round, small flat, medium flat and large flat as reported by ***Kim et al. (2002).*** All the classified grains were then collected in each labeled-plastic bags and stored at 5^{o}C in refrigerator before being tested. The average values of some physical properties of two hybrids of corn kernels were indicated in table 1. Average moisture content at harvest was determined by oven drying for 72h at 103 ^{o}C ***(AACC, 1883***).

Table 1: Some physical properties of two corn hybrids.

Corn hybrids	Moisture content, %	Length, mm	Width, mm	Thickness, mm	Bulk density, kg/m^3	Hundred-grain mass, gm
SC-10	20.7	13.8	9.7	4.4	820	45.5
Sc-162	21.2	11.5	8.5	4.2	756	32.5

Note: Hundred-grain mass and bulk density were adjusted to a grain moisture content of 14% (W.B.).

Drying test:

To determine grain quality at various grain temperature, five drying temperatures (35, 50, 60, 75 and 100^{o}c) were selected for two corn hybrids. Each sample were dried in a single layer in a standard precision oven ***model(RKJ).*** The oven drying temperature was controlled by a temperature-control dial. A reference moisture measurement grain sample of 20 grains in a single layer in a separate drying tray was placed at each test. At 30 min intervals, the reference sample grains were weighed (±0.001g) and their moisture content was calculated. Drying continued until the moisture of the reference grains dried from 20.7 – 21.2% approximately 13%.

Stress cracking test:

Stress cracking analysis was done on freshly and dried samples. Three randomly selected sub-samples of 100 medium flat-grains of two corn hybrids of each test were dried at various temperatures indicated above and inspected for stress cracks. Medium flat grain retained by the 8.73mm, while passed through 9.53mm round-hole sieve and passed through 5.95mm salt-hole sieve, slots were 19.05mm. After drying process, the samples was kept in sealed plastic bags for 24hr at room temperature around 22±1^{o}C and available relative humidity. The kernels were visually inspected for stress cracks using a light board. Kernels were placed germ-side down on alight table and inspected from the top only. Each kernel was classified into one of four stress crack classes: undamaged, single, multiple and checked. The results for each sub-sample were normalized by dividing the number of kernels in each stress category by the total number of acceptable kernels in the sub-sample. In addition to the percentage of kernels in each stress crack category, a damage index (*DI)* was calculated by summing the multiple and checked classes as reported by ***Davidson et al. (2000).***

Breakage susceptibility measurement

A simple method was developed to asses breakage susceptibility ***(Kim et al., 2002)***. A breakage tester **(*BT-drop tester*)** was manufactured as indicated in figure 1. An alumimium drop bar (aluminium tube closed from the bottom had 685mm length; 15mm outer diameter; 11mm internal diameter and a mass of about 150g) was inserted into a plastic tube ,*PVC* (550mm length; 19mm internal diameter and 24mm external diameter). The *PVC* tube had 2mm diameter holes drilled at 5cm intervals from 5 to 50cm. The drop-height of the aluminium bar was manually controlled by a pin inserted in the hole in the middle of a *PVC* tube. The *PVC* tube was clamped to a wooden laboratory stand. The tested grain was placed in the middle of a metal base germ side down and the metal base was then fixed in the wood base exactly under the *PVC* tube. The aluminium bar dropped, hitting the grain when the pin was manually removed at the given drop height. The impact energy (which cause any con cracks appeared or if a piece broke off) depends on the drop height of the standard 150g aluminium bar. In this experiment, the drop height used for the drop tester was selected after preliminary experimentation as tabulated in table 2. The fixed drop height of the aluminium bar was 25cm, the impact energy E_i was 0.368J based on the following relationship:

$$E_i = mgh \quad \ldots\ldots(1)$$

Where: m is the mass of impactor (0.15kg), g is the acceleration due to gravity (9.8m/s^2) and h is the drop height (0.25m).

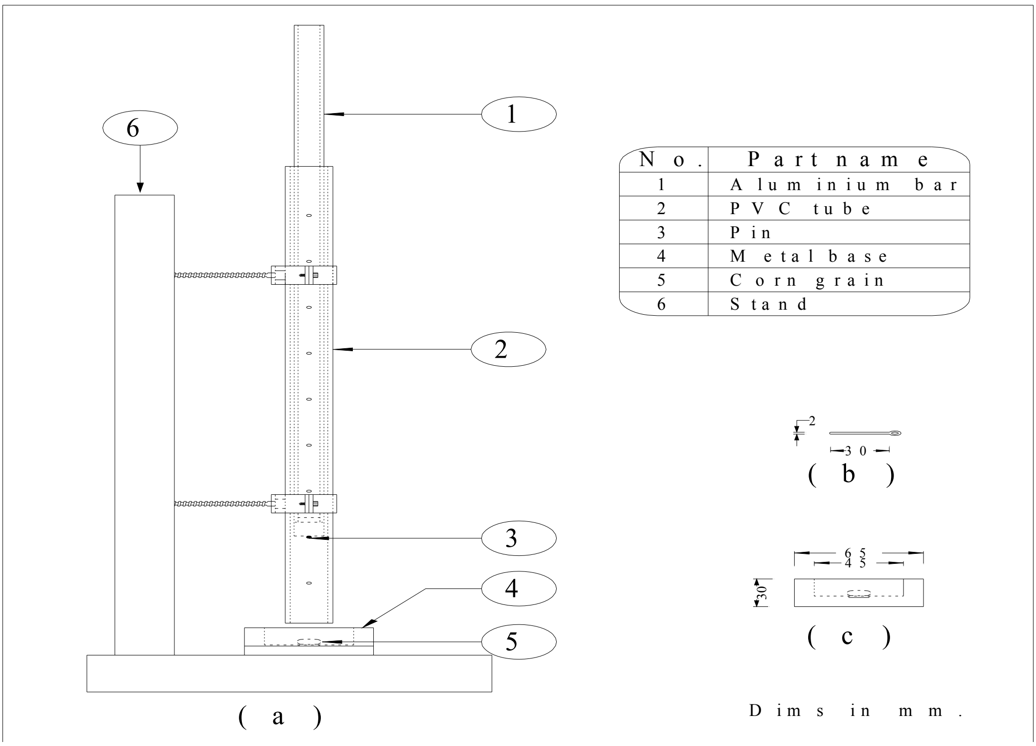


Figure 1: (a) Diagram of breakage tester (BT- drop tester), (b) Pin and (c) Metal base.

Table 2: The impact energy at different drop height of aluminium bar of the *BT-drop tester*.

	Drop height, m									
	0.05	0.10	0.15	0.20	0.25	0.30	0.35	0.40	0.45	0.50
Impact energy, J	0.074	0.147	0.203	0.294	0.368	0.441	0.515	0.588	0.662	0.735

Breakage test at various grain temperatures:

The percentage of breakage (B) is expressed as follows (***Kim et al., 2002***):

$$B = [(T_w - R_w)/T_w] \times 100 \quad \text{……………………………..(2)}$$

Where: T_w is the total grain weight after impact and R_w is the retained grain weight over 4.76mm round-hole sieve after sieving.

To ensure that the breakage test results were attributable to variety and grain temperature effects only and not biased by grain size and shape differences, only medium size flat grains were selected for testing. The samples of each test of two corn hybrids were dried at various temperatures indicated above. At each test, five grains were positioned germ side down on an individual metal base plate and placed in an oven. When the reference grains reached the target moisture content of about 13%, each individual grains was removed from the oven and tested immediately. For completing a replicate, this procedure was replicated four times at each drying temperatures. The impacted 20 grains of each replicate were kept in a plastic bag and weighed before sieving using 4.76mm round-hole sieve. The grains that retained over 4.76mm round-hole sieve were reweighed and the breakage was calculated by using Equ. 2. Grain temperature was measured in extra grains by using a digital temperature probe meter model (***R-81***) at each test as indicated in table (3).

Table 3: Grain temperatures of two corn hybrids dried at various drying temperatures

Drying temperature, °C	**Grain temperatures, °C**		
	SC-10	SC-162	Average
100	91.4	93.2	92.3
75	71.7	72.7	72.2
60	57.2	58.3	57.8
50	46.5	47.2	46.8
35	32.4	33.1	32.7

Breakage after drying:

To determine the grain breakage times after drying, the samples were tested at 0, 3. 6, 10, 20 and 30min after drying at 75 and 100^{o}C. Five medium-flat grains were tested at each time and the whole procedure was repeated three times for each replicate. Another 20 grains were selected for reference, arranged in a single layer in a separate drying tray and placed in each test to calculate moisture content. At each time, a prepared sample of 30 grains per test were arranged on a small tray in the oven at 75 and 100^{o}C drying temperatures until reference gain moisture reached the target moisture content of about 13%. After that, all the 30 grains were removed from the oven and placed at room temperature (22 ±1^{o}C) at available relative humidity and a selected grains was tested at different times indicated above. The impacted 15 grains of each replicate were collected in a plastic bag and weighed before sieving using 4.76mm round-hole sieve. The grains that retained over 4.76mm round-hole sieve were reweighed and the breakage was calculated as described above. The temperature of the corn grain was monitored using an extra grain after drying and during cooling.

The Statistical Analysis:

The analysis of variance, exponential and asymptotic regression models were employed in this experimental work to examine the effect of grain temperatures and times after drying on stress cracks and breakage susceptibility of two local corn hybrids.

RESULTS AND DISCUSSION

Effect of drying temperatures on stress cracking of corn grains:

Table 4 indicates the stress crack analysis for dried two corn hybrids with five drying temperatures after 24hr tempering at ambient temperature as comparison to undried corn grains. The results revealed that both drying temperatures and corn hybrids significantly effect on the final quality of dried kernels. Since, the corn for this experiment work was harvested and shelled by hand, there was minimal damage in terms of stress cracks before drying. The drying temperature with the lowest damage index was 35^{o}C. As drying temperature increased, the percentage of kernels in the multiple and checked categories significantly increased as the percentage in the single cracking and undamaged categories declined. The damage index (*DI*) was the best indicator of the severity of drying conditions as indicated in figure 2. Generally, the *DI* significantly increased as the drying temperature increased for two corn hybrids except for at 100^{o}C with *SC-162*, it was decreased. The *SC-162* was more susceptible to cracking more that *SC-10* at lower temperature. As drying temperature increased above 75^{o}C, the damage index increased with SC-10as reported by ***Watkins and Maier (2001).*** They showed that stress crack formation continuing to increase with an increase in temperature for white corn dried from 20% moisture. While, with *SC-162*, the damage index decreased with high drying temperature. The reduction in damage index for *SC-162* at temperature above 75^{o}C is consistent with observations reported by ***Kirleis and Storshine (1990)*** for three commercial yellow dent corn hybrids. They speculated that the reduction of stress crack formation at elevated temperatures was due to the relaxation of internal stresses facilitated by a more pliable endosperm. Another possible explanation could be starch gelatinization within the kernels drying, which may make the endosperm more resistant to stress failure. This indicates that the optimum drying conditions of SC-162 differ from those of SC-10, and yellow corn hybrids does not need to be dried at the low temperatures recommended for hard endosperm white corn hybrids.

Table 4: stress crack analysis for drying temperatures with two corn hybrids
B as compared to undried corn

Corn hybrids	**Drying temperature, ^{o}C**	**Stress crack measurements**				**Damage index (DI), %**
		Undamaged, %	**Single, %**	**Multiple, %**	**Checked, %**	
SC-10	Undried corn	98.3	1.3	0	0.4	0.4
	35	30.1 a	38.7 a	26.4 e	4.8 d	31.2 e
	50	22.4 b	36.1 b	34.1 d	7.4 c	41.5 d
	60	18.2 c	31.7 cd	39.5 c	10.6 b	50.1 c
	75	14.5 d	32.7 c	41.6 ab	11.2 b	52.8 b
	100	13.3 d	30.4 d	42.4 a	13.9 a	55.3 a
	LSD at 1%	0.957	1.19	1.11	0.764	1.055

	Undried corn	95.2	3.1	1.1	0.6	1.7
	35	22.5 a	38.3 a	31.8 f	7.4 e	39.2 e
	50	18.3 b	35.9 b	35.1 e	10.7 d	45.8 d
SC-162	60	14.1 c	33.4 c	40.2 cd	15.3 b	55.5 c
	75	8.2 d	28.2 e	45.3 a	18.3 a	63.6 a
	100	9.3 d	32.3 c	42.3 b	16.1 b	58.4 b
	LSD at 1%	1.35	1.68	1.58	1.08	1.49

Note: In the same column, mean values with different letters are different at 95% significance level based on Duncan's multiple range test. LSD is the least significant difference.

Effect of corn grain temperatures on breakage susceptibility:

The breakage of corn was very sensitive to the grain temperature at the time of testing as indicated in figure 3. Both hybrids were plastic and had minimal breakage at high temperatures from 72 to 93°C. However, decreasing grain temperature increased breakage exponentially. The corn was more susceptible to breakage after drying at temperatures above ambient. The *SC-162* had a significantly higher percentage of breakage than *SC-10* when the grain temperature was lower than 50°C. Data for the percentage breakage as a function of grain temperature resulted in an exponential model were subsequently analyzed as follows:

$$B = B_{max}\, e^{-bT} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

Where: B is the breakage in %, B_{max} is the maximum grain breakage in %, b is a coefficient and T is the grain temperature in °C at time of testing.

This exponential model for grain breakage according to grain temperature at time of testing successfully predicted the real value of grain breakage. Comparison of the parameters in table 5 indicated that the two hybrids had similar rate increases in grain breakage as grain temperature decreased from 93 to 32°C, even though the two hybrids had different percentage grain breakage as grain temperature was lower than 50°C. Thus, grain temperature should be considered as a correction factor for an accurate measurement of grain breakage along with grain moisture content as reported by ***Paulsen (1983).***

Table 5: The parameters for breakage susceptibility of two corn hybrids as a function of grain temperature at time of testing.

Corn hybrids	Parameters for exponential model for grain breakage	
	B_{max}	*b*
SC-10	48.72	0.0351
SC-162	86.44	0.0373
Significance	*	NS

* and NS significant and non-significant at 5% level.

Breakage susceptibility of corn grains at various time after drying:

The chorological development of percentage grain breakage after drying at 75 and 100^{o}C at various times after finishing drying was fitted by an asymptotic regression function as follows (***Snedecor and Cochran, 1978):***

$$B = A_{max}\ [1 - e^{-k(t+c)}] \qquad (4)$$

Where: A_{max} is the maximum grain breakage in %, k is a coefficient, t the time after drying at ambient temperature in minute and c is the calculated ordinate intercept of the curve.

The parameters of this model was analyzed by *ANOVA* and compared to evaluate the rate and extent of grain breakage for the two corn hybrids as reported in table 6. This model successfully predicted the real value of percentage grain breakage at time after drying. As drying temperature increased from 75 to 100^{o}C, the predicted value A_{max} of percentage breakage of *SC-10* significantly increased and had more heat sensitive endosperm characteristics than *SC-162*. Figure 4 showed that the breakage of the two corn hybrids increased rapidly for the first 10min after drying at both 75 and 100^{o}C and reached an asymptotic level after around 10m cooling at ambient temperature in a single layer. This result was confirmed with the results obtained by ***Kim et al. (2003).*** They reported that the stress cracking started to develop in grains during cooling some times after drying instead of during dying due to viscoelastic characteristics of grain. The results also showed that, corn grain are soft when their temperature exceeds 75^{o}C shortly after finishing drying, but they become rigid within 10min during cooling at ambient temperature. It can be seen that, the models developed in this study in relation with the percentage grain breakage and grain temperature at time of testing might contribute to better understanding of breakage in single grains and could be a useful engineering tools for the design and optimization of corn grain drying and tempering processes.

Table 6: The regression parameters analysis for breakage of two corn hybrids at various times after drying at 75 and 100^{o}C

Drying temperature, ^{o}C	**Hybrids**	**Regression parameters for grain breakage**		
		A_{max}	***k***	***c***
75	*SC-10*	29.5	0.2514	0.6906
	SC-162	32.9	0.2352	0.8435
	Significance	*	NS	*
	LSD (5%)	0.85	-	0.18
100	*SC-10*	38.2	0.2726	0.7645
	SC-162	30.5	0.2428	0.4345
	Significance	**	Ns	*
	LSD (5%)	5.5	-	0.14

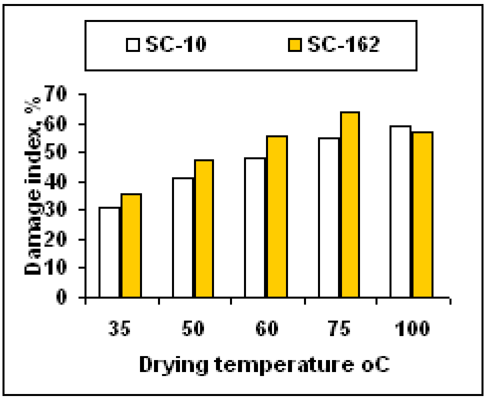
NS, * or **, Non-significant or significant F at 55 and 1% levels, respectively.

Relationship between stress cracked kernels and breakage susceptibility:

The chronological change of physical characteristics of corn grain after high-temperature drying were studied. Analysis of data showed that, there were significant differences in damage index at intermediate drying temperature but breakage variation was only significant at the extreme drying temperatures. The relationship between the breakage increases and the percentage of stress cracks of two corn hybrids after drying temperature at 75^{o}C and tempered 24hr at room temperature was shown in figure 5. The results indicated that, the average percentage breakage susceptibility increased by 37.4% for *SC-10* and by 51.5% for *SC-162* with the average stress cracks (multiple and checked) kernels for two hybrids of about 20.2%. It is obvious that severely cracked kernels can result a large breakage increase of the kernels in a lot of corn during commercial necessary extensive handling. It can be recommended that, limiting the stress cracking, and therefore the breakage susceptibility of corn kernels, is accomplished by reducing temperature gradient after drying and selecting corn hybrids that resistant to breakage.

CONCLUSIONS

1. Both drying temperatures and corn hybrids had the high significant effect on the final quality of dried kernels.
2. The damage index increased significantly as the drying air temperature increased for two corn hybrids. While, SC-162 was more susceptible to cracking more than SC-10 especially at lower grain temperature.
3. The exponential model for predicted grain breakage indicated that the two corn hybrids were plastic and had minimal breakage at high grain temperatures from 72 to 93^{o}C, while, decreasing grain temperature lower than 50^{o}C, increased breakage exponentially.
4. An asymptotic regression model for predicted grain breakage showed that the breakage increased rapidly for the first 10min after finishing drying of two corn hybrids at both 75 and 100^{o}C and reached an asymptotic level after around 10min cooling at ambient temperature in a single layer.
5. At the same grain temperature, the breakage susceptibility increased by 37.4% for *SC-10* and by 51.5% for *SC-162* with the average stress cracks kernel for two hybrids of about 20.2%.
6. A simple inexpensive single-grain breakage tester was manufactured, and is applicable to growers, dryer operators and researchers.



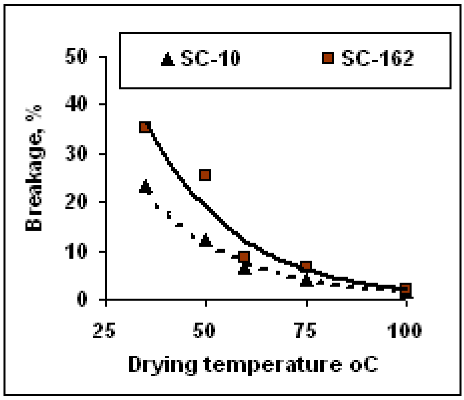


Figure 2: Damage index at various drying temperature of two corn hybrids.

Figure 3: Breakage susceptibility at various grain temperatures of two corn hybrids.

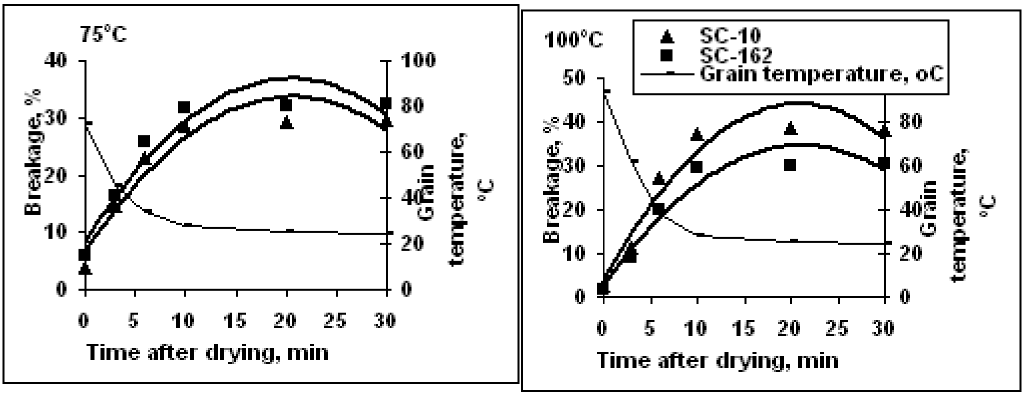


Figure 4: Grain breakage susceptibility dried for 75 and 100°Cat various times after drying of two corn hybrids.

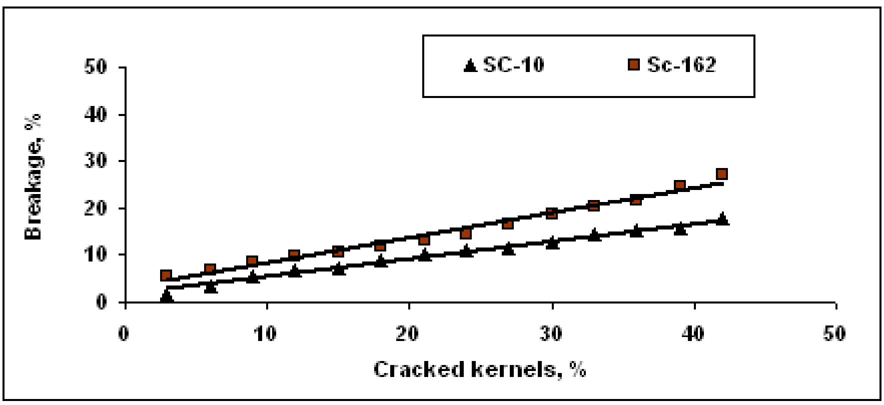


Figure 5: Relation ship between number of stress cracked (Multiple and checked) corn kernels and breakage susceptibility.

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الملخص العربي

تأثير درجات حرارة التجفيف علي جهد التشرخ وقابلية الكسر لحبوب الذرة

د/محمد إسماعيل شوغى[1] د / سامى عبد الجيد مرعي[1] أ.د./ عباس عبدا لحي الشناوي[2]

أجرى هذا البحث فى معمل مركز ميكنة الأرز بميت الديبة بهدف دراسة التغير فى الجودة لحبوب الذرة نتيجة التغير فى درجات حرارة التجفيف وكذلك درجة حرارة الحبوب بعد التجفيف مباشرة و بعد التجفيف بفترات زمنية محددة. وتم تصنيع جهاز لقياس طاقة التصادم اللازمة لكسر حبوب الذرة واختباره بنجاح مع هجيني الذرة: الأبيض (هجين فردي 10) ، و الأصفر (هجين فردى 162) وهذا الجهاز يمكن أن يستخدم لقياس طاقة التصادم اللازمة لكسر الحبوب للمحاصيل الأخرى. وتم الحصول على العينات من قسم بحوث الذرة بمحطة بحوث سخا بعد موسم حصاد صيفي 2008م. تم تجفيف حبوب الذرة من محتوي رطوبي متوسط مقداره 21.2 الى 13 % (على أساس رطب) فى فرن قياسي عند خمس درجات حرارة للتجفيف (35 ، 50 ، 60 ، 75 ، 100 ^{5}م). وتم دراسة تأثير درجات حرارة الحبوب لهجيتي الذرة على نسبة التشرخ بعد 24 ساعة تبريد فى هواء الغرفة بعد التجفيف والقابلية للكسر للحبوب بعد التجفيف مباشرة وكذلك بعد التجفيف أثناء التبريد فى هواء الغرفة بفترات زمنية (صفر ، 3 ، 6 ، 10 ، 20 ، 30 دقيقة) بغرض معرفة بعض الخواص والأسس العلمية التى يتم على أساسها تصميم وتشغيل نظم التجفيف والتداول لحبوب الذرة . وتم إجراء التحليل الإحصائي واستنباط النماذج الرياضية التي توصف التغير التراكمي فى سلوكيات الحبوب مثل العلاقة بين قابلية الكسر لحبوب الذرة (كعامل متغير) مع التغير فى الزمن عند درجات حرارة الحبوب المختلفة بعد التجفيف (كعامل مستقل) لهجيتي الذرة تحت الدراسة.

<u>ومن أهم النتائج ما يلى:</u>

1. أوضحت النتائج من التجارب أن كل من هجيني الذرة ودرجات الحرارة لها تأثير عالي المعنوية على جودة حبوب الذرة. فزادت نسبة التشرخ فى هجيني الذرة بزيادة درجة الحرارة التجفيف من 35 الى 100 ^{5}م وكانت نسبة التشرخ أعلي في الهجين فردي 162 عند درجات الحرارة المنخفضة للتجفيف عنه في الهجين فردي 10 ولكن عند درجة الحرارة المرتفعة (100 ^{5}م) انخفضت نسبة التشرخ مع هجين فردي 162.
2. أظهرت نتائج المعادلات المتنبأ بها وملاحظات التجارب أن نسبة القابلية للكسر لهجيتي الذرة تحت الدراسة انخفضت بزيادة درجة حرارة الحبوب بنفس الدرجة عند درجات حرارة التجفيف المرتفعة (75 – 100 ^{5}م) بسبب زيادة مرونة الحبوب وتحملها لقوى التصادم ولكن عند درجات الحرارة المنخفضة (أقل من 50 ^{5}م) زادت نسبة القابلية للكسر وكانت للهجين فردى 162 أعلي من الهجين فردى 10.

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[1] باحث بمعهد بحوث الهندسة الزراعية - الدقي - الجيزة - مصر.

[2] رئيس بحوث ورئيس قسم بحوث الذرة- معهد بحوث المحاصيل الحقلية- الجيزة - مصر.

3. زادت القابلية للكسر لحبوب الذرة زيادة سريعة لكلا الهجينين تحت الدراسة بعد انتهاء عملية التجفيف أثناء التبريد فى هواء الغرفة ولكن قيمتها ثبتت بعد 10 دقائق تقريبا بعد انتهاء التجفيف.
4. تم استنباط نمازج رياضية توصف التغير فى القابلية للكسر نتيجة التغير فى درجات الحرارة بعد التجفيف مباشرة وكذلك أثناء التبريد فى هواء الغرفة بعد التجفيف يمكن أن تستخدم فى وصف التغير فى الصفات الطبيعية لهجيني الذرة تحت الدراسة أثناء تداولهما علي النطاق الاقتصادي.
5. عند نفس درجة حرارة التجفيف (75 ^{5}م) زادت قابلية الكسر فى حبوب الذرة بنسبة 37.4% مع هجين فردى 10 و بنسبة 51.5 % مع هجين فردى 162 مع متوسط نسبة تشرخ فى الحبوب لكلا الهجينين فى حدود 20.2% .

من هذه الدراسة يتضح أهمية دراسة خواص الحبوب عند التغير فى درجات الحرارة أثناء و بعد عملية التجفيف مثل التغير فى نسبة التشرخ وبالتالي قابلية الكسر فى الحبوب مع الزمن أثناء التبريد عند درجة حرارة الغرفة للهجن المختلفة بهدف تقليل الفواقد عند تصميم وتشغيل نظم التجفيف والنقل والتفريط والطحن لحبوب الذرة للحصول على جودة عالية للمنتج وبالتالي زيادة الدخل القومي من الإنتاج الزراعي.