Harvest Date and Conditioned Moisture Content Effects on Test Weight of Soft Red Winter Wheat

B. J. Lloyd, T. J. Siebenmorgen, R. K. Bacon, E. Vories

Abstract. *Test weight of four cultivars of soft red winter wheat was measured by FGIS methods at different conditioned moisture contents. Test weight generally increased as conditioned moisture content decreased until approximately 13% moisture content (wet basis, w.b.) after which test weight changed little. Test weight and moisture content were shown to have an inverse relationship as samples were gently dried. Artificially increasing the moisture content of wheat samples and then gently drying caused test weight to decrease an average of 4.4% for the cultivars tested. The effect of harvest date on test weight showed that test weight did not dramatically decrease during a three-week harvest span during the 1996 season, however progressive harvesting in 1997 showed a decrease in test weight of 3.4, 5.4, and 1.4% for Madison, Jaypee, and Jackson, respectively. These reductions were overall less than previous values reported for hard red wheat of 5% after delayed harvesting. Standard deviation of the individual kernel moisture contents decreased exponentially as harvest moisture content decreased. At or below 14% moisture content, individual kernel moisture content standard deviations ranged from 0.5 to 0.8%.*
Keywords. *Wheat, Test weight, Delayed harvest, Moisture content.*

Test weight is a fundamental measurement that currently determines the official market grade of wheat. If the test weight of wheat is lower than the usual standard (U.S. Grade No. 2), the grower typically will receive a reduced price. This is because approximately 40% of U.S. soft wheat is exported and foreign buyers often specify U.S. Grade No. 2. Discounts for low test weight wheat are responsible for millions of dollars of losses annually for growers in the Eastern soft wheat region (Frahm, 1994). Test weight is defined by the USDA FGIS (1997) as "*Test weight per bushel*, The weight per Winchester bushel (2,150.42 in.^{3}) as determined using an approved device according to procedures prescribed by FGIS instructions". It is generally understood that this important physical property is dependent on grain/cultivar type, moisture content (m.c.), harvest location, kernel density, and other factors such as kernel shape and surface characteristics that affect packing behavior.

The physical kernel characteristics affecting test weight or bulk density of wheat have been the focus of several studies. Yamazaki and Briggle (1969) studied test weight of soft winter wheat (*Triticum aestivum)*. They determined that kernel density of soft wheat was not a varietal characteristic but was related to air spaces within the kernel, which they attributed to environmental influences. Similarly, Schuler et al. (1994) showed only a weak association of kernel density and test weight in soft red winter (SRW) wheat cultivars. Kernel density, however, was correlated to endosperm protein content (Schuler et al., 1995).

The volume of grain required to fill a container is affected by a characteristic coined packing efficiency. Yamazaki and Briggle found that packing efficiency was associated with cultivar and was a function of grain shape and surface characteristics. The shape and surface characteristics of the kernels affected the random positioning of each kernel. Ghaderi et al. (1971) determined that packing efficiency had the greatest effect on test weight when comparing soft winter wheat cultivars. Packing efficiency was highly correlated with test weight (r = 0.961) while kernel density had a low correlation coefficient (r = 0.169). It was concluded that kernel surface characteristics were responsible for most test weight variations in soft winter wheat cultivars.

The influence of moisture content on test weight of wheat has been investigated by Nelson (1980). Nelson measured the test weight at harvest moisture contents 11.3% to 11.9% for several hard red wheat cultivars, then adjusted the moisture content one to two percentage points by adding distilled water or drying in a hot-air oven. Nelson derived a third-order polynomial equation relating test weight to moisture content where r = 0.991. Chung and Converse (1971) measured the test weights of hard red wheat with moisture contents ranging from 9 to 19%. Moisture content was increased from initial levels by exposing samples to moist air in environmental chambers to obtain an adsorption curve. For a desorption path, samples were dried in laboratory conditions to 9% m.c. The relationship between test weight and moisture content was

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reported as quadratic, with the overall slope similar to Nelson's results. Brusewitz (1975) also measured the bulk density change of hard red wheat by rewetting an initially low moisture content sample. He determined that the bulk density of wheat decreased 9% during adsorption from 15% to 30% m.c. Browne (1962) used similar procedures to determine the bulk density of rewetted wheat in the range of 10% to 30% m.c.

The effect of weathering and delayed harvest of wheat has been investigated by Czarnecki and Evans (1986) in Canada. They evaluated the effects of field exposure of hard red spring wheat prior to dry-ripe (defined by Czarnecki and Evans as a fully mature kernel at a moisture content ideal for harvest, typically 12 to 15%). Five cultivars were harvested on three successive dates following a common date for windrowing. They determined that test weight decreased significantly with each progressing harvest date. The reduction in test weight was initially due to a rapid decrease in kernel density after which further losses were primarily attributed to changes in packing efficiency. Swanson (1941) investigated the effects of wetting and drying cycles on several quality indices including test weight. He found that "test weight (deviation) was mostly due to swelling of the kernels and partly to the roughening of the bran coat." Pool et al. (1958) determined that delayed harvest of soft red winter wheat decreased test weight significantly. They concluded that the decrease in test weight brought about by weathering was caused by a decrease in kernel weight and an increase in kernel volume.

Changes in test weight with moisture content and harvest date have been reported for hard red wheat. SRW wheat, which is commonly associated with lower test weight when compared to other wheat classes, has not received as much research focusing on test weight reduction. Few studies have addressed test weight fluctuation with harvest and conditioned moisture content. Also, modern high-yielding SRW wheat cultivars have not been included in past studies. This project was conducted to evaluate the effect of moisture content on test weight and the effect of artificial and natural rewetting on test weight of SRW wheat cultivars grown in the U.S. mid-South.

Materials and Methods

Trials were conducted in the 1996 and 1997 growing seasons using four commonly grown SRW wheat cultivars. 'Hazen', 'Madison', and 'Jaypee' were harvested at the University of Arkansas Northeast Research and Extension Center at Keiser, Arkansas, during the 1996 season while only Madison was harvested at Keiser in 1997. Additionally, 'Jackson' and 'Jaypee' were harvested from the University of Arkansas Pine Tree Experiment Station near Colt, Arkansas, in 1997. All samples were harvested from production scale fields with plot combines. Weather data, including rainfall, were collected at the experiment stations at Keiser and Pine Tree. The soil at the Keiser location was a Sharkey silty clay (a very fine, montmorillonitic, non acid, thermic *Vertic Haplaquepts*) and at Pine Tree the soil was a Loring silt loam (a fine-silty, mixed thermic, *Typic Fragiudalfs*).

Table 1. Description of 1996 harvest lots

Harvest Date*	Cultivar	Harvest m.c. (% w.b.)	Test Weight† (kg/m^3)	Test Weight† (lb/bu)
6/6/96	Madison	19.0	686	53.3
	Jaypee	19.2	707	55.0
	Hazen	18.1	723	56.2
12/6/96	Hazen	17.0	718	55.8
13/6/96	Madison	17.4	693	53.8
	Jaypee	18.6	685	53.2
	Hazen	15.3	725	56.3
14/6/96	Madison	16.0	718	55.8
	Jaypee	17.5	703	54.6
	Hazen	14.2	719	55.8
17/6/96	Madison	14.1	733	56.9
	Jaypee	14.0	738	57.3
	Hazen	12.4	723	56.2
19/6/96	Madison	14.3	695	54.0
	Jaypee	14.9	723	56.2
	Hazen	14.1	711	55.3
25/6/96	Madison	17.0	669	52.0
	Jaypee	17.6	695	54.0
	Hazen	15.4	692	53.8
1/7/96	Madison	12.0	712	55.3
	Jaypee	14.4	729	56.7
	Hazen	11.7	721	56.0

* All 1996 samples were harvested at Keiser, Ark.
† Test weights reported were measured at the indicated harvest moisture content.

Table 2. Description of 1997 harvest lots

Harvest Date	Cultivar	Harvest Location	Harvest m.c. (% w.b.)	Test Weight * (kg/m^3)	Test Weight * (lb/bu)
12/6/97	Madison	Keiser	19.2	643	50.0
	Jackson	Pine tree	18.4	757	58.8
18/6/97	Madison	Keiser	18.8	641	49.8
	Jaypee	Pine tree	12.6	708	55.0
	Jackson	Pine tree	13.5	749	58.2
20/6/97	Madison	Keiser	12.8	708	55.0
	Jaypee	Pine tree	13.0	713	55.4
	Jackson	Pine tree	13.5	743	57.8
23/6/97	Madison	Keiser	11.0	725	56.4
	Jaypee	Pine tree	10.9	727	56.5
	Jackson	Pine tree	13.0	716	55.6
27/6/97	Madison	Keiser	12.3	734	57.0
1/7/97	Madison	Keiser	11.2	702	54.5
	Jaypee	Pine tree	11.9	700	54.4
	Jackson	Pine tree	11.6	736	57.2
10/7/97	Jaypee	Pine tree	11.8	682	53.0
	Jackson	Pine tree	12.0	712	55.3

* Test weights reported were measured at the indicated harvest moisture content.

1996 Tests

A summary of the 1996 harvest sampling is given in table 1. Samples were cleaned by hand of any debris or chaff, then all lots were placed in drying trays in a laboratory environment of approximately 21°C and 60% relative humidity (r.h.). A Boerner divider was used to reduce sample size to approximately 1 kg prior to all test weight measurements. MC and test weight measurements were taken approximately every two percentage points in moisture content drop until an equilibrium moisture content (e.m.c.) of approximately 12.5% was reached. (Unless otherwise specified, moisture content is expressed on a wet basis percentage.)

Lots harvested on 6/17/96 were partially dried two to three moisture content percentage points then submerged in water for approximately 2 h to raise the moisture content to approximately 20%. This was done to simulate the effect of rapid rewetting caused by rain during the course of natural field drying. The wheat was then placed back in the drying trays and exposed to drying air at 24°C and 45% r.h. After surface moisture had evaporated, sub-samples were tested for moisture content and test weight every two percentage

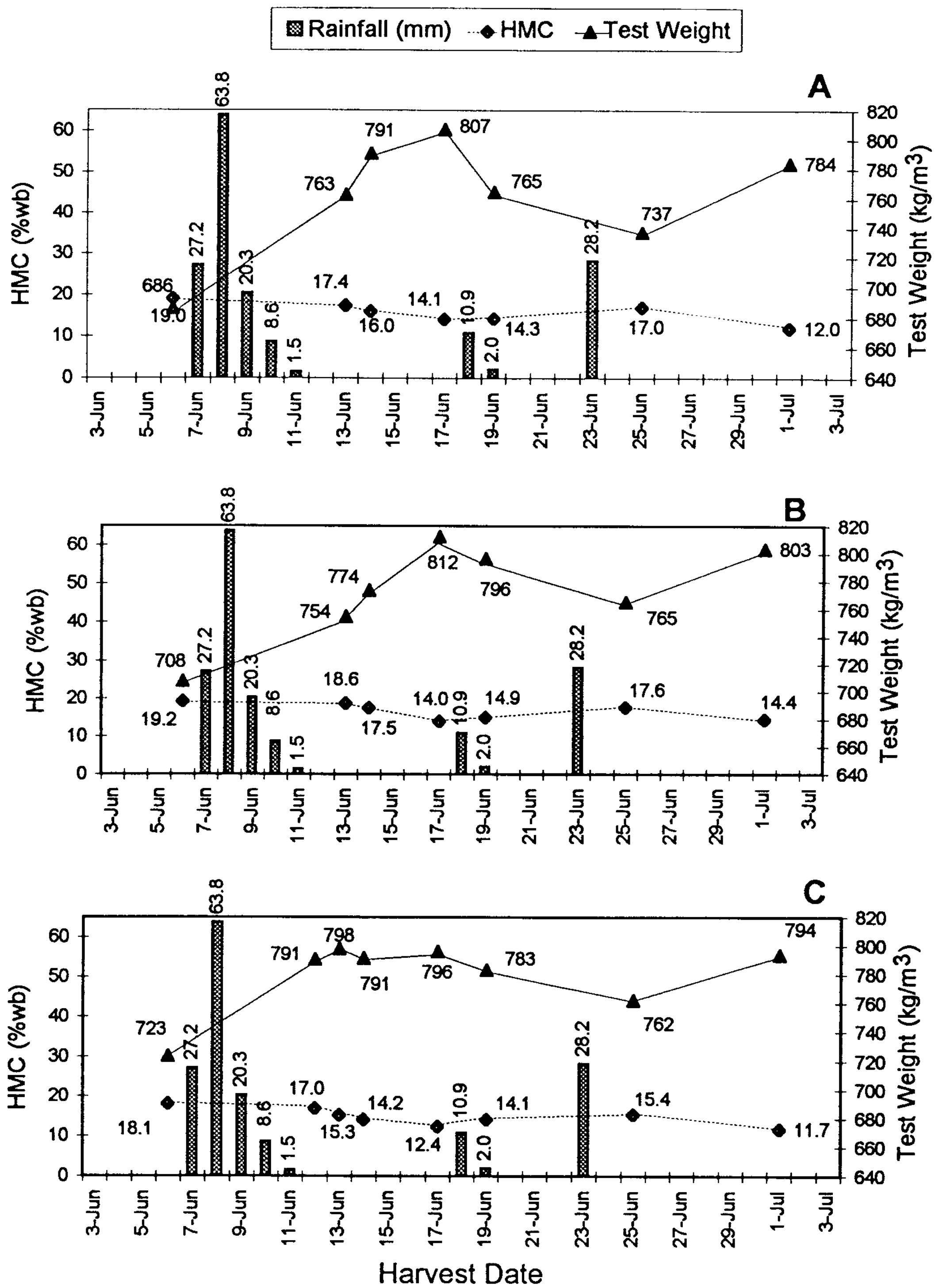

Figure 1–Rainfall effects on harvest moisture content (HMC) and test weight of (A) 'Madison', (B) 'Jaypee', and (C) 'Hazen' wheat harvested on the indicated dates at Keiser, Arkansas, in 1996.

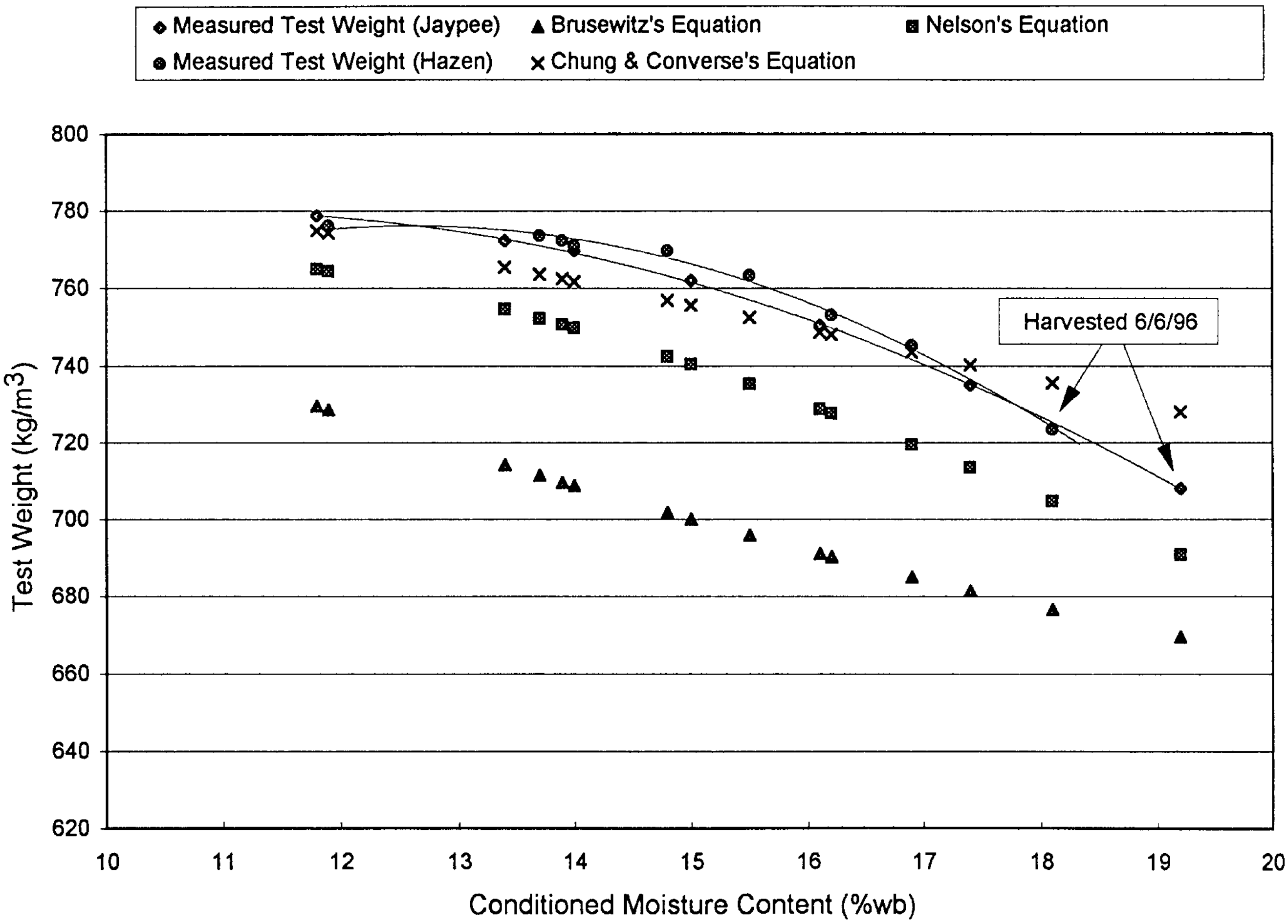

Figure 2–Test weight dependence on conditioned moisture content for 'Hazen' and 'Jaypee' harvested during 1996 field testing in Keiser, Ark., and the predicted test weights for these cultivars as a function of moisture content using the indicated equations.

points in moisture content decrease as the rewetted lots approached the equilibrium moisture content (e.m.c.).

1997 Tests

The 1997 harvest procedure included sampling before and after field rewetting at low field moisture contents. Samples were harvested during June and July beginning at approximately 19% m.c. and ranging to 11% m.c. at intervals of approximately three percentage points. A summary of the 1997 harvest sampling is given in table 2. Immediately after being harvested, the highest harvest moisture content sample from each cultivar was allowed to dry in a lab to an estimated moisture content of approximately 12.5%. Moisture content and test weight data were taken every two percentage points, reiterating the 1996 procedure. In order to study field rewetting effects on test weight, each field was harvested four to five times throughout the drying season to obtain a collection of samples that had been exposed to several rains and other natural weathering effects. Moisture content and test weight of these samples were measured, along with 1,000 kernel weight, at the harvest moisture content. One thousand randomly selected kernels were counted using an electronic seed counter then weighed on an electronic balance.

Moisture Content Determination

All moisture content measurements were determined by a Shizuoka Seiki Co. (Yamana, Japan), model CTR-800A individual kernel moisture meter. The meter output includes the moisture content of each individual kernel, the average moisture content of the sample, and the standard deviation of kernel moisture contents within the sample. One hundred randomly selected kernels were tested from each cultivar/harvest date/conditioned moisture content sample for both years.

Table 3. Regression analysis of moisture content dependent test weight (ρ_B) equations* used with soft red winter wheat

	Lab Conditioned SRW Wheat		Weathered SRW Wheat	
Nelson†	F > 99999	P < 0.0001	F = 36085	P < 0.0001
Brusewitz‡	F = 18240	P < 0.0001	F = 4185	P < 0.0001
Chung & Converse§	F = 14.72	P = 0.0004	F = 77.03	P < 0.0001

* All equations were formulated and intended for use with hard red winter wheat. Each equation requires specific units for moisture content and test weight.

† $\rho_b = 0.7744 - 0.00703\ mc + 0.001851\ mc^2 - 0.00014896\ mc^3 + 0.000003116\ mc^4$, $R^2 = 0.997$).

‡ $\rho_b = 0.8853 - 1.631\ mc + 2.64\ mc^2$, ($R^2 = 0.886$).

§ $\rho_b = (64.9 - mc)\ [100/(100 - mc)]$, ($R^2$ not given).

TEST WEIGHT MEASUREMENTS

Test weight measurements were made using a USDA FGIS approved bulk density apparatus and procedures prescribed by FGIS. A Seedburo (Chicago, Ill.) 151 filling hopper was used to overflow a Seedburo dry quart container as described by USDA FGIS methods (USDA, 1997). The full rounded quart was leveled by a consistent see-saw stroke across the container top using a straight edge. The mass of the wheat was measured to the nearest 0.1 g by a Seedburo balance, model 8800. The test weight, generally described by a bulk density measurement, was calculated by dividing the mass of the wheat in the cup by the standard dry quart volume. Reported test weights are the average test weights of three replicated sub-samples, where each sub-sample represented average of three individual test weight measurements. The average standard deviation of all test weight measurements was 5.39 kg/m^3 (0.42 lb/bu). The test weights were converted from g/dry qt to kg/m^3 by multiplying by a factor of 0.908083.

RESULTS AND DISCUSSION

1996 FIELD TESTING

Figure 1 shows the effect of harvest date and moisture content on test weight. Only one major rainfall occurred during the 1996 harvest period on 24 June, and it did not cause a dramatic test weight reduction. More data was obtained during the 1997 harvest period to elucidate rainfall and harvest moisture content (h.m.c.) effects on test weight.

Figure 1 shows an inverse relationship between harvest moisture content and test weight; as the harvest moisture content decreased from the initial high moisture content level of approximately 18% to 14%, test weight correspondingly increased for all three cultivars. The 28 mm rain on 23 June caused an increase in moisture content of approximately 3 percentage points (as measured at the time of harvest) which reflected a decrease in test weight of approximately 25.7 kg/m^3 (2 lb/bu). Subsequent drying produced increases in test weight in all three cultivars. These trends, along with related findings of the dependence of rice test weight on harvest and conditioned moisture content (Fan et al., 1998), prompted the 1996 laboratory tests and additional field tests in 1997.

1996 LABORATORY TESTING

The test weight dependence on conditioned moisture content of Hazen and Jaypee harvested in 1996 at high moisture content (18% to 19%) and then gently dried down to an estimated moisture content of approximately 12.5% is shown in figure 2. Test weight generally increased as conditioned moisture content decreased until approximately 13%, after which test weight changed little. The test weights associated with this desorption curve over this conditioned moisture content range are lower in value but consistent with observations for drying hard red wheat as reported by Chung and Converse (1971) and Nelson (1980). Figure 2 also depicts the inaccuracy of the Nelson, Brusewitz, and Chung and Converse equations, all of

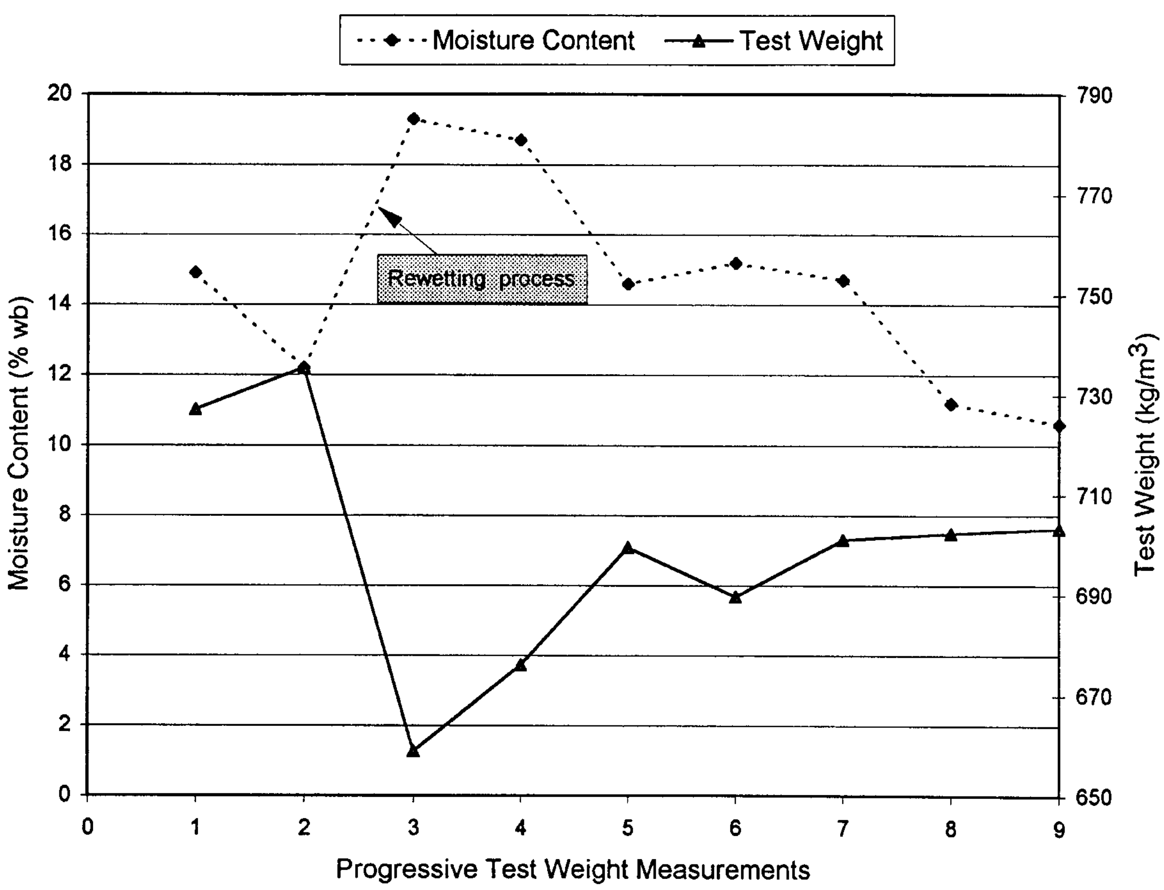

Figure 3–Test weight changes due to artificial rewetting/drying of ‘Madison’ wheat harvested at Keiser, Ark., on 17/6/96.

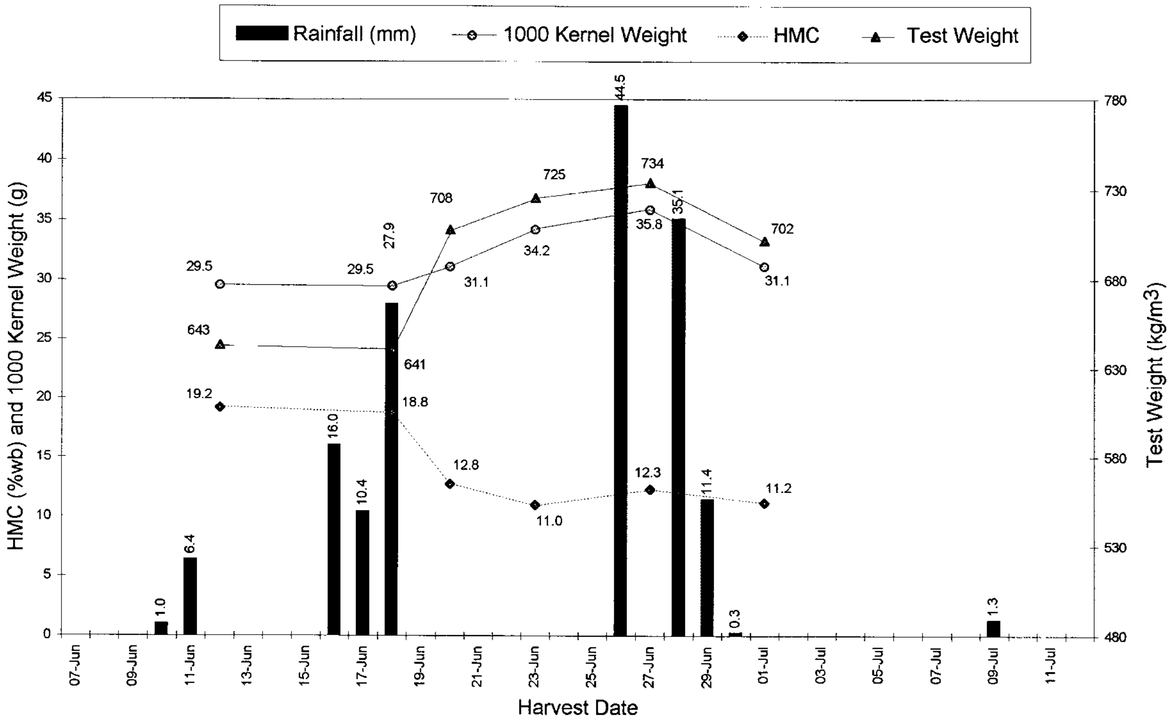

Figure 4–Rainfall effects on harvest moisture content, test weight, and 1,000 kernel weight for 'Madison' wheat harvested at the indicated dates in 1997 at Keiser, Ark.

which were empirically determined using hard red winter wheat, to predict test weight based on the moisture content of SRW wheat. Table 3 shows that each equation was significant ($P < 0.05$) for lack of fit in representing the conditioned moisture content samples although it appears that only the intercept causes the SRW wheat data to deviate from Nelson's and Brusewitz's equations in this moisture content range of approximately 12 to 20%.

The change in test weight of Madison wheat due to artificial rewetting is shown in figure 3, similar trends were

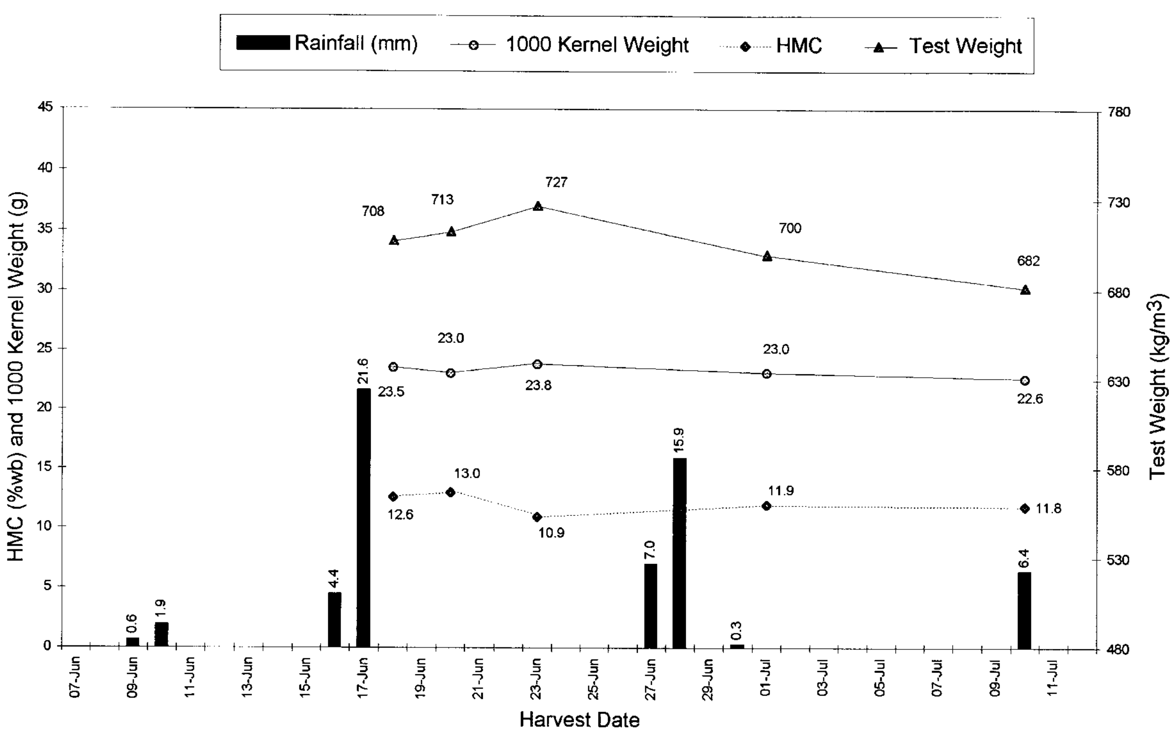

Figure 5–Rainfall effects on harvest moisture content, test weight, and 1,000 kernel weight for 'Jaypee' wheat harvested at the indicated dates in 1997 at the Pine Tree Experiment Station near Colt, Ark.

obtained for 'Hazen' and 'Jaypee'. Through the addition of water, the moisture content of the sample was increased to approximately 20%; this is indicated by the positively sloped section of the moisture content trend line. Moisture content and test weight were clearly shown to have an inverse relationship. This inverse relationship, however, was not as strongly correlated after rewetting occurred. Test weight at a given moisture content prior to rewetting and drying never returned back to the initial test weight value after rewetting at that moisture content. This was also observed by Pushman (1975) for European winter wheat cultivars artificially rewetted. The overall decrease of test weight due to the artificial rewetting treatments was 4.7% for 'Madison', 6% for 'Jaypee', and 2.6% for 'Hazen'.

1997 Field Testing

The effect of natural rewetting on test weight for the 1997 season during multiple progressive harvests is shown in figures 4 through 6. The harvest moisture content for each cultivar fell within the range of 11.5% to 13% m.c. after a dry-down period from approximately 18%. Beyond this initial decrease in moisture content, the remaining harvest moisture contents consistently fell within a narrow range with a maximum deviation of 1.5 percentage points. At this stage, it was postulated that the kernels had reached the 'dry ripe' maturity stage as described by Czarnecki and Evans (1986). These figures also show that test weight generally had an inverse relationship with moisture content, while 1,000 kernel weight closely followed the trend of test weight with moisture content change. The results indicate that the kernels underwent shape and volume change during moisture loss or gain as described by Nelson (1980), Pool et al. (1958), and Pushman (1975).

The average net reduction in test weight due to rainfall was approximately 3.4, 5.4, and 1.4% for 'Madison', 'Jaypee', and 'Jackson', respectively. The test weight reduction for Madison was calculated as the percentage test weight drop from 22 June to 1 July and was attributed to 91 mm of rainfall on 26 to 29 June at Keiser, Ark. (fig. 4). At the Pine Tree experiment station, 'Jaypee' had the highest test weight reduction while Jackson showed little reduction. Test weight reduction for both cultivars at Pine Tree was calculated as the percentage test weight drop from the 23 June to the 10 July harvest. Harvest moisture content on these date deviated only 1 percentage point, and in the moisture content range of 11.0 to 12.0% the corresponding change in test weight was estimated to be 6 kg/m^3 (0.44 lb/bu) as seen in figure 2 and noted by Chung and Converse (1971); therefore, a correction factor of the corresponding percentage test weight deviation due to moisture content was appropriately added to or subtracted from the later harvested samples to adjust for the moisture content effects in the calculations. Samples harvested on 1 and 10 July expressed bran roughening and surface wrinkling. This was attributed to swelling during rainfall with subsequent rapid drying. Due to surface roughing of kernels, packing efficiency would be expected to decrease (Swanson, 1941) causing test weight to progressively decrease depending on the severity of weathering. Based on visual observation, Jackson expressed the least amount of surface wrinkling. Jackson is a more plump, spherical kernel and was apparently better able to retain surface integrity and test weight. Jackson's test weight did not appear to reduce due to the 27 and 28 June rainfall. These test weight reduction values were overall slightly lower than those observed by Czarnecki and Evans (1986) for hard red wheat which were

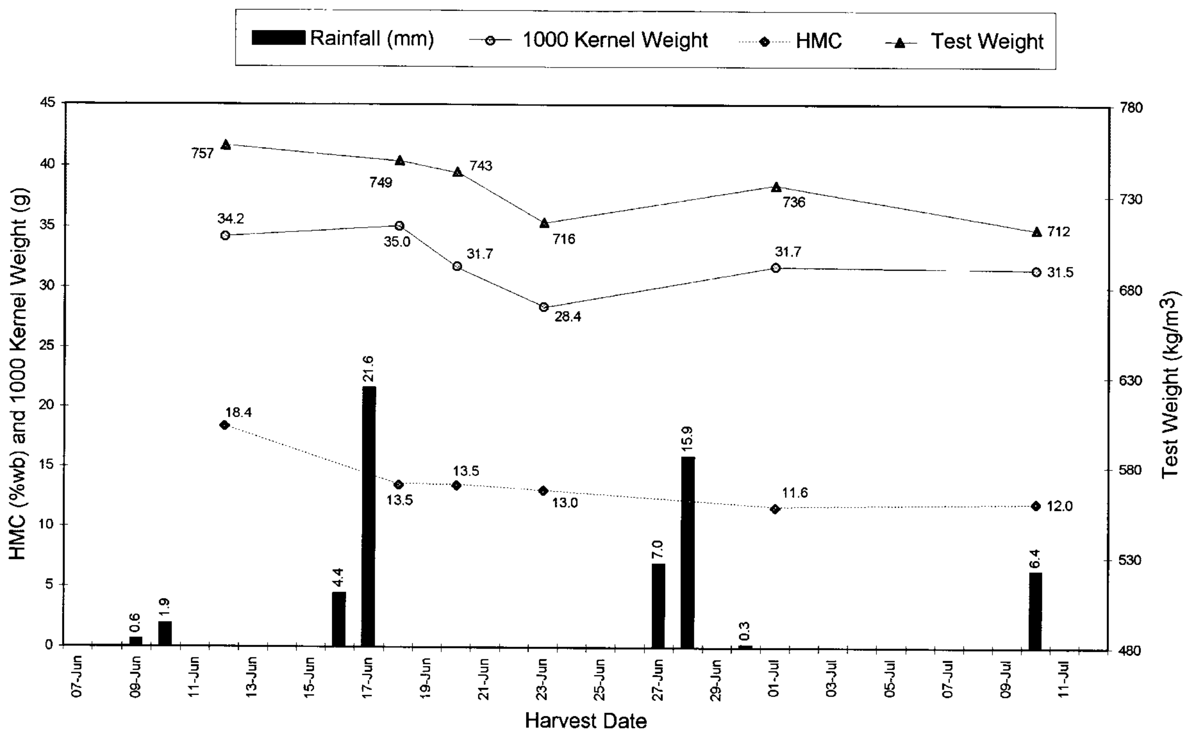

Figure 6–Rainfall effects on harvest moisture content, test weight, and 1,000 kernel weight for 'Jackson' wheat harvested at the indicated dates in 1997 at the Pine Tree Experiment Station near Colt, Ark.

approximately 5%. However, Czarnecki and Evans studied the weathering of windrowed grain, while for this study the grain was cut and immediately threshed, which is the more common practice in the U.S. mid-South.

The decrease in test weight due to natural weathering in the 1997 tests was not as high as the artificial rewetting treatment in the 1996 lab tests. This could be due to the fact that artificial rewetting created a more severe change in kernel moisture content than natural rewetting (rainfall) since the artificial weathering treatment soaked each kernel thoroughly. Rainfall certainly caused the kernel moisture content to increase, but apparently not at the high rate caused by the soaking treatment of artificial rewetting.

Figure 7 shows the inaccuracy of the Nelson, Brusewitz, or Chung and Converse equations to predict test weight as a function of moisture content for delayed harvest SRW wheat. Each test weight equation was significant for lack of fit ($P < 0.05$) for representing the combined 1996 and 1997 harvest moisture content test weight measurements for all cultivars as a function of harvest moisture content. When compared to the lab conditioned wheat test weights (fig. 2), the weathered SRW wheat test weights were not a function of moisture content alone which suggested that other factors, presumably physical weathering effects, caused test weight to deviate from established moisture content dependent prediction equations used for hard red wheat.

Individual Kernel Moisture Content Testing

As a means of examining each harvest sample as a population of individual kernel moisture contents, the individual kernel moisture content standard deviations (S.D.) for both the 1996 and 1997 data at each harvest moisture content are presented in figure 8. In both seasons, the individual kernel moisture content standard deviations decreased exponentially as the harvest moisture content decreased. Kernel moisture contents became more uniform within the entire population of kernels as harvest moisture content decreased below approximately 14%. The 1997 data for individual kernel moisture content deviation followed this general trend, although the standard deviations were higher at harvest moisture contents greater than 14%. At the high moisture content levels in 1997, Madison showed large standard deviations in kernel moisture content. This response was speculated to occur because of a progressively greater number of immature kernels, associated with high moisture content levels, in the high moisture content samples. These immature kernels caused the overall kernel moisture content variation to increase and was speculated to cause the 1,000 kernel weight to increase while the overall harvest moisture content was decreasing during the initial part of the harvest period (figs. 4-6). At the lower moisture content levels, the effect of this immature kernel population was minimally present due to these kernels having matured and lost moisture. In both seasons, the standard deviations at moisture contents at or below 14.0% were 0.5 to 0.8%. This response was similar to the standard deviation of individual kernel moisture contents in rice, which was observed to be 0.5% to 0.6% at low moisture contents of approximately 14% (Siebenmorgen et al., 1990).

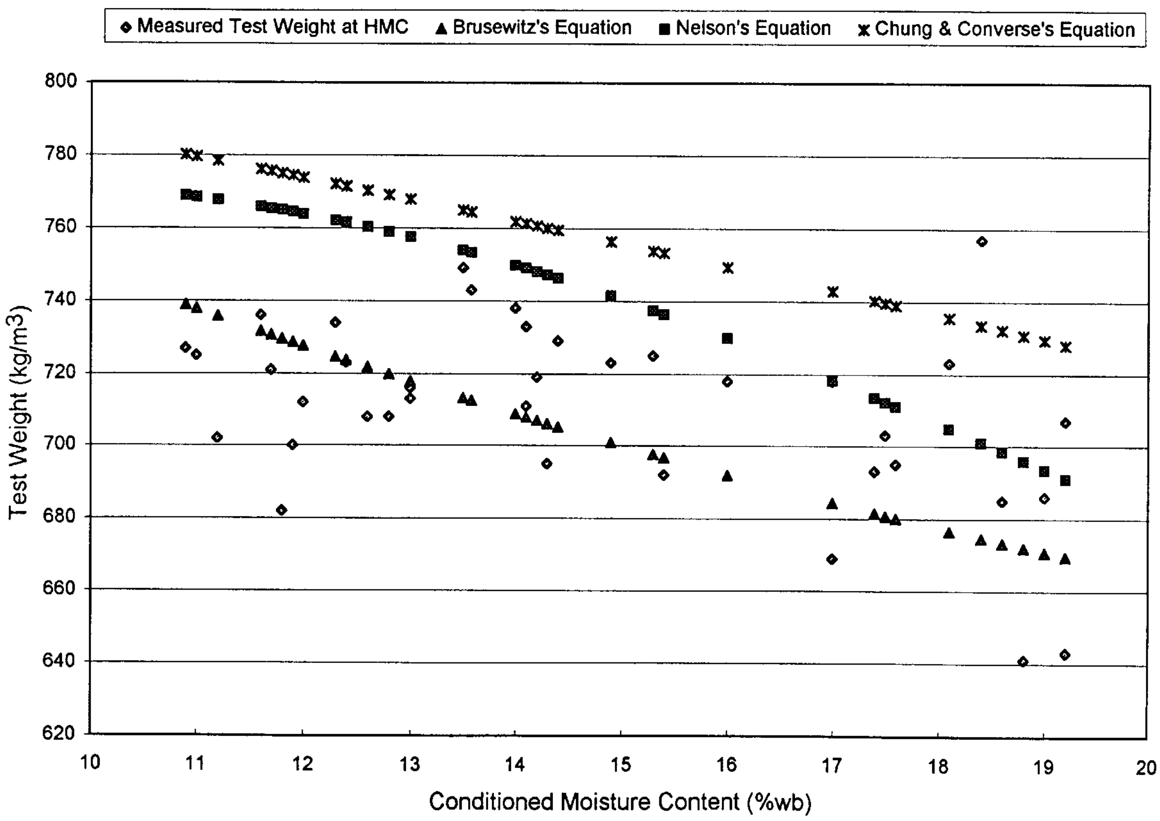

Figure 7–Test weights and moisture contents for the combined 1996 and 1997 harvest lots, and the corresponding predicted test weights as a function of moisture content using the indicted equations.

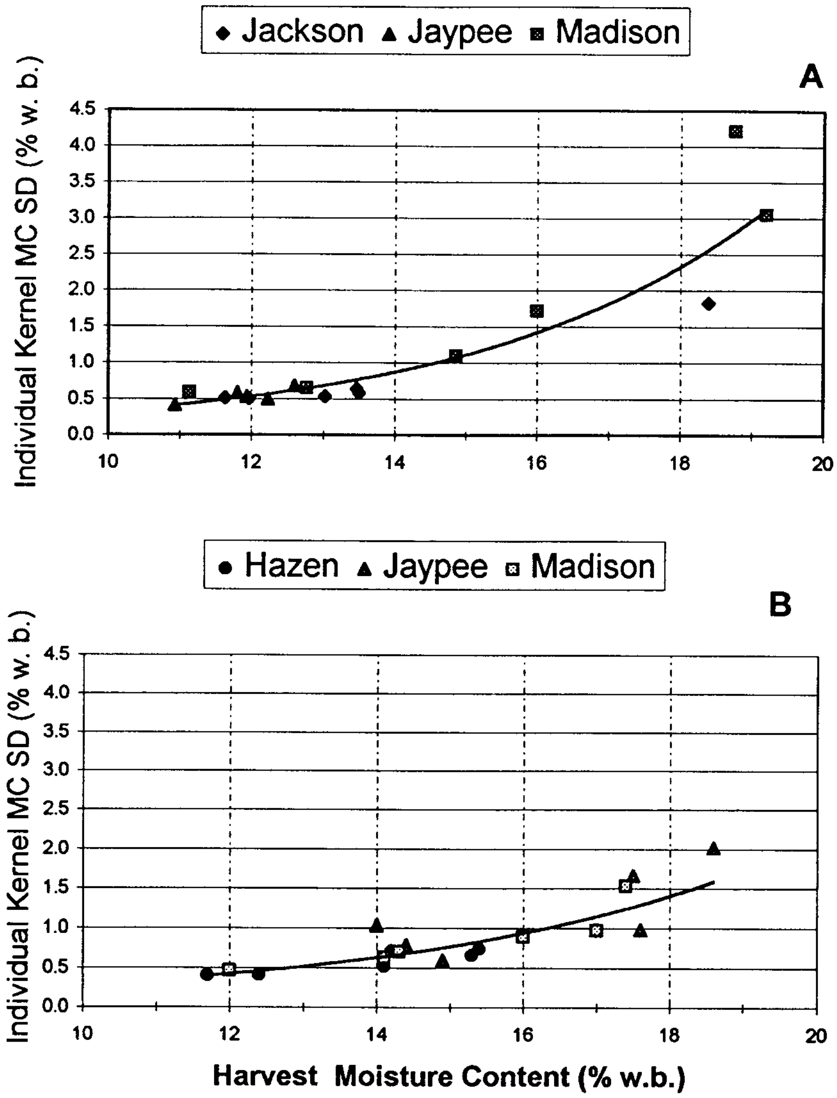

Figure 8–Individual kernel moisture content standard deviation at harvest for (a) 1996, and (b) 1997 season.

CONCLUSIONS

Test weight was shown to have an inverse relationship with moisture content as samples were gently dried. By artificially increasing the moisture content of a dry-ripe sample and then gently drying caused the test weight to decrease an average of 4.4% for the three cultivars tested. The test weight that had been dried and returned to a higher moisture content was lower than that of the original moisture content sample.

Natural weathering did not dramatically decrease the test weight of SRW wheat in the 1996 experiments. Progressive harvesting over a three week span in 1997 showed a decrease in test weight of 3.4%, 5.4%, and 1.4% for 'Madison', 'Jaypee', and 'Jackson', respectively. The standard deviation of the individual kernel moisture contents decreased at an exponential rate as harvest moisture content decreased. At or below 14% moisture content, the individual kernel moisture content standard deviations ranged from 0.5 to 0.8%.

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