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Inheritance and Genotype-Environmental
Studies of Test Weight and Related
Kernel Characteristics in Soft Winter
Wheat, Triticum aestivum L.

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ABSTRACT

INHERITANCE AND GENOTYPE-ENVIRONMENTAL STUDIES OF TEST WEIGHT AND RELATED KERNEL CHARACTERISTICS IN SOFT WINTER WHEAT, Triticum aestivum L.

By

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Test weight is defined as the weight of grain necessary to fill a given unit of volume. It is the product of density and volume of grain occupying the container. The latter component, when expressed as percentage of the volume of the container, is referred to as packing efficiency and this component was shown to have a much greater effect on test weight than density.

A significant but negative correlation was found between test weight and length width ratio. Approximately 39 percent of the variation in test weight was shown to be associated with this ratio and the remainder was unexplained. Volume or weight of the grain was shown to have no effect on test weight. Within varieties pearling index and kernel protein were found to be related to kernel size.

Test weight, packing efficiency, flour yield, and other physical properties of the kernel such as weight, density, length and width were affected by environment.

With few exceptions, reduction in kernel weight was usually accompanied by reduction in test weight. Kernel length was more resistant to environmental factors than kernel width at later stages of kernel development. By removing the effect of density and dealing with packing efficiency alone, a definite gain was obtained in the genetic variance. Using the analysis of variance procedure, the second order interaction, $V \times Y \times L$, was demonstrated to be highly significant. The first order interactions, i.e., $V \times L$ and $V \times Y$, were not significant. Heritability estimates, both on the basis of single plots and line means differences, were made and a much higher value was obtained for the latter than the former.

Stability analysis for 22 lines under 15 environments revealed that some lines did not show genotype-environment interaction. A negative but significant correlation was obtained between the stability parameter (β) and the average performance over all environments.

For the study of inheritance of test weight the diallel technique was employed and high test weight was shown to be dominant over low.

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IN SOFT WINTER WHEAT, Triticum aestivum L.

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INTRODUCTION

Test weight is widely recognized as an important grading factor. Low test weight in soft wheats has been a matter of concern to the farmer, breeder, and industry. Farmers have been penalized for wheats of low test weight because industry is reluctant to accept such wheats since there is a belief that low test weight is related to poor milling quality. The recent introduction of semidwarf Norin 10 germplasm into newly released soft wheat varieties has revived the controversy concerning the relationship between test weight and quality, especially flour yield.

Neither physical properties of the kernel contributing to low or high test weight nor the relationship between these properties and quality is clearly established. Mode of inheritance, stability of performance, and the environmental effect on test weight have received little attention. The intent of this study was to establish the relationship(s) between test weight and other physical properties of the kernel. Such information might lead to a better understanding of test weight and may find its usefulness in the breeding of high test weight varieties.

The relationships between physical properties of the kernel and some quality characteristics were investigated. The study was further oriented toward a better understanding of environmental effect, its stability, and its mode of inheritance.

REVIEW OF LITERATURE

Test weight, weight per bushel or bushel weight of wheat was used by practical millers as a measure of flour yield potential long before the establishment of the present grading system. It is defined as the weight of a volume of grain necessary to fill level full a unit of volume, the volume used being a Winchester bushel with a capacity of 2150.42 cubic inches (55, p. 7). Because of the simplicity involved in the determination of test weight, it was probably the first to be recognized as an important grading factor (53). Boerner in 1916 emphasized the importance of test weight and described an improved apparatus for its determination (12). He also explained that test weight determinations should be carried out under controlled conditions. The standard method of test weight determination has been described (4, 21).

Micro determination of test weight was proposed by Harris and Sibbitt (23), Swanson (56), Aamodt and Torrie (1), Roberts (49), and Yamazaki (60 and personal communication). They used containers of different sizes to measure test weight. These measurements were reported to be valuable when the amount of available seed is not

sufficient to run the standard test. The correlation coefficients between micro-test and the standard method were reported to be very high.

Roberts (49) discussed the importance of test weight and the possibility of breeding for kernel types with high packing quality and consequently, a high test weight. In his comprehensive study on test weight, he measured some physical properties of wheat kernels for 52 lines. The properties measured were: weight, volume, density, length, width, packing quality, and length width ratio. He employed a micro-test weight method and explained packing quality as percentage of volume of the grain capable of being packed into 100 cc. There was a high correlation between packing quality and test weight. He also stated that within limits, test weight was correlated with kernel volume if length width ratio was kept constant. The importance of kernel shape was emphasized with the hope that the length width ratio and kernel volume would explain shape differences. The importance of kernel shape as a factor influencing test weight has also been emphasized by many other workers.

Boshankian (11) outlined the factors which influence the shape of the wheat kernel. These factors were: rigidity of the glumes; the size and form of the space within which kernel development occurs; number of kernels and

their locality in the spikelet; spike density; the amount of pressure exerted by different growing parts of the spike; and finally the species characteristics. He stated:

"...that the grain of wheat throughout its period of development is very soft and that it hardens only after it attains its maximum development. Hardening is a drying process and occurs during the last few days of its period of maturation. As the kernel is very soft before this period, the slightest pressure on the grain through contact is very apt to modify its shape."

Lamba (32) in a study of relationships between kernel and glume dimensions reported that the highest correlation was obtained between length of the kernel and length of the glume. He concluded that the kernel length is least affected by environment. Clark and Bayles (14) stated that the wheat kernel reached its maximum length several days before the kernel matures and it is a valuable characteristic for taxonomical research. Murphy and Frey (41) in a study of the components of kernel weight in oats broke down groat weight into its components as follows: $G. W. = L (W/2)^2 D K$, where G. W. is groat weight; L, length; W, width; D, density, and K a constant related to shape factor.

Hlynka and Boshuk (26) discussed the relationship between kernel size, packing, and density with test weight. By presenting a model, they concluded that test weight is

independent of kernel size. Shape of the kernels and their heterogeneity were the factors which influenced the density of packing. They stated the possibility of obtaining different packing densities from random packing of long and round plump kernels. They further stated that mixing of small and large kernels may still lead to a different test weight. Heizer and Johnson (25) obtained a correlation coefficient of -0.19 between test weight and kernel volume. Frequent reports have been published, indicating low correlations between test weight and kernel weight.

Yamazaki (60 and personal communication) used the term packing efficiency rather than the term packing quality as was used by Roberts (49) to express the percentage of the volume of the container being occupied by the volume of the grain. Test weight is the product of density and the volume of the grain occupying a certain volume. The second component is different from packing efficiency only by a constant. Yamazaki (60 and personal communication) studied the relative importance of packing efficiency and density and obtained a higher correlation between test weight and packing efficiency than between test weight and density. He also reported separation of broken kernels of several samples and noted that broken kernels always gave a lower packing efficiency due to their irregular shape.

Shollenberger and Coleman (52) separated kernels of a hard red winter wheat lot into 3 groups; dark, hard, and vitreous; spotted or mottled; and starchy or yellow. The effect of kernel texture on test weight was very small; mottled kernels had a tendency to be the highest and starchy kernels to be the lowest in test weight. Yamazaki (60 and personal communication) divided a sample of Purkof wheat into vitreous and mealy kernels. The third group consisted of a sub sample of the original lot. Test weight for the mealy kernels tended to be the lowest and for the vitreous kernels the highest. The original lot fell between the two groups.

The amount of moisture present in the grain influences test weight. Bates, et. al. (8) tempered a quantity of wheat in a temporary storage for 24 hours. A reduction of 1.2 pounds per bushel as compared with the test weight on entering the washer was reported. Swanson and Pence (57) reported on the test weight of wheat with varying moisture levels. An increase in moisture content was always accompanied by a decrease in test weight. Low test weight of the moist samples was attributed partly to lower density of the moist kernels and partly due to swelling of the kernels. The effect of moisture in lowering the density of the grain is due to grain density being greater than water density (26).

Sharp (50) showed that when kernels of wheat are moistened and then redried, they will not regain their original size. Swanson (55, p. 140) indicated that scouring of the treated samples increased their test weight. Shollenberger and Coleman (52) showed that scouring of the kernels (without previous wetting) increased the test weight of both hard red winter and hard red spring wheats; however, they obtained opposite results from durum wheat which they could not explain.

There has been a tendency to correlate test weight with protein content of the kernel. This is mainly due to higher protein content of vitreous kernels which usually gives a higher test weight. Snyder (54) demonstrated that within varieties dark kernels contained more protein than the lighter ones. Shollenberger and Kyle (53) using a multiple and simple correlation technique found a significant correlation between test weight and protein in hard red spring wheats. They noted a tendency for protein content to increase as test weight increased; however, this tendency was for samples with test weight of less than 54 pounds per bushel. For wheats weighing more than 54 pounds per bushel the correlation was reversed. They indicated that 44 percent of variation in protein is due to the combined effect of kernel texture and test weight, the former being more important than the latter.

Specific gravity or density as a component of test weight has been studied by many investigators. Density of grain as defined by Swanson (55, p. 8) is "concentration of matter in a unit of volume, the standard being a cubic centimeter of water at its greatest density at 4 C." Shollenberger and Coleman (52) reported that there is a definite relation between density and kernel texture. Shollenberger and Kyle (53) also reported that there was a definite increase in the amount of protein as the percentage of dark, hard vitreous kernels was increased. Sharp (50) discussed the relationship between density and test weight. He stated that a low test weight may not necessarily be correlated with density. He emphasized the fact that test weight depends on two factors: (1) density of the grain and (2) the actual volume of the grains which occupy a certain volume. He also studied the effect of moisture on the vitreous and yellow berry kernels of the same lot of wheat. It was reported that an increase in moisture content of both types of kernels is accompanied by a decrease in density; however the vitreous kernels decreased in density at a higher rate. On the basis of these results, Sharp concluded that there may be a tendency for water to fill the air spaces in the yellow berry kernel rather than expand it. Heizer and Johnson (25) studied the effect of moisture on density of wheat

grain. They reported that an increase in moisture was accompanied by a decrease in density. The Purkof variety (with the highest density) tended to decrease in density at the highest rate compared with other varieties. Moisture content and moisture history, amount of protein, and the kind of protein were reported by Sharp (50) to be the main factors which determine density. When he ground vacuum dried samples of kernels, the density of the two samples (vitreous and yellow berry) was very close, indicating that the lower density of yellow berry kernels was due to a larger number of small air spaces. Yamazaki (60 and personal communication) selected three varieties of soft wheat with low, medium, and high density and samples of each variety were subjected to different degrees of cracking. He divided samples of each variety into four categories as follows: 1) unground kernels, 2) coarse ground kernels with kernels barely broken, 3) medium ground kernels, more severe than the second category but not so hard to produce flour, and finally 4) wheat meals of each variety. For all three varieties of wheat, the wheat meal samples had the highest density followed by medium ground, coarse ground, and unground samples. Assuming the amount of air spaces in wheat meal to be zero, he showed that unground samples of the three varieties had 2.7, 5.5, and 8.3 percent air in the high, medium, and low density varieties respectively.

Shape of the kernel has been reported as the main factor influencing test weight (7, 26, 49, 55), but there has been no success in quantifying this characteristic. Other factors such as shriveling of the kernels, or the condition of the kernel surface, depth of crease, extent of brush, frequency of handling, have also been pointed out as the factors affecting weight per bushel.

It has been an accepted concept that high weight per bushel is associated with plumpness of the grain and consequently a higher flour yield (38, 39). On the basis of averages obtained for test weight and flour yield for numerous samples Thomas (58) concluded that there was a definite relation between test weight and flour yield. However, when he considered individual samples this relationship was not consistent. He found no relationship between kernel weight and flour yield. Swanson (55, pp. 137-138) presented data which had been collected by the Howard Testing Laboratories from many thousands of samples over 15 years. The data showed that there was a relationship between test weight and flour yield, but this relation was not linear. An almost constant ratio between weight per bushel and flour yield was obtained between the range of 51 and 61 pounds per bushel. The data presented by Bailey and Sherwood (6) showed that wheats of the same test weight may differ considerably in their flour yield.

This inconsistency as described by Swanson (55, p. 138) is due to the use of a smaller mill for flour extraction. Swanson (55, p. 138) further pointed out that when milling is carried out on a small laboratory mill the amount of flour cannot be predicted from test weight. Bailey (5) studied the relationship between kernel volume and actual percentage of endosperm. He took samples of grain from a field of the Bluestem variety starting 10 days after heading and continuing until maturity. Endosperms of the samples were dissected, weighed and dried. A progressive increase in kernel volume was accompanied by an increase in the percentage of the endosperm. On the basis of these results, he concluded that within the same variety, kernels with high volume would possess a higher flour yield potential due to their higher percentage of endosperm. He also pointed out that under equal conditions large kernels have a higher specific gravity than small kernels, indicating a higher density for endosperm rather than the bran and germ. Swanson (55, p. 6) explained the situation in another way. He stated that within the same variety large kernels would produce a higher flour yield, because the variation caused by kernel volume would be more pronounced on total size of the kernel than on the bran coat. Sheuy (51) presented data and reached the conclusion that wheats may be

as much as 9 pounds different in their test weight with the same flour yield. He further pointed out that frequent handling would increase test weight without any increase in flour yield. He developed a wheat sizer by which the kernels were separated according to their cross-sectional area. He obtained a correlation of 0.957 between flour yields calculated from this sizing procedure and commercial flour yields. The correlation between test weight of the same samples and flour yield was reported to be 0.747.

Barmore and Bequette (7) stated that compactness of the head and distorted contours of the grain in club wheat always led to a lower test weight than common varieties. They pointed out that this special characteristic of club wheats has resulted in (unfair) penalization of club wheat producers. Further data indicated that club wheat varieties may produce a 5 percent or higher flour yield than common white varieties. They further concluded that in white wheats of the Pacific Northwest, weight per bushel is a poor predictor of flour yield, and test weight is a poor index of flour yield between varieties, within varieties, within a white wheat subclass, or between subclasses.

Pfiefer (46) without presenting data stated that a correlation of 0.152 had been obtained between test weight and flour yield. He made the statement that the millers have no reason to expect a high or low extract in the 58-61

pound test weight range. He suggested that research should be carried out and methods should be developed so that exact flour potential could be predicted. Johnson and Hartsing (30) suggested that weighing of a specific amount of grain and then counting the number of kernels per weighed sample would be a more precise measure of kernel weight. He referred to this characteristic as kernel count and obtained a significant correlation of -0.84 between this property and flour yield among hard wheats; however, the correlation among soft wheats was reported to be of the magnitude of -0.68 .

Fisher and Halton (20) in a much earlier paper reached the same conclusions with regard to sampling for 1000 kernel weight determinations. They proposed weighing of samples of about the same amount, counting the number of kernels per sample, and then converting the results into 1000 kernel weights. Using this procedure they were able to reduce the sampling error to a great extent.

Regarding the effects of various environmental factors on test weight, no comprehensive report has yet been published; however, there have been some short reports on the effect of lodging and delayed harvesting on test weight. Pendleton (43) showed that different degrees of artificial lodging at different dates had a definite effect in lowering test weight. Laude and Pauli (33) accomplished

artificial lodging of different degrees at different dates on winter wheat and concluded that the effect of lodging on test weight is minimum if the lodging occurs 5 days before heading. Lodging after or before this time was more effective in reducing test weight. They pointed out that lodging within 2 weeks immediately before heading would lead to the production of small but fairly plump kernels; however, shrinkage of the partly developed kernels accounted for the low test weight from plots lodged during heading and for two weeks after this time. Day (17) used 2 varieties of barley and employed 2 degrees of lodging (45° and 90° from the perpendicular) at 3 stages of growth. He showed that 90 degree lodging had a severe effect in decreasing test weight and kernel weight at all stages of heading. Weibel and Pendleton (59) demonstrated that a 4.8 pound loss in test weight resulted from lodging at heading time; however lodging at a later period, 3 weeks after heading, during the hard dough stage resulted in a reduction of only 1.1 pounds loss in test weight.

The effect of delayed harvesting on test weight was reported by Pool, et al. (48). They showed that delayed harvesting resulted in some decrease in test weight. The heads of 3 soft red wheat varieties were harvested at different times following maturity. They reported that delayed harvesting had a pronounced effect in lowering test weight.

This decrease in test weight was attributed partly to reduction in kernel weight and partly to some increase in kernel volume brought about by weathering.

Date of seeding was reported by Pitman and Andrews (47) to influence test weight. They showed that late and early planting resulted in lower test weights. The low test weight obtained from wheat planted late was probably due to late maturity and greater effect of stem and leaf rusts. When winter killing was severe, higher bushel weights were obtained.

Bayles and Suneson (9) reported that bearded varieties of wheat may have higher test weight than beardless varieties. They made crosses between bearded and beardless varieties. Segregating populations then were divided into bearded and beardless populations. On the basis of replicated plots over a period of 4 and 5 years they reached the conclusion that the grains from the composite of bearded plants were superior to that from the composite of beardless plants both in kernel weight and test weight for each cross.

MATERIALS AND METHODS

1. Relationships among the Physical Properties of the Kernel and Possible Correlation of these Properties with Quality in Soft Winter Wheat

A micro-test weight was developed and was especially important in cases where the amount of seed was insufficient for running the standard test weight determination. The term "standard test weight" in this study is defined as the weight of the grain necessary to fill level full a pint measure and is expressed as grams per pint. The container used for the micro-test weight determinations was a small glass jar with a capacity of 47 ml. The procedure of running the micro-test in this study and other studies (when it was necessary to run the micro-test) can be summarized as follows: 1) the container was filled until the grain flowed over; 2) the container then was gently tapped on the table to let the grain pack, but not so hard that the grain on the top fell off; 3) starting from the edge of the glass jar, with a stroker the grain was leveled with a zig zag movement; 4) and finally the weight of the grain in the glass jar was measured by a balance. All the data obtained during the course of the study represent averages of 10 such determinations.

A total number of 59 samples of soft winter wheat representing a great amount of diversity among the available materials with regard to test weight, kernel weight, and other physical properties were studied. Test weight (both micro and the standard) and other physical properties of the kernel such as weight, length, and width were determined on all the 59 samples. Length measurements were made by taking 100 kernels from each sample at random and placing them end to end on a measuring board somewhat similar to the device developed by Roberts (47). Width determinations were also made on the same 100 kernels by placing them crease down on another measuring board. Then length width ratios were calculated by dividing the former over the latter. Later samples of about one pound representing all the 59 samples were sent to the U.S.D.A. Soft Wheat Quality Laboratory in Wooster, Ohio to make measurements on density, kernel volume, packing efficiency, and quality characteristics.

Packing efficiency and kernel volume were determined by a Beckman air comparison pycnometer, an instrument by which volume of a certain weight of kernel can be measured without damage. By using this instrument it was possible to make rapid measurements of test weight, packing efficiency, and density at the same time. A cup with a known volume is

filled with grain and then the grain on the top of the cup is leveled in the same manner as described for the micro-test weight measurements. The weight of the grain in the cup, also called micro-test weight, is a measure of test weight and is highly correlated with test weights measured by the standard method. Then the cup filled with grain is placed inside of the instrument and the volume of the grain is measured by air replacement. Having obtained this volume, density can be calculated by dividing the weight of the grains (micro-test weight) by their volume; however, for volume determination of individual kernels, the number of grains in the cup should be counted.

Among the determined quality characteristics, only the data for flour yield, kernel protein, and pearling index will be presented. Pearling index is a measure of softness of the grain and is measured by subjecting a sample of grain to a rotating carborundum wheel and metal screen for a certain period of time. It is expressed as percentage of reduction in weight of the sample (10). Higher values represent softer textures.

In order to see if the kernel size within varieties had any effect on test weight and quality, 8 commercial varieties were taken. Each variety was separated into 4 groups. This separation was based on sieving each variety through 2 sieves of different size. The kernels remaining

on the top of the first sieve (with larger sieve size) were graded as large, and the kernels passing through the second sieve were graded as small. Medium sized kernels consisted of kernels which could pass through the first sieve, but not through the second. The fourth group was composed of the natural bulk of the variety. Standard test weights were made on all the groups within each of the 8 varieties. The samples of about one pound from each group were then sent to the U.S.D.A. Soft Wheat Quality Laboratory in Wooster, Ohio for determination of flour yield, kernel protein and pearling index.

2. Effect of Environment on Test Weight And Other Kernel Characteristics in Soft Winter Wheat

a. Pattern of Change in Kernel Characteristics Under Different Environments

This study was conducted to determine the varietal behavior of test weight, kernel weight, length, width, and flour yield under different environments.

Test weight and 1000 kernel weight measurements were made on 30 lines replicated 3 times at 7 locations in 1968. The 7 locations and their corresponding symbols which will be used henceforth, are as follows: Ingham County, (I01); Lenawee County, (L41); Ionia County, (S51); Tuscola County, (T61); Huron County, (H71); Kalamazoo County, (K81); and Berrien County, (B91). Flour yield extractions were made

by the U.S.D.A. Soft Wheat Quality Laboratory on the same 30 lines, but only from 4 of the locations, namely I01, L41, H71, and B91. For the latter experiment only the first 2 replications were taken.

To study the effect of environment on kernel length and width, only seeds from one replication of the 30 lines from locations I01, L41, and H71 were used. Length and width measurements followed the same procedure as previously described.

Locations I01, L41, and H71 were deliberately selected because lodging following heavy rainfall occurred in I01 at maturity whereas prevalence of extremely unfavorable and favorable environmental conditions occurred at L41 and H71, respectively.

All possible differences of test weight and kernel weight for all pairs of locations for lines were calculated. The lines at each location were represented by averages over replications. Differences of test weight were regressed on kernel weight and flour yield differences. As a result 21 appropriate correlation coefficients of differences between test weight and kernel weight at paired locations were obtained; however, only 6 correlation coefficients of this type were obtained between test weight and flour yield and another 6 between kernel weight and flour yield. An example might be helpful in illustrating the procedure. Let test

weight in Huron County (H71) and Berrien County (B91) be denoted by TH71 and TB91 respectively, and 1000 kernel weight for the same 2 locations be represented by KH71 and KB91 respectively. Then differences between corresponding lines at these 2 locations were calculated both for test weight (TH71 - TB91) and kernel weight (KH71 - KB91). Finally the regression of the former on the latter was calculated. Length and width comparisons were made only between the means of the locations.

b. Estimation of Variance Components And Heritability of Test Weight

The purpose of this study was to explore and evaluate the proportion of phenotypic variance for test weight arising from genetic differences among lines, interactions of genotype with environment and finally a random error associated with plot error and a composite of errors due to sampling within plots, measurements, etc.

The data used in this study came from yield evaluation experiments in 1967 and 1968. Two sets of advanced breeding lines and commercial varieties were planted in 7 locations in both years. Each set hereafter will be referred to as nursery I and nursery II. For any one year the same 30 lines appeared in nursery I in all locations. The same was true for nursery II. However, the composition of nursery I and II was not the same in both years. The 7 locations used were: I01, L41, S51, T61, H71, K81, and B91.

Among the 30 lines planted in nursery I in 1967 and 1968, 16 were common in both years and in all locations. A total number of 3 replications was used at any one location for any one year. Each plot consisted of 4 rows and each row was 12 feet long with 12 inches between the rows. A seeding rate of 80 grams per plot (2 bushels per acre) was used. The two center rows were harvested and test weight measured by the standard method, and expressed as grams per pint. Because of insufficient seed from many plots at L41 and S51 in 1968 the micro-test was employed and the results then were converted into grams per pint.

For the present study test weight data from the above mentioned 16 lines over both years and the 7 locations were used. Locations S51 and L41 in 1968 were characterized by heavy weed infestation and by lodging in S51. Because of the prevalence of such unusual environments in these two locations, the data was analyzed one time with and another time without these two locations. In the latter case the data for these two locations from 1967 should be ignored. For the sake of simplicity the first set of data including these 2 locations will be referred to as set A, and for the next set, excluding these 2, as set B. The data were analyzed for both sets in the same manner.

For statistical analysis, years, locations, and lines were assumed to be random. Any phenotypic value was presented as:

$$Y_{ijkl} = \mu + v_i + l_k + y_j + r_{jkl} + (vl)_{ik} + (vy)_{ij} + (ly)_{jk} + (vly)_{ijk} + e_{ijkl}$$

In this model Y_{ijkl} being phenotypic value; μ , grand mean of the population; and v_i , the average genotypic effect. l_k , y_j , and r_{jkl} are the direct effects of locations, years, and replications respectively (15, 36). Interaction components are presented as combinations between or among these main factors and e_{ijkl} is an error term associated with plot errors. Estimation of variance components was obtained from expected mean squares as described by Comstock and Robinson (15). The following estimates of variance components were calculated:

σ_v^2 = variance component due to genetic differences among lines.

σ_{vl}^2 = variance component due to lines x locations interaction.

σ_{vy}^2 = variance component due to lines x years interaction.

σ_{vly}^2 = variance component due to lines x locations x years interaction.

σ_e^2 = error variance arising from different plots within locations within years.

Having calculated the estimated value of these variance components, heritability estimates of differences among line means and single plots were calculated. The formula used for estimation of the latter:

$$H = \frac{\sigma_v^2}{\sigma_v^2 + \sigma_{vl}^2 + \sigma_{vy}^2 + \sigma_{vly}^2 + \sigma_e^2}$$

and for the former:

$$H = \frac{\sigma_v^2}{\sigma_v^2 + \frac{\sigma_{vl}^2}{1} + \frac{\sigma_{vy}^2}{y} + \frac{\sigma_{vly}^2}{ly} + \frac{\sigma_e^2}{rly}}$$

In order to investigate the effect of environment on the components of test weight, i.e., packing efficiency and density, the same 30 lies from 3 of the locations, i.e., H71, B91, and L41 in 1968 were used. Packing efficiency and density were measured. Test weight data are presented in its original unit, grams per pycnometer cup and no attempt was made to convert them to another unit. The data for packing efficiency also were not converted into percentage of the container volume and they represented the real volume of the grains occupying the pycnometer cup. Two measurements per plot were made and the average of these two was used to represent each plot. A randomized block design with 2 replications in each location was used. Estimates of heritability and the variance components were calculated by the same procedure as explained before.

c. Stability Study

This study was designed to assess the stability of 22 lines of soft winter wheat for test weight and to obtain more information about the interaction of individual genotypes with environments. Analysis of variance procedure as used before is useful for estimation of genotype-environment interaction variance components; however, it does not provide information about interaction of individual genotypes with environments. Neither does it provide information about the stability of the genotypes.

Yates and Cochran (61) using a pure statistical analysis partitioned genotype-environment interaction into linear and nonlinear components. This technique was modified by Finlay and Wilkinson (19), Eberhart and Russell (18), and Perkins and Jinks (45). Finlay and Wilkinson regressed the mean performance of each line onto the mean performance of all lines for each environment, and the regression slope was suggested to be the measure of stability. A stable line was described as one which performs the same over all environments ($b = 0$). Eberhart and Russell (18) developed a model and described a stable line which possesses a slope of unity. They further employed two ancillary measures of stability, i.e., high mean and deviation from regression of zero. Bucio-Alanis and Hill (13) developed a model from which more information could be gained about

genotype-environmental interaction of paired lines. Perkins and Jinks extended Bucio-Alanis' model to cover any number of inbred lines. Their model also provides a better understanding of stability and they further subdivide genotype-environment interaction of individual lines into linear and non-linear components.

The data for this study was obtained from the yield evaluation experiments in 1967 and 1968. The same 16 lines and 7 locations used in the previous study for the estimation of genotype-environment variance components, were employed; however, an additional 6 lines which were planted in nursery II in 1967 and in nursery I in 1968 at all locations were also included in the analysis. The data from Monroe County (M31) in 1968 were also incorporated into the procedure. This gave a total number of 22 lines planted in 8 locations in 1967 and in 7 of the same locations in 1968. These 15 environments were considered without regard to their nature, i.e., separate environments. This procedure resulted in 15 environments with 22 lines within each environment. A total number of 3 observations were made on each line at each environment. The means over the three observations were used to represent the performance of each line at each environment and for the variance analysis.

For the analysis the Perkins and Jinks' model was employed. In this model we have:

$$Y_{ij} = \mu + D_i + E_j + g_{ij}$$

y_{ij} being the performance of the i th line at the j th environment; μ , population mean; D_i , additive effect of genotype; E_j , additive effect of environment; g_{ij} , the interaction of i th line with j th environment.

μ , D_i , E_j , and g_{ij} can be estimated as follows:

$$\mu = y_{..} / ts$$

$$D_i = y_{i.} / s - \mu$$

$$E_j = y_{.j} / t - \mu$$

$$g_{ij} = y_{ij} - \mu - D_i - E_j$$

t and s correspond to the number of lines and environments, respectively. The next step in the analysis is the regression of g_{ij} for the individual lines onto the environmental index (E_j). The analysis of variance for the regression of g_{ij} on E_j requires an additional error term for testing the significance of the residuals. This error term arising from within line within environment variation averaged over all environments and lines was estimated on the assumption of complete randomization of lines within each environment. Non-significant regression and residual mean squares is the indication of the absence of genotype-environment interaction. Presence of genotype-environment interaction is evidenced by significance of either regression or residual mean squares or both. Significance of the regression mean squares alone

is the indication that genotype-environment interaction is a linear function of the environment and depending on the amount of error, prediction of genotype-environment interaction can be made. On the other hand, significance of the residual mean square is the indication of no simple relationship and as a result, no prediction can be made. Comparison of the magnitude of mean squares would be of value if both regression and residual mean squares are significant. It can be shown mathematically that the regression slope $\hat{\beta}$ (obtained from regression of g_{ij} on E_j) is exactly one unit less than the stability parameter, β , (obtained from regression of y_{ij} on E_j) or $\beta = 1 + \hat{\beta}$. Analysis of variance for the regression of individual lines on environment can be combined in one table as developed by Yates and Cochran.

3. Inheritance Of Test Weight

For studying the inheritance of test weight, the diallel technique as developed by Jinks and Hayman (24, 27) was employed. Seven parental soft wheat lines were deliberately selected and all possible crosses were made in the greenhouse in the Winter of 1966. Lack of reciprocal effects was assumed and seeds from each cross were bulked without regard to the parental sex. F_1 seeds were harvested and along with the selfed seeds of the parents were planted in peat pots in April, 1967. The F_1 seedlings

were kept in the vernalization chamber for a period of 8 weeks. After this period, individual seedlings were transplanted in pots and were transferred to the greenhouse. Because of insufficient seed and the abnormal effect of greenhouse environment on test weight (and kernel weight) no observations were made on F_2 seeds arising from F_1 plants. After maturity in the greenhouse a total number of 200 seeds from each cross and each of the parents was taken randomly for planting in the field at East Lansing. A completely randomized design with 2 replications was used. The F_2 seeds from each cross and each of the parents were divided into two lots. Each lot consisting of 100 seeds was used to plant a row 3 feet long. Planting was effected in mid-October (later than usual planting time in East Lansing). Winter killing of some seedlings in each plot and a total loss of 3 plots occurred. Maturity and harvesttime was characterized by heavy rains with consequent lodging in many plots. After maturity each plot was harvested separately and micro-test weight determinations were made. Test weight results for the 21 crosses and the 7 parental lines were averaged over the two replications. Prevalence of such environmental stresses during growth and maturity produced kernels with low test weight and low kernel weight.

Due to the high stress situation described above, it is unlikely that any inheritance pattern revealed by analysis would have general application; however, it was decided to make a brief genetical analysis by the Jinks-Hayman W_r , V_r graph method. For such analysis, variances of the arrays (V_r) and the covariance of each array with the non-recurrent parents (W_r) were calculated and the regression of the latter on the former was fitted. A regression slope of unity is the indication of the fulfillment of the hypotheses (such as lack of epistasis) underlying this technique. Deviation from a slope of unity would be due to the failure of one or more of these assumptions; however, this deviation can be tested by appropriate statistical procedures. The arrangement of the points representing the parents along the regression line indicates the dominance relationship of the parents; points toward the origin having a higher proportion of dominant genes and vice versa. The position of the line indicates the average degree of dominance. The line passes through the origin if dominance is complete ($H = D$). Intersection of the line with W_r axis in the positive side is an indication of partial dominance ($H < D$), and on the negative side is an indication of over dominance ($H > D$). The parabola $W_r^2 = V_r V_p$ (V_p being the variance of the parents) limits the area where the points (V_r , W_r) may mathematically occur.

RESULTS AND DISCUSSION

1. Relationships Among Physical Properties And Quality Characteristics Of The Kernel

Test weight (standard and micro), (1000) kernel weight, (1000) kernel volume, (100) kernel length, (100) kernel width, and the length width ratio appear in the Appendix Table A. Packing efficiency (expressed as percentage of the air comparison pycnometer cup volume occupied by the grain), density, flour yield (%), pearling index (%), and protein (%) data are also included.

The correlation between micro-test weight and the standard test weight was 0.99, suggesting a reliable prediction of the standard test weight by the micro-test. This relation is shown in Fig. 2.

Test weight is the product of density and the volume of the grain occupying a certain volume. For the purpose of simplicity, henceforth, the second component will be represented as packing efficiency which is different from that component by $c/100$, c being the volume of the container. These two characteristics differing from each other only by a constant, will be used hereafter interchangeably. The correlation between test weight and packing efficiency is highly significant Fig. 1-d, with $r = 0.96$ indicating the

minor importance of the other component, i.e., density. A low correlation coefficient of about 0.16 was obtained between test weight and density Fig. 1-c. This relationship was also evidenced by a very low standard partial regression coefficient for density (.23), and a very high value (.98) for packing efficiency, in a linear model using these two as dependent and test weight as independent variables; however, in the model:

Test Weight = $b_0 + b_1$ (packing efficiency x density)
the correlation is near unity ($r = 0.99$). Packing efficiency is associated to a higher degree with test weight and seems to be a varietal characteristic. For more accurate studies of test weight, only this component should be taken into consideration.

Among other properties, the regression of test weight over length width ratio is highly significant ($r = -0.62$). Stated in another way L/W ratio is responsible for 39 percent of the variability in test weight. Roberts (49) in his studies reached the same conclusion; however, he indicated that with a constant L/W ratio, higher kernel volumes would correspond to higher test weights. In the linear equation:

$$\text{Test Weight} = b_0 + b_1 (L/W) + b_2 (\text{kernel volume})$$

assuming L/W represents the kernel shape, the partial correlation coefficient for L/W had a value of -0.57 and a

value of 0.0007 for kernel volume. Therefore, by keeping the shape of the kernel constant (if shape is assumed to be represented by L/W ratio) there would be no gain in test weight if kernel volume is increased; however, more than 60 percent of variation in test weight remains unexplained. Undoubtedly, factors such as depth and width of the crease, shriveling of the kernel and other inherent shape characteristics influence the test weight.

Concerning the relation between other physical properties, the correlation between kernel width and kernel volume is highly significant ($r = 0.91$), Fig. 1-a. A significant high correlation was also obtained between kernel weight and kernel width ($r = 0.91$), Fig. 1-b; however, the correlation between length and volume (or weight) is significant but the r value is much lower (0.44). Kernel volume as calculated by the formula:

$$V = L (W/2)^2 K \pi$$

was significantly correlated with the kernel volume as measured by the pycnometer ($r = 0.95$). In this formula V being volume of the grain, W and L representing width and length respectively. K is a constant and is used because the shape of the grain is not a cylinder. This high correlation indicates that by having values for length and width we can closely estimate the volume of the grain. It further indicates that in the study of components of kernel volume (or kernel weight) such a breakdown is pertinent.

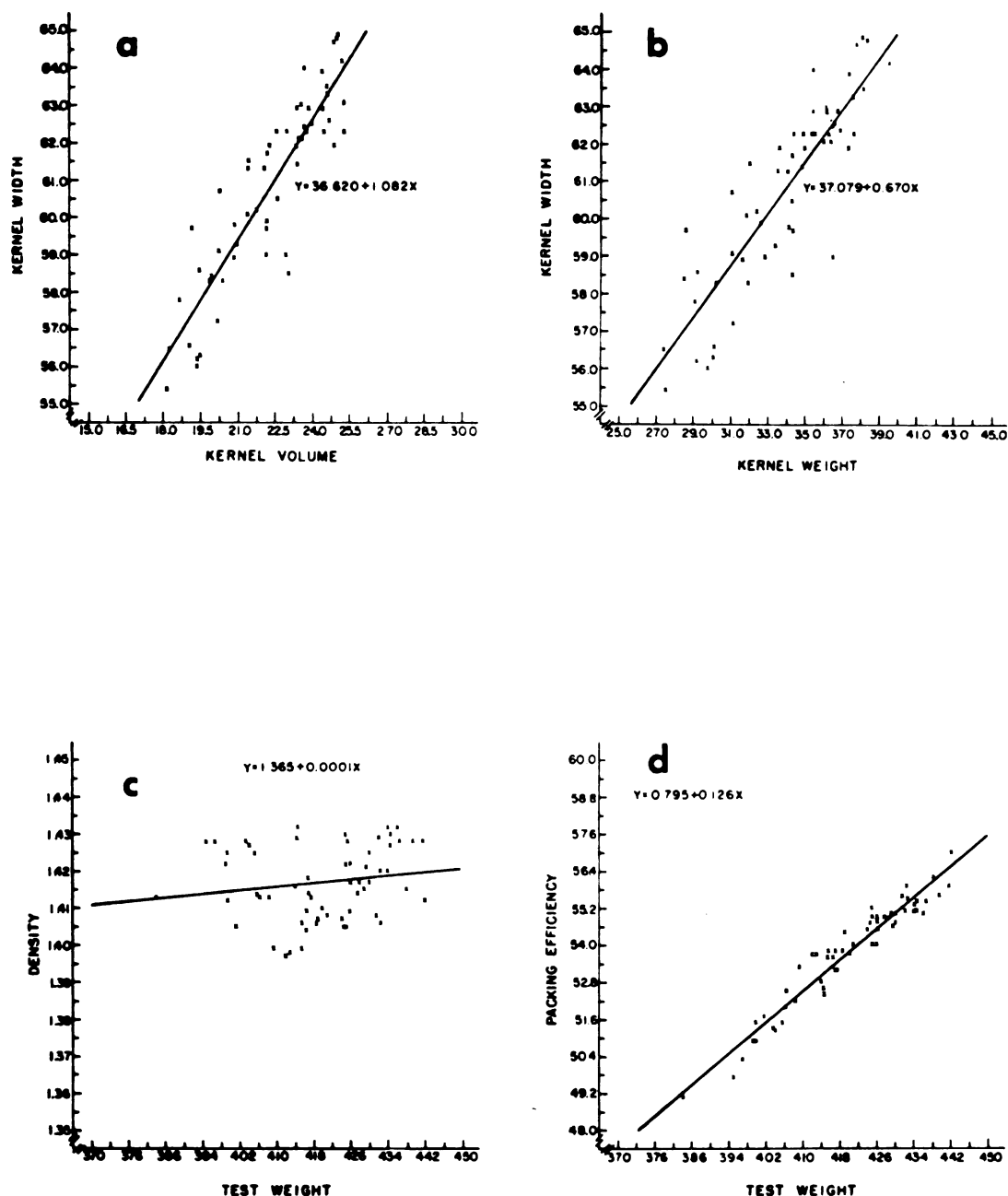


Figure 1-a Relationship between (100) kernel width (cm.) and (1000) kernel volume (ml.); b, Relationship between (100) kernel width (cm.) and (1000) kernel weight (gms.); c, Relationship between density and test weight (gms/pint); d, Relationship between test weight (gms/pint) and packing efficiency (%)

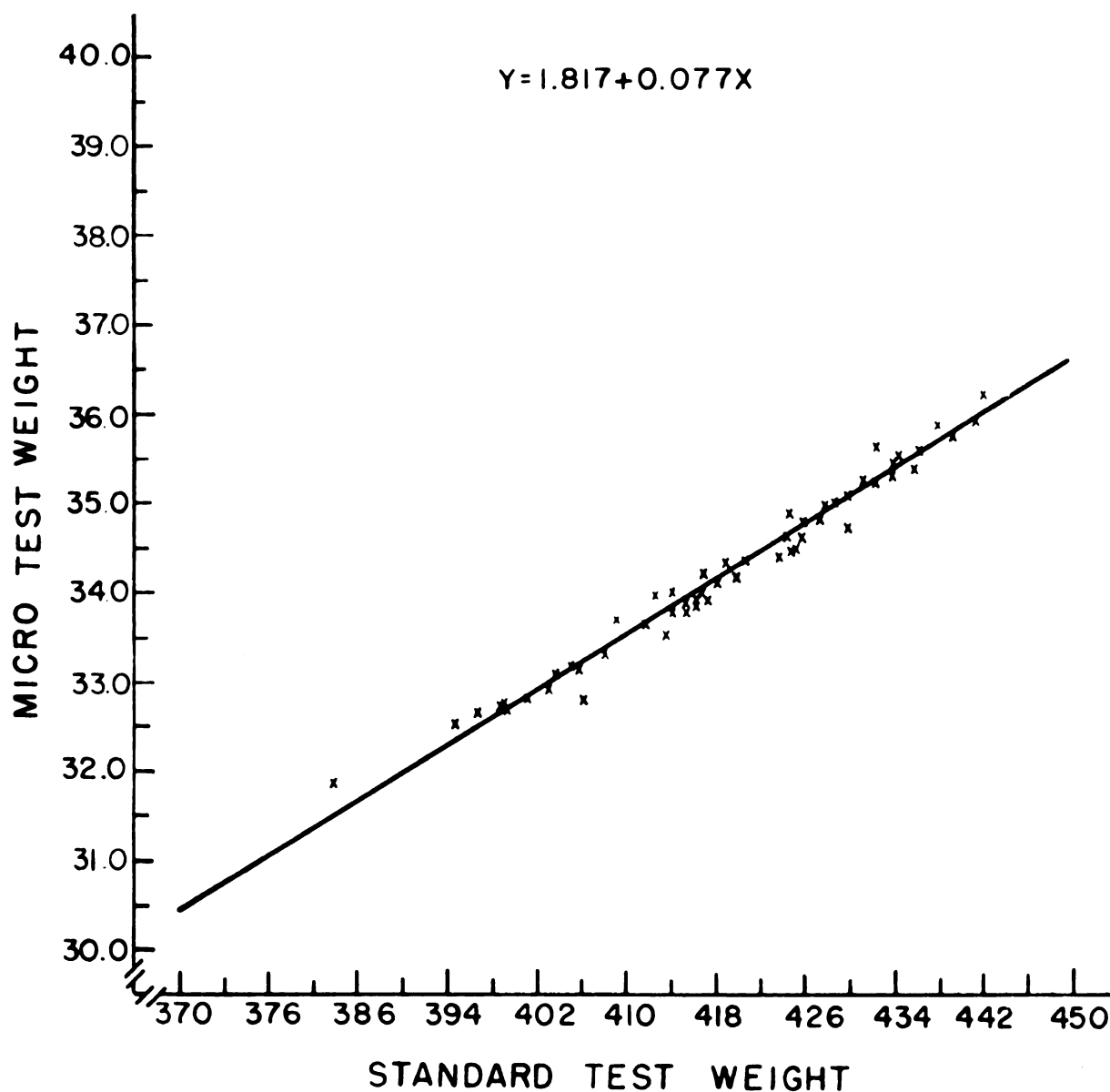


Figure 2. Relationship Between Standard Test Weight (gms/pint) And Micro Test Weight (gms/47 ml. glass jar).

As far as the relation between test weight and L/W ratio and its practical implications is concerned, we should either select for short or wide kernels. There are limits to these values and small kernels with low L/W ratio would not be of interest to the breeder because of the direct effect that this type of kernel might have on the yield. On the other hand, selection for large but plump kernels would lead not only to a higher test weight but also a higher yield. Visual selection of large and plump kernels at early generations would be effective in increasing both test weight and yield. Any cross giving shriveled and small kernels should be discarded and only crosses with superior kernel type should be maintained. At the beginning of development of short strawed varieties at the International Maize and Wheat Improvement Center in Mexico, there were some problems with the low test weight of the short strawed lines; however, rigorous selection for large and plump kernels could very well have been one of the effective procedures for overcoming this problem.

The correlation coefficient between test weight and flour yield is of very low magnitude ($r = 0.03$) and nonsignificant, supporting the reports that test weight is a poor estimator of flour yield. The reports on the relation of test weight and flour yield is so contradictory that any further treatment of the subject involves more extensive

data and experience. This contradiction could be partly due to differences between techniques and instruments that have been used for flour extractions by different authors. Low test weight could be either due to shriveling of the kernels or to the inherent shape of the grain. As far as low test weight is reflected by kernel shape, there would be no reason to expect a lower test weight of this type to give lower flour yield. The Yorkstar variety which was developed in New York State has always given low test weight even in the best environment where no kernel shriveling occurred. Yorkstar does have some problems with consistency of performance but flour yields obtained from this variety on frequent occasions have been as good or better than other commercial varieties with higher test weights (60). The same situation has been reported to be true with the Blueboy variety developed in North Carolina (42). A low correlation was obtained between test weight and kernel protein ($r=0.11$). The correlation between test weight and pearling index was also of a low magnitude (-0.21). These low correlations were probably due to a greater variation of these properties within the same bulk of a variety.

Concerning the relation between kernel size and test weight and quality characteristics, the data for test weight, flour yield (%), pearling index (%) and protein content appear in Table 1. The t values for all the possible comparisons appear in Table 2.

Table 1. Test Weight (grams/pint), Protein (%), Flour Yield (%) And Pearling Index (%) Data For 8 Varieties Separated Into 4 Groups; Large, Medium, Small, and Bulk

No.	Var.	Test Weight				Protein				Flour Yield				Pearling Index			
		L	M	S	B	L	M	S	B	L	M	S	B	L	M	S	B
1	Red Coat	434	434	429	434	12.4	11.8	11.2	12.2	61.6	63.4	63.8	61.7	46.1	44.6	40.3	45.6
2	Dual	419	421	414	419	13.1	12.5	12.1	12.7	64.0	65.4	64.7	65.0	57.6	56.8	52.8	56.3
3	Talbot	417	415	409	416	11.7	10.9	10.6	11.5	66.2	67.5	66.7	65.5	51.0	52.8	43.0	50.8
4	Benhur	431	433	431	432	14.1	13.3	12.7	13.7	64.4	63.7	61.0	63.0	51.4	47.5	39.1	47.6
5	Genesee	442	439	420	438	11.9	11.4	10.9	11.8	66.7	65.9	64.0	66.1	46.0	45.3	39.8	44.6
6	Nugains	427	424	406	415	11.9	11.7	11.3	11.6	65.8	65.9	61.8	63.8	47.9	53.8	38.3	43.5
7	Suwon 92	430	433	428	436	14.9	14.4	13.9	14.4	61.7	62.2	60.4	60.9	45.6	45.5	41.3	44.3
8	Reed	434	436	428	433	13.9	13.4	12.6	13.6	63.3	62.9	61.2	63.6	58.0	52.8	46.6	53.0
Mean		429.25	429.37	420.62	427.12	12.98	12.42	11.91	12.68	64.21	64.61	62.95	63.70	50.45	49.88	42.65	48.21

Table 2. The t Values For Comparisons Of Different Kernel Sizes For Test Weight, Flour Yield, Pearling Index And Kernel Protein

<u>Test Weight</u>			<u>Flour Yield</u>		
		(t)			(t)
Large	v. Medium	0.143 ^{N.S.}	Large	v. Medium	1.119 ^{N.S.}
Large	v. Small	2.935**	Large	v. Small	1.626 ^{N.S.}
Large	v. Bulk ⁺	1.412 ^{N.S.}	Large	v. Bulk ⁺	1.510 ^{N.S.}
Medium	v. Small	3.945**	Medium	v. Small	3.448*
Medium	v. Bulk ⁺	2.081 ^{N.S.}	Medium	v. Bulk ⁺	2.492*
Small	v. Bulk ⁺	3.476*	Small	v. Bulk ⁺	1.260 ^{N.S.}

<u>Pearling Index</u>			<u>Kernel Protein</u>		
		(t)			(t)
Large	v. Medium	0.467 ^{N.S.}	Large	v. Medium	8.277**
Large	v. Small	7.280**	Large	v. Small	12.485**
Large	v. Bulk ⁺	3.392*	Large	v. Bulk ⁺	6.479**
Medium	v. Small	5.197**	Medium	v. Small	9.335**
Medium	v. Bulk ⁺	1.315 ^{N.S.}	Medium	v. Bulk ⁺	3.193*
Small	v. Bulk ⁺	8.174**	Small	v. Bulk ⁺	3.081**

+ Bulk - sample prior to size grading

** Significant at 1%

* Significant at 5%

N.S. Not Significant

For test weight, the three comparisons involving the small sized kernels are significant. The 1000 kernel weight means for medium and large size kernels over all the 8 varieties are 36.56 and 43.64 grams respectively; however the difference between the test weight of these two groups is not significant. These results support the previous reports concerning the effect of kernel volume (or weight) on test weight. Although the kernel size in the large group is substantially higher than the medium group (119%) the difference in test weight is not significant, mainly because the kernel shape remains the same in both groups. The lower test weight of small sized kernels could be either due to their shriveled condition or their lower density. In a spike of wheat the small kernels arise from the late developed florets which get filled later in the season. This may result in a slight shriveling of the small sized kernels within a spike and consequently within a variety. No measurements on the density of these groups were taken but the smaller kernels may have a lower density than the larger. This is evidenced by the higher protein content of the larger kernels when compared with small ones.

As far as the relationship between kernel size (within varieties) and protein content of the kernel is concerned, there seems to be a definite relation between

kernel protein and kernel size. The t values for all the comparisons are significant.

In the wheat plant, flowering of the spikelets begins slightly above the middle of the spike and then proceeds in both directions (34, p. 310). Percival (44) stated that there is a close relationship between the weight of the grains and their position on the spike. The heaviest kernels occur where flowering begins (44). The reports by Levis and Anderson (35) and McNeal and Davis (37) showed a progressive decrease in protein content from large to small kernels. Levis and Anderson reported that the upper spikelets (where small sized kernels develop) had a decidedly lower protein content than the remaining spikelets. They also reported that within a spikelet the middle kernel tended to have a higher protein content. Within a spikelet, there is a definite relationship between kernel weight and protein content. The kernels heavier than the average, tend to be higher in protein. McNeal et al. (37) reported that a higher, but non-significant protein content was obtained from the central kernels. The protein content of the earlier formed and matured kernels was the highest.

The results obtained in this study are in complete agreement with previous studies. Smaller sized kernels with lower protein content arise either from the later developed florets in the spikelets located in the middle

of the spike or later developed spikelets at the top or bottom of the spike. In contrast larger kernels with greater protein content originate either from the spikelets in the center of the spike or from the florets which develop at an earlier time in the spikelet.

Concerning the relation between kernel size and flour yield, the results are inconsistent from one variety to another. One would expect to obtain a higher percentage of flour from the larger sized kernels than the smaller sized ones; however, such differences were not obtained. These results are contradictory to what was reported by Bailey (5). The data is not extensive and the inaccuracy of a small laboratory mill (55, p. 138) and small sample size could very well have been responsible for such results.

As far as the relationship between kernel texture and kernel size is concerned, there seems to be a definite trend for smaller kernels to have lower pearling index values. These results could be attributed to a higher bran-endosperm ratio of the smaller kernels. Bran has more elasticity than the endosperm and it resists attrition.

2. Effect Of Environment On Test Weight And Other Kernel Characteristics

a. Pattern Of Change In Kernel Characteristics Under Different Environments

The data for test weight and kernel weight averaged over the 3 replications appear in Tables B and C. The data for length and width are presented in Table D. Micro-test weight, packing efficiency, density and flour yield data appear in Table E, all in the Appendix. The 21 possible correlation coefficients of differences between test weight and 1000 kernel weight are presented in Table 3.

Table 3. Correlation Coefficients Of Differences Between Test Weight And 1000 Kernel Weight At Paired Locations

Pairs of Locations	Correlation Coefficient	Pairs of Locations	Correlation Coefficient	Pairs of Locations	Correlation Coefficient
T61 - K71	0.53	H71 - B91	0.40	K81 - L41	0.90
T61 - K81	0.47	H71 - I01	0.57	B91 - I01	0.75
T61 - B91	0.13	H71 - S51	0.90	B91 - S51	0.89
T61 - I01	0.57	H71 - L41	0.74	B91 - L41	0.87
T61 - S51	0.90	K81 - B91	0.85	I01 - S51	0.93
T61 - L41	0.82	K81 - I01	0.82	I01 - L41	0.81
H71 - K81	0.69	K81 - S51	0.95	S51 - L41	0.88

Regression analysis indicated that reduction due to regression is significant for all but one of the possible pairs, i.e., T61-B91. The majority of correlation coefficients

are high, indicating a lower amount of error or deviation from linearity. Therefore, in most environments the factors affecting kernel weight also affect test weight in the same direction. Reduction in test weight cannot be attributed to reduction in kernel weight per se. Adverse environmental conditions not only reduce weight of the grain, but may also cause some shriveling of the grain leading to lower packing efficiencies and consequently lower test weights. In some cases environmental factors may alter the conformation and shape of the grain without reducing its weight. Occurrence of rain during the last stage of maturity could not affect weight of the grain significantly but may result in kernel expansion and thus a low test weight. The degree to which this occurs would certainly determine the size of the correlation coefficients.

The correlation coefficients of differences between test weight-flour yield and 1000 kernel weight and flour yield (%) at paired locations appear in Table 4. Location means for flour yield (%), test weight, and 1000 kernel weight are presented in Table 5.

The correlation coefficients obtained for both test weight and kernel weight are inconsistent. A higher flour yield was expected from locations with higher test weight and kernel weight means. This expectation was mainly due to a higher proportion of endosperm from larger sized kernels.

Table 4. Correlation Coefficients Of Differences
Between Test Weight And Flour Yield;
And Of Differences Between 1000 Kernel
Weight And Flour Yield

Pairs of Locations	Test Weight vs. Flour Yield	1000 Kernel Weight vs. Flour Yield
I01 - L41	-0.22	0.65
I01 - H71	0.04	0.46
I01 - B91	0.08	0.53
L41 - H71	0.82	0.52
L41 - B91	0.89	0.79
H71 - B91	0.34	0.02

Table 5. Location Means For Flour Yield, 1000 Kernel
Weight, And Test Weight From 30 Lines
Averaged Over 2 Replications

Location	Flour Yield(%)	1000 Kernel Weight(gms)	Test Weight gms/pycnometer cup
I01	64.86	31.14	34.40
L41	64.98	25.26	32.92
H71	68.21	40.85	38.02
B91	69.31	34.16	37.42

In the previous experiment in which kernels within varieties were separated into different sizes, no definite relation between flour yield and kernel size was established. By considering the first 2 environments as one group (I01 and L41) and the last 2 environments as another group (H71 and B91) the trend is for larger flour yields from locations with high test weight and kernel weight. This grouping represents extremes of locations for test weight and kernel weight and it is not known what the flour yields of the intermediate group would be.

The means of 100 kernel length and 100 kernel width for the 3 locations appear in Table 6. The correlation coefficients between locations for both length and width are presented in Table 7.

Table 6. Mean 100 Kernel Length (cm.) And 100 Kernel Width (cm.) For Locations Obtained From 30 Lines With 1 Replication

	Length	Width
H71	61.32	33.20
I01	59.91	28.58
L41	57.64	26.18

Table 7. Correlation Coefficients Between Locations
For Length And Width of The Kernel

<u>Length</u>				<u>Width</u>			
	H71	I01	L41		H71	I01	L41
H71	1.00			H71	1.00		
I01	0.83	1.00		I01	0.49	1.00	
L41	0.70	0.78	1.00	L41	0.02	0.33	1.00

Although the location H71 is 102% of location I01 in kernel length, it differs substantially (116%) from this location in kernel width. Clark and Bayles (14) stated that kernel length is a genetical character and the kernel reaches its full length several days before maturity. These differences are readily explainable. In H71 and I01 kernels developed and reached their full length. Heavy rains followed by lodging of the lines at maturity in I01 prevented maximum starch formation during the final days of maturation; therefore the seed shrank as moisture content decreased at maturity. The slight decrease of length in I01 compared with H71 could be attributed to the extremely favorable environmental condition at H71 in 1968.

The picture at location L41 was completely different. This location was characterized by plots heavily infested with weeds. This situation resulted in a stress condition for the wheat plants at the very beginning of growth and

all through the whole life of the plants. Prevalence of such continuous environmental stress during the life history of the plant resulted in kernels small in both dimensions. The high correlation coefficients between paired locations for length are indicative of similarity in the pattern of length development under different environments. Such high correlations were not obtained for width. The high correlation obtained between kernel volume (or weight) and kernel width and these results indicates that environment plays an important role in determining kernel volume (or weight). On the other hand length of the grain seems to have higher heritability and any increase in kernel volume or kernel weight (and as a result in yield) due to fertilization, weed control, and other cultural practices is reflected mainly in increasing the width of the grain.

b. Estimation Of Variance Components And Heritability.

The magnitude of variance components for both set A (that includes S51 and L41) and set B (that does not include S51 and L41) are presented in the following table:

Table 8. Estimates Of Variance Components For Test Weight in Set A and Set B.

Set	σ_v^2	σ_{vl}^2	σ_{vy}^2	σ_{vly}^2	σ_e^2	σ_p^2
A	106.46	3.46	5.71	40.68	34.74	191.05
B	87.65	3.13	3.38	19.20	22.76	136.12

For the purpose of comparison between the two sets, each variance component was expressed as percentage of its corresponding total phenotypic variance - σ_p^2 as follows:

Table 9. Variance Components In Set A & Set B Expressed As Percentage Of Their Corresponding Total Phenotypic Variance.

Set	σ_v^2	σ_{vl}^2	σ_{vy}^2	σ_{vly}^2	σ_e^2	σ_p^2
A	.557 (H)	0.018	0.030	0.213	0.181	1.000
B	.644 (H)	0.023	0.025	0.141	0.167	1.000

The data and the analysis of variance appear in Appendix Tables F, G, and H. The differences between the lines are highly significant. The effects of location and year in both sets are highly significant. Among interaction sources of variance, years x lines and locations x lines are not significant in either set but the second order interaction, i.e., lines x locations x years is highly significant in both sets.

Elimination of L41 and S51 from the analyses did not change the results of the analysis of variance. Considering the magnitude of variance components this elimination had a great effect in decreasing the magnitude of σ_{vly}^2 . This is not surprising because the second order interaction as explained by Comstock (16) "...has to be due to one or more aspect of environment for which the pattern of variation

among locations differs from year to year." Plots at locations L41 and S51 were heavily infested with weeds. This was accompanied by some lodging in S51. Competition for nutrients, water, light, and space resulted in stunted plants which produced small shriveled kernels and consequently a low test weight for all lines. The effect of lodging in lowering test weight is a well known phenomenon (17, 33, 43, 59).

Elimination of these 2 locations did not have a major effect either on the value of σ_{vy}^2 or the value of σ_{v1}^2 expressed as percentage of their corresponding total phenotypic variance. The effect on the former was higher because both locations had a similar situation in the same year, 1968. This elimination caused a decrease of about 7 percent in the second order interaction, i.e., σ_{vly}^2 . The magnitude of this component is still higher than σ_{v1}^2 and σ_{vy}^2 , even though these locations have been eliminated.

This high magnitude of σ_{vly}^2 is an indication of differential response of the varieties to different environments. A number of factors exist which affect test weight seriously. Among the lines planted were those which had field resistance to either mildew or leaf rust or both. Prevalence of one or both of these diseases at one location and in one year may have a profound effect in lowering the test weight of susceptible lines in that location and in

that year and would lead to a larger second order interaction variance. This is also true with lodging, a serious problem in rainy seasons. The environment in East Lansing (I01) in 1968 was characterized by heavy rains prior to harvest. This resulted in severe lodging of many lines; however, among the lines used in this study some, such as Arthur, were resistant to lodging. Differential response of the lines to this particular environmental stress may have contributed to a large second order interaction. Shriveling of the kernel is directly related to test weight. Among the lines tested and used for this study some lines like Yorkstar are very sensitive to environmental stress and under such an environment Yorkstar and lines similar to it shrivel drastically and will bring about a differential response.

Test weight is a complex trait and differential response of the components under different environments may result in a differential response with regard to test weight and hence a larger second order interaction (3).

Statistically non-significant locations x lines and years x lines sources of variation and relatively small values of their corresponding variances are indicative of no consistent year and location effect on differential varietal response. Non-significant lines x locations and lines x years sources of variance may result from lines

under study which were either commercial varieties or advanced breeding lines selected for adaptation for many years.

Considering the present results, little is gained by including years and locations in the experiment in a balanced manner. Thus when one considers only test weight in a breeding program, he should include a sample of years and locations which are likely to be encountered and carry the analysis with respect to environment (36, 40).

In any breeding program attention is rarely focused on test weight alone. Yield is of great concern to the breeder and because of significant and large values of σ_{v1}^2 and σ_{vy}^2 for yield, the breeder may have to replicate his trial both in time and space.

Estimates of heritability for single plots for set A and set B are presented in Table 9. Estimations for line means are much larger and are of the magnitude of 0.94 and 0.95 for set A and B, respectively. A lower estimate of heritability for single plots for set A is mainly due to a substantially higher σ_{vly}^2 in this set than in set B. The great amount of difference between the two estimates of heritability --on the basis of single plots and on the basis of variety means is mainly due to the smaller contribution of non-genetic variance to the line means (22).

The estimate based on differences among line means is the characteristic of the environment and sets of material used in this study, while the estimate based on single plots is the characteristic of the trait-test weight (22).

By having such estimates of heritability we would be able to make predictions of gains in any hypothetical population.

These estimates are characteristic of the environments, and sets of materials used. Another experiment with another set of materials under dissimilar environments may result in different estimates of heritability. A knowledge of heritability under any set of environments and known materials would be helpful in arriving at a more efficient selection scheme.

The Effect Of Environment On Test Weight And Its Components

The analysis of variance for test weight, packing efficiency, and density appear in the Appendix Tables I, J and K. The data are presented in the Appendix Table E.

Differences between locations and lines for test weight and its components are significant. Lines x locations interaction source of variation is also significant for test weight and its components. Estimates of variance components for test weight, packing efficiency, and density appear in the following table:

Table 10. Estimates Of Variance Components For
Test Weight, Packing Efficiency, And Density

	σ_v^2	σ_{vl}^2	σ_e^2	σ_p^2
Test Weight	0.6106255	0.5260645	0.1485356	1.2852256
Packing Efficiency	0.3884833	0.2291525	0.0765506	0.6941864
Density	0.0000335	0.0000377	0.0000342	0.0001055

To make comparisons among variance components of test weight and variance components of packing efficiency and density, every variance component was converted into the percentage of its corresponding total phenotypic variance as follows:

Table 11. Estimates Of Variance Components Expressed
As Percentage Of Their Corresponding Phenotypic Variance

	σ_v^2	σ_{vl}^2	σ_e^2	σ_p^2
Test Weight	0.475 (H)	0.409	0.116	1.000
Packing Efficiency	0.560 (H)	0.330	0.110	1.000
Density	0.317 (H)	0.358	0.325	1.000

Heritability estimates for all three factors appear in the first column of the above table. Genetic variance estimates contain interaction variances (2, p. 98, 20, 31)

and as a result larger estimates of heritability should have been obtained. On the other hand, the peculiar characteristic of L41 has led to a larger lines x locations interaction variance and consequently a lower estimate for this parameter resulted. The experiment was not conducted solely to make estimates of heritability, but, within limits, to make a comparison among the variance components of test weight, packing efficiency, and density.

Table 11 shows that the proportion of genetic variance for density is lower than the other two components, i.e., σ_{vl}^2 and σ_e^2 . The variance between plots within locations, σ_e^2 , is greater than the variance of differences between the lines and this may imply a greater effect of micro-environment, sampling error, or error of measurement on density. The range in density among commercial and advanced breeding lines is very narrow and density does not seem to be a varietal characteristic. Low heritability for density obtained in this study supports this idea. The contribution of density as a component to test weight is very low compared with the other component-packing efficiency. Packing efficiency is a varietal characteristic and a major proportion of variability in test weight is being controlled by this component. Taking out the variability due to density and dealing with packing efficiency alone, an increase of about 18 percent in heritability was obtained when compared with test weight.

The heritable portion of test weight is packing efficiency and for genetical studies we should eliminate the density factor and deal only with the former component. For practical purposes and in selection programs test weight should be the basis of selection because of the simplicity involved in measuring this property and because the correlation coefficient between test weight and packing efficiency is very high (0.96).

c. Stability Study

The mean over the three observations for the 22 lines in the 15 environments appear in the Appendix Table F. For the purpose of illustration, the analysis of variance for the regression of individual genotypes on environment are presented only for Genesee and Yorkstar, Tables 12 and 13. The combined analysis of variance for all 22 lines appear in Table 14. Table 15 summarizes the results of the analysis for all the lines under study.

In this analysis the absence of genotype-environment interaction will result in $\hat{\beta} = 0$ and $\beta = 1$. Values of 0 and 1 for these parameters respectively are not necessarily an indication of the absence of genotype-environment interaction. Table 12 shows that with Genesee neither the regression mean square nor the residual mean square are significant, suggesting the absence of genotype-environment interaction for this variety. Eleven of the lines under

Table 12. Analysis Of Variance for Regression Of
Genotype-Environment Interaction Over
Environmental Index For Genesee

Source	DF	MS
Regression	1	3.71 N.S.
Residual	13	31.16 ^{N.S.}
Error	660	49.31

Table 13. Analysis Of Variance For Regression Of
Genotype-Environment Interaction Over
Environmental Index For Yorkstar

Source	DF	MS
Regression	1	407.29**
Residual	13	41.49 ^{N.S.}
Error	660	49.31

Table 14. Combined Regression Analysis For The
22 Lines Planted In 15 Environments

Source	d.f.	ss	MS
Lines	21	26990.70	1285.27**
Environments	14	93978.78	6712.77**
Lines x Env.:	294:	17144.08:	
Heterogeneity between regression	21	6174.65	294.03**
Residual	273	10969.42	40.18 ^{N.S.}
Error	660	32546.00	49.31

Table 15. Average Performance, Slope, And Genotype-
Environmental Relationship Of 22 Lines
Planted In 15 Environments.

Line	Av. Performance	$\beta=1 + \hat{\beta}$	G x E Absent	G x E Present	
				Res.	Reg.
Genesee	414.82	1.029	X		
Avon	412.93	1.185			X
Talbot	414.09	0.856	X		
Monon	414.27	1.106	X		
Arthur	424.95	0.682			X
Reed	430.35	0.428			X
Yorkstar	393.67	1.309			X
A1224	417.35	0.836	X		
A2554	417.47	0.708			X
A2739	416.82	1.347			X
A2747	420.22	0.912	X		
A3116	399.64	1.233		X	
A3136	412.13	0.713			X
A3141	414.27	0.655			X
A4129	394.44	1.066	X		
A4528	397.09	1.102	X		
A5044	417.87	0.850	X		
A5127	408.60	1.124	X		
A5131	412.80	1.147	X		
A5132	411.42	1.374			X
A5134	411.42	1.378			X
A5266	419.89	0.959	X		

study fall into this category and do not show a significant genotype-environment interaction. The stability parameter, β for these lines does not deviate significantly from unity. These results are in agreement with the past experience with these lines. Genesee has been the standard variety over many years and it has been more predictable with respect to environment. Yorkstar and 10 other lines showed a significant genotype-environment interaction whereas most of the genotype-environment interaction for Yorkstar and 9 other lines (with significant genotype-environment interaction) was accounted for by the linear regression on the environmental values. Only one line (A3116) had a significant residual mean square. Nevertheless in the combined analysis in Table 14, the mean square for the residual is not significant, mainly because sum of squares and degrees of freedom are pooled values. Mean square for heterogeneity of regression lines, Table 14, is significant, indicating definite differences among the stability parameter of the lines.

Depending on the breeder's ideal, either criterion of stability, i.e., $\beta = 1$ or $\beta = 0$ may be adopted. If adaptation over a broader range of environments is desired ($\beta=0$) such lines as Reed and Arthur would provide excellent materials. In these lines, above average stability ($\beta<1$) is accompanied by a superior performance over all environments.

This relation also exists among other lines and the regression of average performance over all environments on the stability parameter resulted in a negative but significant correlation. ($r = -.57$). This might be a reflection of the fact that most of the lines under study have been selected over many years for superior performance over a wide range of environments. These results are in contrast to previous reports that the stability parameter is positively correlated to average performance (18, 45). Lines such as Reed and Arthur undoubtedly will show some degree of genotype-environment interaction. This will be mainly due to higher positive interactions in the poorer environments and to a much lesser extent due to negative interactions in the more desirable environments. Variance or standard deviations over all environments might be equally desirable if absolute stability over all environments ($\beta=0$) is sought. To reduce the effect of different means, coefficient of variation may provide a better index of stability.

If complete absence of genotype-environment interaction is desired lines with $\beta=1$ and high D_i should be developed. Such lines will keep their relative performance to other lines in all environments. The D_i was shown to be highly heritable for test weight. The β also has been shown to be a heritable characteristic and it has been reported that selection for β has been effective.

Crosses involving Genesee type for lack of genotype-environment interaction and Reed or Arthur for their performance and selection in the segregating generations for lines with $\beta = 1$ and superior performance may result in lines closer to the breeder's ideal.

3. Inheritance Of Test Weight

Micro-test weight data averaged over 2 replications and the W_r , V_r graph appear in Table 16 and Fig. 3 respectively. The slope of the line (0.97) does not deviate from unity, an indication of the fulfillment of the assumptions underlying the diallel cross analysis. It also suggests that the differences between the parents used in this study are mainly due to additive and dominance effects, a system uncomplicated by inter-allelic interactions. The arrangement of the points representing the parents along the regression line suggest that high test weight parents (Genesee, Avon, and Monon) possess the higher proportion of dominant genes and the other four parents with low test weight (I0113, A4520, A1339, and A1290) possess the highest proportion of recessive genes. There seems to be a definite tendency for high test weight to be dominant over low test weight.

The regression line intersects the W_r axis on the positive side, an indication of partial dominance ($H < D$). As mentioned before, the analysis was based on F_3 seeds

Table 16. F₃ Micro Test Weight (gms per 47 ml. glass jar) For A Set Of
7x7 Diallel Averaged Over 2 Replications

Parental Number	Parent	1	2	3	4	5	6	7	Vr	Wr	Array Mean
1	Genesee	30.895							1.2782	2.0591	29.5136
2	Avon	30.395	29.410						1.0284	2.2924	29.3343
3	Monon	29.895	30.870	31.750					0.6981	1.3269	30.4029
4	IQ113	27.510	28.045	29.040	25.085				2.1043	2.9609	26.7836
5	A4520	28.625	29.100	30.560	26.220	28.465			2.6370	3.7158	28.3343
6	A1339	29.595	28.370	30.425	25.440	26.125	26.340		3.4953	4.0478	27.6750
7	A1290	29.680	29.150	30.280	26.145	29.245	27.430	30.345	2.4222	3.6380	28.8964

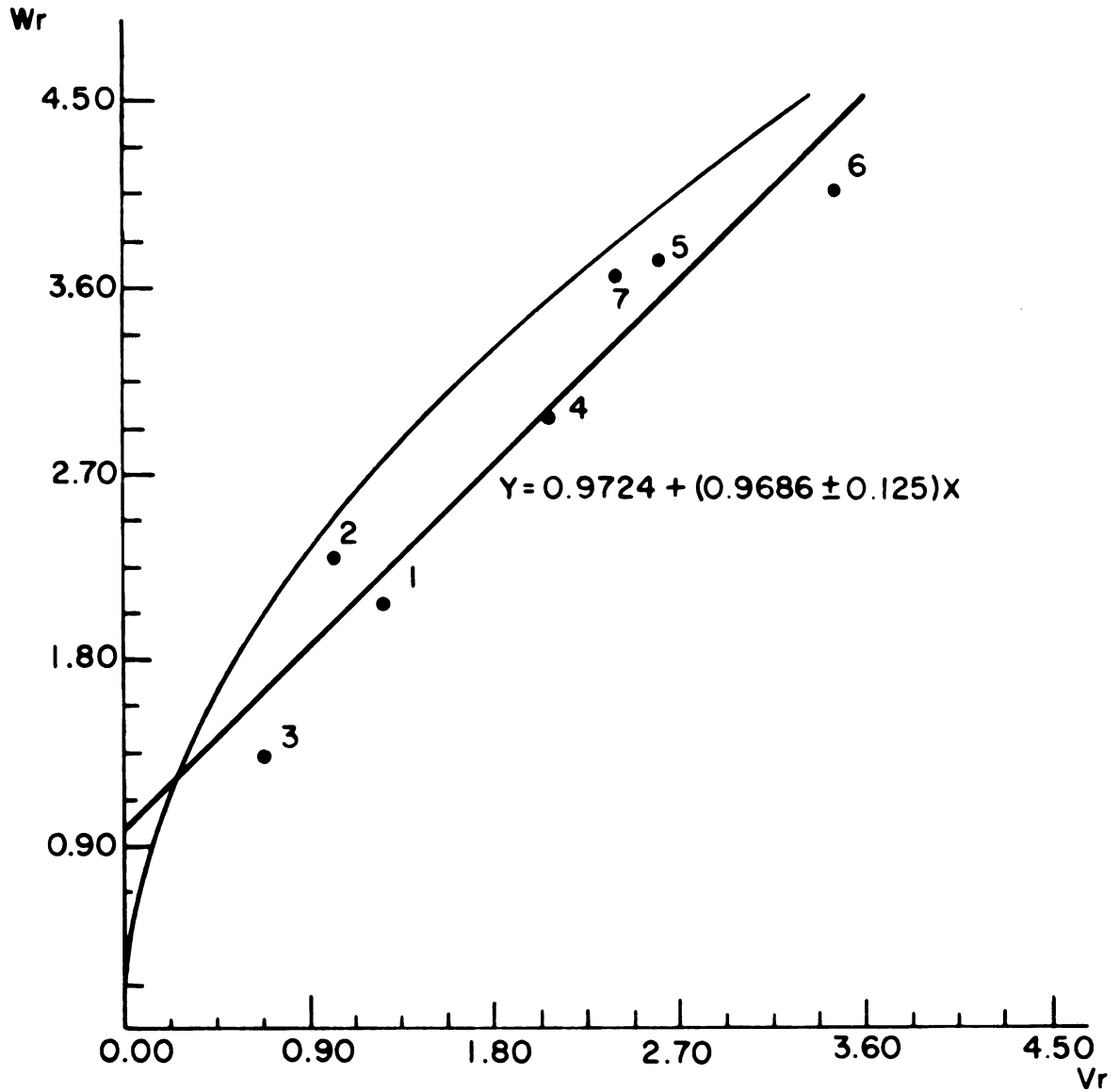


Figure 3. W_r - V_r Graph for Micro-Test Weight From a set of 7x7 Diallel, F_3 .

coming from F_2 plants. Considering the fact that the amount of H at any one generation is halved over the previous generation (29), such a degree of dominance is not surprising. In fact it would have been possible for the previous generations to denote some degree of overdominance ($H > D$). As far as the breeder of self-pollinated crops is concerned, this possibility of initial overdominance has less practical importance, since the potential value of any cross is evaluated by homozygous lines generated from this cross (28).

A W_r , V_r analysis of kernel weight for the same diallel set led to the same general conclusions obtained for test weight. There were, however, very slight changes in the position of points representing each parent. As far as low test weight is associated with shriveling of the kernels, visual evaluation of kernels in earlier generations would be effective in selecting against the genes responsible for shriveling. Large, plump kernels may also give low test weight, because of their intrinsic shape. Past experience has shown that this type of low test weight is of minor consequence. Varieties with this type of low test weight may be as superior as high test varieties in quality features. As the wheat producers are always penalized for low test weight, the breeders are concerned about both types of low test weight. In the case where kernel shape

causes low test weight, visual selection is not feasible. In earlier generations where the amount of seed is not sufficient to run the standard method of test weight determinations, the micro-test weight determinations would be very valuable to the breeder.

Visual selection against shriveled kernels not only improves test weight, but also has a direct effect in increasing yield, because kernel weight is one of the components.

SUMMARY AND GENERAL CONCLUSIONS

Test weight is the product of density and the total volume of the grain in a given unit volume. The latter component expressed as percentage of the volume of the container is referred to as packing efficiency and this component has a much greater effect on test weight than density. Because of the minor importance of density and its narrow range in genetical studies of test weight, the variation due to density should be removed and the analysis should be carried out with respect to packing efficiency. Using the analysis of variance procedure, a definite gain in genetic variance was obtained when the effect of density was removed from the test weight and the data were analyzed with regard to packing efficiency.

A significant but negative correlation was obtained between test weight and length width ratio. Less than 40% of variation in test weight was shown to be associated with length width ratio and the remainder remained unexplained. Within varieties kernel size had no effect on test weight, mainly because shape of the grain remains constant. Kernel shape and degree of shriveling are some of the factors which cause low test weight. Visual selection

in the segregating generations against shriveled kernels and for large plump kernels was suggested to be an effective procedure for improving test weight. Use of micro-test weight would be an effective tool for discrimination against the lines which, because of their shape, give low test weight.

No relationship between flour yield and test weight either between varieties or within varieties was established. Low test weight is either due to shriveling of the grain or intrinsic shape of the kernel. As far as low test weight is reflected by the shape of the grain, no relationship between flour yield and test weight should be expected. Inaccuracy of the small laboratory mill is another factor which adds to the complexity of the relationship between test weight and flour yield. A more definite relationship between protein content of the grain and kernel size within varieties was established. Higher protein content of larger sized kernels is partly due to the fact that the spikelets located in the middle of the spike contain larger kernels with higher protein (35, 37). Within a spikelet, the larger kernels have higher protein contents. Within varieties pearling index was related to kernel size. Harder texture (lower pearling index values) of small sized kernels was attributed to higher proportions of bran endosperm ratios. More elasticity of the bran and its

resistance to attrition was suggested as responsible for such relationship.

As far as the effect of environment on test weight and other properties of the grain is concerned, length of the grain was more resistant to environmental factors at later stages of kernel development. Width of the grain was more vulnerable to environmental changes. Test weight, kernel weight, packing efficiency, density, and flour yield were also affected by environment. With few exceptions, reduction in kernel weight is usually accompanied by reduction in test weight. Reduction in kernel weight per se could not be responsible for reduction in test weight.

Using the analysis of variance procedure, the second order interaction, $V \times Y \times L$, was demonstrated to be highly significant. The first order interactions, i.e., $V \times L$ and $V \times Y$, on the other hand were not significant. In breeding programs, the analysis should include a number of environments which are likely to be encountered. Heritability estimates, both on the basis of single plots and differences among line means were made and a higher value was obtained for the latter than the former. The high heritability estimates obtained in this study suggested that selection for test weight would be effective and will result in favorable amounts of gain in test weight.

Stability analysis for 22 lines under 15 environments revealed that some lines did not show any genotype-environment interaction. Genesee and 10 other lines fell into this category and they were characterized by slopes which did not deviate from unity significantly. Varieties Reed and Arthur showed genotype-environment interactions; however, most of the interaction was accounted for by linear regression on the environmental index. A negative but significant correlation was obtained between the stability parameter, β , and the average performance over all environments. Depending on the breeder's ideal either definition of stability, i.e., $\beta=1$ or $\beta=0$ may be employed. Arthur and Reed represent the ideal types if the absolute stability ($\beta=0$) is sought. In these lines superior performance is accompanied by regression slopes significantly lower than unity. If the other type of stability is desired ($\beta=1$), crosses involving lines with no genotype-environment interaction ($\beta=1$) such as Genesee and superior performance such as Reed or Arthur, would provide initial materials from which lines with high test weight and slope of unity can be selected.

An inheritance study of test weight revealed that a simple genetic system is involved. Additivity and dominance with no complications of epistasis was evident from the analysis.

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APPENDIX

Table A Test Weight (gms/pint), Micro Test Weight (gms/glass jar), 1000 Kernel Weight (gms), Packing Efficiency (%), Density, 1000 Kernel Volume (ml), 100 Kernel Length (cm), 100 Kernel Width (cm), Length Width Ratio, Kernel Protein (%), Pearling Index (%), and Flour Yield (%) for 59 Samples of Wheat Grown in 1968

No.	Test Weight	Micro Test	Kernel Pack Weight	Den.	Kernel Vol.	Kernel Length	Kernel Width	L/W Ratio	Kernel Prot.	Flour Yield
01	442.0	36.24	31.3	1.412	22.2	116.9	59.0	1.981	12.7	63.5
02	425.0	34.87	28.0	1.405	19.9	116.2	58.3	1.993	12.3	62.4
03	419.0	34.34	27.3	1.407	19.4	119.3	56.0	2.130	11.9	63.9
04	438.0	35.86	26.5	1.415	18.7	113.0	57.8	1.955	12.7	63.7
05	432.5	35.23	27.0	1.406	19.2	107.7	59.7	1.804	12.2	63.4
06	431.5	35.26	31.3	1.408	22.2	112.1	59.9	1.871	13.6	65.6
07	426.0	34.81	27.5	1.409	19.5	108.8	58.6	1.857	13.3	61.2
08	417.0	34.21	28.7	1.414	20.3	120.0	59.1	2.030	12.6	62.5
09	432.0	35.28	35.1	1.429	24.6	120.2	63.5	1.893	13.4	63.0
10	434.0	35.34	33.9	1.432	23.7	120.9	62.4	1.937	12.8	62.7
11	434.5	35.53	34.2	1.427	24.0	121.4	62.5	1.942	12.8	63.3
12	434.5	35.54	33.7	1.430	23.6	119.9	62.1	1.931	12.8	64.7
13	436.0	34.62	28.9	1.422	20.3	118.3	60.7	1.949	12.4	63.5
14	434.0	35.46	35.5	1.420	25.0	117.4	64.9	1.809	12.5	61.8
15	414.5	33.99	30.1	1.432	21.0	122.3	59.3	2.062	12.0	62.1
16	404.0	33.10	29.8	1.427	20.9	120.1	58.9	2.039	11.1	60.3
17	409.5	33.69	27.1	1.399	19.4	119.5	56.2	2.126	12.2	57.6
18	432.5	35.62	28.7	1.420	20.2	117.2	57.2	2.049	12.4	65.0
19	425.0	34.92	25.9	1.422	18.2	120.0	55.4	2.166	11.5	64.2
20	429.5	35.02	35.8	1.421	25.2	119.4	64.2	1.860	12.3	70.1

Table A Continued

No.	Test Weight	Micro Test	Kernel Weight	Kernel Pack Eff.	Den.	Kernel Vol.	Kernel Length	Kernel Width	L/W Ratio	Kernel Prot.	Pearl. Index	Flour Yield
21	406.0	33.14	30.3	52.0	1.414	21.4	120.3	60.1	2.002	11.0	52.5	67.9
22	384.0	31.86	26.0	49.1	1.413	18.3	116.8	56.5	2.067	12.3	45.0	65.0
23	399.0	32.72	27.1	50.9	1.422	19.1	120.3	56.6	2.125	12.1	43.3	65.1
24	399.5	32.75	27.8	50.9	1.425	19.5	121.1	56.3	2.151	11.2	43.8	62.4
25	418.5	34.12	33.4	53.8	1.406	23.8	121.9	62.3	1.957	13.1	47.1	64.4
26	395.0	32.51	29.2	49.7	1.428	20.4	122.9	58.3	2.108	12.8	42.4	62.7
27	403.5	32.91	31.1	51.3	1.428	21.8	118.6	60.2	1.970	12.5	43.8	66.4
28	405.5	33.17	33.6	51.5	1.425	23.6	119.0	63.0	1.889	12.3	46.8	65.6
29	412.0	33.64	28.0	53.7	1.397	20.0	117.6	58.4	2.014	12.0	47.2	67.0
30	413.0	33.95	24.1	53.7	1.398	17.2	115.8	54.6	2.121	11.8	45.0	62.7
31	399.5	32.68	32.6	51.5	1.412	23.1	127.8	58.5	2.185	12.4	45.1	63.3
32	401.5	32.79	32.3	51.7	1.405	23.0	127.4	59.0	2.159	12.3	46.9	65.3
33	406.5	32.80	35.7	52.5	1.413	25.3	128.2	62.3	2.058	12.2	48.0	63.9
34	430.0	34.73	34.6	55.0	1.417	24.4	116.4	63.9	1.822	12.0	40.3	66.2
35	397.0	32.64	29.9	50.3	1.428	20.9	123.5	59.8	2.065	12.9	41.4	66.4
36	414.5	33.79	32.3	52.6	1.429	22.6	125.0	60.5	2.066	12.8	38.8	64.0
37	425.5	34.47	35.5	54.0	1.428	24.9	125.6	61.9	2.029	12.6	38.1	66.4
38	425.0	34.45	35.2	54.0	1.430	24.6	123.0	63.3	1.943	12.3	37.4	65.3
39	414.0	33.54	33.1	52.8	1.416	23.4	123.2	61.4	2.008	12.3	43.6	66.7
40	416.5	33.85	34.8	53.3	1.409	24.7	124.0	62.6	1.981	12.6	43.1	66.0

Table A Continued

No.	Test Weight	Micro Test	Kernel Weight	Kernel Pack Eff.	Den.	Kernel Vol.	Kernel Length	Kernel Width	L/W Ratio	Kernel Prot.	Pearl. Index	Flour Yield
41	427.5	34.84	33.6	54.9	1.414	23.8	117.7	62.3	1.889	12.1	40.4	64.9
42	417.0	33.96	31.5	53.2	1.418	22.2	118.3	61.7	1.917	12.1	43.3	67.4
43	426.0	34.60	35.3	54.8	1.417	24.9	117.8	64.7	1.821	11.8	44.5	69.2
44	428.0	34.99	33.1	54.9	1.417	23.4	122.7	61.9	1.982	12.4	37.0	61.8
45	420.0	34.17	31.4	53.7	1.410	22.3	117.4	61.9	1.897	12.0	49.9	63.9
46	424.5	34.64	34.4	54.7	1.405	24.5	118.2	62.3	1.897	11.5	50.4	64.1
47	429.0	35.03	33.1	55.0	1.415	23.4	116.3	62.9	1.849	12.1	45.4	69.1
48	424.0	34.39	38.4	54.5	1.407	27.3	122.8	65.5	1.875	12.0	52.9	69.7
49	408.5	33.30	31.3	52.2	1.413	22.2	123.4	59.7	2.067	12.1	49.5	64.9
50	415.5	33.88	31.8	53.6	1.406	22.6	118.2	62.3	1.897	12.1	52.8	64.4
51	417.5	33.93	32.5	53.2	1.413	23.0	121.1	62.3	1.944	12.0	52.1	68.7
52	415.5	33.77	34.2	53.8	1.399	24.4	124.6	62.9	1.981	12.2	52.9	68.7
53	416.5	33.91	30.2	53.6	1.404	21.5	117.6	61.5	1.912	11.7	50.9	65.3
54	421.0	34.33	33.3	54.0	1.408	23.7	123.5	64.0	1.929	12.2	51.0	69.4
55	441.5	35.91	35.7	55.9	1.428	25.0	121.8	64.8	1.880	11.8	40.4	65.6
56	436.0	35.37	33.7	55.0	1.432	23.5	120.0	62.1	1.932	11.8	41.0	67.4
57	439.5	35.77	31.5	55.6	1.428	22.1	117.8	61.3	1.922	12.0	39.6	62.7
58	436.5	35.59	30.5	55.4	1.428	21.4	119.7	61.3	1.953	11.3	37.3	64.1
59	430.0	35.08	34.1	54.7	1.425	23.9	121.3	62.9	1.928	11.0	40.9	65.4

Table B Test Weight (gms/pint) for the Mean of 3 Replications of 30 Lines of Wheat at 7 Locations in 1968

No.	Line	Site						
		T61	H71	K81	B91	I01	S51	L41
01	Genesee	423.33	436.67	433.00	431.00	411.67	372.00	378.00
02	Avon	421.67	437.00	432.00	431.00	400.33	364.00	370.00
03	Talbot	411.67	421.67	431.67	430.67	417.33	372.67	379.00
04	Monon	428.33	447.67	413.67	431.67	384.00	391.00	363.00
05	Arthur	434.00	452.33	427.00	436.00	420.67	408.67	396.00
06	Reed	435.33	450.33	428.33	435.33	423.00	413.33	419.00
07	Yorkstar	413.00	423.00	416.33	417.33	377.33	366.67	392.33
08	A1224	423.67	438.00	425.00	431.33	414.33	379.00	388.67
09	A2554	427.00	439.67	429.67	427.00	408.33	396.67	390.67
10	A2739	428.00	443.00	427.00	434.67	398.67	368.33	358.00
11	A2747	427.33	443.00	424.67	431.00	413.33	378.33	388.33
12	A3116	411.67	423.67	417.00	421.67	384.33	381.33	329.33
13	A3136	426.00	438.33	420.67	424.33	402.33	403.33	378.33
14	A3141	424.67	439.33	422.33	424.00	406.67	399.00	387.67
15	A4129	409.33	417.33	403.33	411.33	380.67	363.33	346.00
16	A4528	412.00	426.33	411.00	411.00	386.00	361.00	349.33
17	A5044	430.67	446.67	426.00	427.67	407.67	393.00	386.00
18	A5127	422.67	430.67	429.33	427.67	405.33	380.00	353.00
19	A5131	423.67	436.00	432.67	430.33	390.00	380.33	363.00
20	A5132	424.00	433.67	433.33	429.67	407.00	356.00	351.00
21	A5134	423.67	435.33	432.00	429.67	415.00	353.67	350.00
22	A5266	427.67	441.00	437.33	436.33	413.67	398.67	369.67
23	A6624	441.00	454.67	426.67	442.33	426.33	414.67	399.33
24	A6625	433.67	443.33	431.33	436.33	418.67	402.33	385.67
25	A6626	431.00	445.00	430.33	438.33	414.00	401.67	378.00
26	A6628	444.67	457.33	434.67	443.67	421.00	410.67	396.00
27	A6629	435.33	447.00	433.67	435.33	415.67	410.00	389.67
28	A6630	438.00	452.67	436.33	436.00	419.00	415.00	406.33
29	A6631	436.33	451.67	432.67	438.67	413.67	404.67	389.67
30	A6632	436.00	452.67	426.33	435.33	405.33	402.00	384.00

Table C 1000 Kernel Weight (gms) for the Mean of 3 Replications of 30 Lines of Wheat at 7 Locations in 1968

No.	Line	Site						
		T61	H71	K81	B91	I01	S51	L41
01	Genesee	40.96	43.96	40.82	35.74	33.80	28.45	26.94
02	Avon	40.65	44.16	39.90	37.10	31.53	27.30	25.71
03	Talbot	35.77	37.59	39.66	37.08	33.58	26.25	25.99
04	Monon	32.38	36.00	29.63	30.27	24.06	26.78	21.46
05	Arthur	37.50	41.14	35.13	34.81	34.18	32.97	26.62
06	Reed	39.89	43.53	36.03	34.94	33.07	35.65	32.07
07	Yorkstar	36.78	37.64	36.38	34.44	27.72	28.72	20.70
08	A1224	34.73	38.34	32.25	31.45	31.93	26.35	24.85
09	A2554	40.61	44.00	38.96	34.95	33.43	34.90	28.45
10	A2739	42.31	46.44	38.10	37.33	33.94	29.40	25.63
11	A2747	35.34	39.56	32.61	32.56	32.32	26.12	25.30
12	A3116	36.01	38.20	35.61	34.73	28.85	29.67	20.13
13	A3136	37.11	41.28	37.15	35.52	30.78	34.11	25.77
14	A3141	36.30	40.14	34.56	33.53	28.83	30.83	25.56
15	A4129	34.35	36.51	34.57	34.40	28.88	27.38	21.83
16	A4528	36.65	39.87	36.09	34.74	30.81	27.64	23.07
17	A5044	36.06	39.43	35.19	32.23	29.82	29.29	24.80
18	A5127	44.48	46.80	41.21	39.52	36.66	33.22	25.77
19	A5131	42.42	44.52	41.04	37.01	29.71	30.64	25.44
20	A5132	40.36	43.19	39.14	35.11	31.51	26.04	22.77
21	A5134	40.99	43.86	40.41	35.80	33.56	26.50	23.03
22	A5266	39.24	41.70	37.51	35.93	31.44	30.70	24.00
23	A6624	35.55	40.22	32.28	34.51	31.15	31.32	25.19
24	A6625	36.36	39.29	32.71	31.66	30.85	31.12	26.75
25	A6626	33.34	37.35	32.03	31.32	29.16	28.96	21.95
26	A6628	34.80	39.37	33.15	32.59	30.94	30.00	23.13
27	A6629	33.19	37.54	31.31	29.83	26.38	29.82	21.92
28	A6630	39.10	41.44	34.38	32.60	31.81	32.55	26.78
29	A6631	32.83	37.20	32.10	31.12	28.51	28.35	21.74
30	A6632	34.39	39.23	32.43	34.41	27.69	27.89	22.48

Table D 100 Kernel Length (cm) and 100 Kernel Width (cm)
for 30 Lines Planted in 3 Locations
in 1968

No.	Line	Length			Width		
		H71	I01	L41	H71	I01	L41
01	Genesee	61.0	60.5	59.1	33.9	28.6	27.2
02	Avon	60.6	59.1	55.7	34.6	27.1	24.7
03	Talbot	61.0	59.8	56.7	32.6	29.8	26.1
04	Monon	59.0	58.4	57.6	31.8	26.6	27.0
05	Arthur	60.2	59.6	57.4	33.5	29.5	28.1
06	Reed	65.8	65.0	61.4	32.3	27.6	27.4
07	Yorkstar	61.4	59.9	56.7	32.7	26.1	22.3
08	A1224	60.9	59.2	55.3	34.0	29.5	25.9
09	A2554	61.1	59.0	58.9	34.2	28.3	26.6
10	A2739	63.7	63.0	61.5	35.7	29.6	27.1
11	A2747	61.9	62.0	58.8	33.8	30.0	26.8
12	A3116	61.1	60.7	56.2	32.5	28.0	23.9
13	A3136	61.8	60.4	58.8	32.7	28.4	26.3
14	A3141	60.6	58.3	58.6	33.8	29.2	28.4
15	A4129	61.5	62.3	60.2	31.4	27.6	25.1
16	A4528	63.3	63.3	60.3	33.3	28.7	25.7
17	A5044	59.5	60.3	59.2	33.3	29.8	28.5
18	A5127	64.5	62.5	59.2	35.8	32.3	26.0
19	A5131	65.2	62.9	59.7	34.4	29.1	24.9
20	A5132	64.8	60.0	60.5	33.7	26.4	25.3
21	A5134	63.9	61.0	56.9	34.5	28.5	23.2
22	A5266	61.5	59.7	56.6	34.2	28.8	25.9
23	A6624	60.5	56.5	56.1	32.5	28.7	27.8
24	A6625	59.6	58.0	56.8	32.3	28.6	27.4
25	A6626	59.0	58.2	55.8	31.7	29.3	24.4
26	A6628	59.8	58.8	55.5	32.4	29.6	26.1
27	A6629	58.9	57.6	57.3	31.1	26.3	26.6
28	A6630	58.6	56.0	53.3	33.7	29.3	28.4
29	A6631	59.5	57.4	54.6	31.6	28.7	26.2
30	A6632	59.3	57.9	53.6	32.0	27.4	26.1

Table E. Micro Test Weight (gms/air comparison pycnometer cup), Volume of the Grains Occupying the Air Comparison Pycnometer Cup (ml), Density, and Flour Yield (%), Averages of 2 Replications for 30 Lines of Wheat at Different Locations

No. Line	Micro Test Weight				Volume*				Density				Flour Yield			
	L41	H71	B91	L41	H71	B91	L41	H71	B91	L41	H71	B91	L41	H71	B91	I01
01 Genesee	32.84	37.40	37.40	23.42	26.49	26.31	1.402	1.412	1.422	64.80	67.10	68.85	65.20			
02 Avon	33.72	37.48	37.32	23.84	26.50	26.23	1.414	1.410	1.423	66.90	69.40	70.55	66.00			
03 Talbot	33.37	36.60	37.59	23.52	25.89	26.45	1.419	1.413	1.421	66.05	69.50	70.60	67.35			
04 Monon	31.78	38.59	37.25	23.05	27.11	26.41	1.379	1.423	1.410	65.95	69.55	70.65	64.85			
05 Arthur	34.49	38.45	37.75	24.51	27.12	26.76	1.407	1.417	1.410	68.15	68.55	71.05	65.95			
06 Reed	36.19	38.76	37.98	25.39	27.33	26.77	1.425	1.418	1.419	68.20	67.95	69.80	66.10			
07 Yorkstar	29.60	36.60	36.63	21.00	25.94	25.80	1.409	1.411	1.420	60.60	68.25	68.60	62.60			
08 A1224	34.39	37.92	37.81	24.44	26.68	26.62	1.407	1.421	1.421	65.85	67.55	68.40	64.60			
09 A2554	34.64	38.04	37.19	24.72	26.90	26.31	1.401	1.414	1.413	67.85	69.05	69.70	65.45			
10 A2739	31.93	38.18	37.66	22.70	27.12	26.57	1.407	1.408	1.417	62.40	67.85	68.35	62.40			
11 A2747	33.40	38.12	37.52	23.68	26.88	26.41	1.411	1.418	1.421	65.45	68.05	69.70	65.05			
12 A3116	29.14	36.97	37.16	20.65	26.23	26.24	1.411	1.409	1.416	60.55	67.60	69.15	63.15			
13 A3136	33.11	37.93	36.90	23.51	26.78	25.97	1.408	1.417	1.141	64.80	66.85	67.80	64.65			
14 A3141	33.49	37.73	36.99	23.86	26.78	26.27	1.404	1.409	1.408	65.25	67.55	68.90	64.10			
15 A4129	30.55	36.48	36.31	21.80	25.75	25.66	1.401	1.417	1.415	62.25	67.00	69.25	61.21			

*Volume of the grains occupying the air comparison pycnometer cup

Table E Continued

No. Line	Micro Test Weight			Volume*			Density			Flour Yield			
	L41	H71	B91	L41	H71	B91	L41	H71	B91	L41	H71	B91	101
16 A4528	30.50	36.83	35.95	21.74	26.09	25.50	1.402	1.412	1.410	64.00	68.30	69.35	63.30
17 A5044	33.55	38.44	37.17	24.04	27.26	26.42	1.396	1.410	1.407	66.40	68.55	70.70	65.45
18 A5127	31.46	37.46	37.13	22.53	26.43	26.19	1.396	1.417	1.418	62.80	66.00	67.70	61.35
19 A5131	32.33	37.65	37.29	22.79	26.50	26.27	1.418	1.421	1.419	62.40	66.55	67.35	60.40
20 A5132	30.97	37.69	37.37	21.90	26.56	26.30	1.414	1.419	1.421	61.10	66.00	67.30	63.15
21 A5134	31.93	37.62	37.30	22.54	26.62	26.19	1.416	1.414	1.424	60.95	65.85	68.40	63.50
22 A5266	32.99	38.15	38.06	23.37	27.04	26.89	1.412	1.411	1.415	64.00	67.25	69.30	64.35
23 A6624	34.51	39.19	38.17	24.77	27.79	27.34	1.393	1.410	1.396	66.45	69.45	69.65	67.00
24 A6625	33.38	38.36	37.77	23.99	27.24	27.00	1.392	1.408	1.394	66.50	69.30	69.05	68.15
25 A6626	33.28	38.62	37.80	23.73	27.21	26.93	1.402	1.420	1.404	66.40	68.45	69.30	66.75
26 A6628	34.55	39.57	38.32	24.71	27.96	27.45	1.398	1.415	1.396	65.95	69.60	69.65	66.70
27 A6629	33.64	38.71	37.52	24.01	27.31	26.90	1.401	1.417	1.395	66.60	69.85	71.10	65.75
28 A6630	35.15	38.97	37.84	25.10	27.64	27.33	1.401	1.410	1.385	67.50	70.15	69.65	67.80
29 A6631	33.59	39.14	37.98	24.21	27.67	27.05	1.387	1.415	1.404	66.65	69.55	69.75	66.90
30 A6630	33.01	38.90	37.55	23.95	27.58	27.07	1.379	1.410	1.387	66.75	70.30	69.80	65.70

*Volume of the grains occupying the air comparison pycnometer cup

Table F Test Weight For 22 Lines Averaged Over 3 Replications Per Environment
And Environmental Means Over 22 Lines
(gms per pint)

Env.	Env.	Mean	York-									
			Genesee	Avon	Talbot	Monon	Arthur	Reed	Star	A1224	A2554	A2739
167	409.53	411.33	413.33	417.00	417.33	427.00	428.33	388.67	411.00	411.33	421.67	421.67
L67	411.97	414.00	414.67	417.67	415.67	419.00	426.33	394.33	416.33	415.33	421.00	423.67
S67	407.71	403.33	403.33	412.00	409.00	415.67	426.33	382.00	412.00	413.00	413.33	410.00
T67	419.85	425.00	424.67	421.00	422.00	427.33	433.33	398.33	427.33	415.00	429.00	432.67
H67	417.64	412.67	420.00	416.67	427.67	423.33	441.33	391.00	430.67	418.67	429.33	429.00
K67	414.67	415.00	411.33	413.33	417.67	423.67	427.33	401.67	424.33	414.67	421.33	426.00
B67	419.70	425.67	424.67	419.67	422.67	429.67	434.33	404.67	422.33	422.00	428.00	432.00
168	403.08	411.67	400.33	417.33	384.00	420.67	423.00	377.33	414.33	408.33	398.67	413.33
L68	369.24	378.00	370.00	379.00	363.00	396.00	419.00	329.33	388.67	390.67	358.00	388.33
S68	381.14	372.00	364.00	372.67	391.00	408.67	413.33	366.67	379.00	396.67	368.33	378.33
T68	423.15	423.33	421.67	411.67	428.33	434.00	435.33	413.00	423.67	427.00	428.00	427.33
H68	436.39	436.67	437.00	421.67	447.67	452.33	450.33	423.00	438.00	439.67	443.00	443.00
K68	425.15	433.00	432.00	431.67	413.67	427.00	428.33	416.33	425.00	429.67	427.00	424.67
B68	427.73	431.00	431.00	430.67	431.67	436.00	435.33	416.67	431.33	427.00	434.67	431.00
M67	421.67	429.67	426.00	429.33	422.67	434.00	433.33	402.00	416.33	433.00	431.00	422.33

Table F Continued

Env.	A3116	A3136	A3141	A4129	A4528	A5044	A5127	A5131	A5132	A5134	A5266
I67	399.67	408.33	406.00	393.67	399.67	407.67	393.67	402.00	410.33	411.33	408.67
L67	405.33	403.33	412.33	399.00	399.33	414.33	411.33	407.00	406.67	409.00	417.67
S67	393.33	407.67	411.33	384.33	391.33	407.33	407.33	417.67	420.00	417.33	415.00
T67	406.67	415.00	416.33	404.00	399.33	425.33	417.00	429.00	423.33	418.33	426.67
H67	386.00	417.00	412.67	392.00	399.00	431.33	413.00	424.00	423.67	423.00	426.00
K67	408.67	408.67	412.33	403.33	404.33	417.67	408.67	415.33	412.67	417.00	417.67
B67	411.00	416.67	416.67	410.67	405.67	420.67	411.67	418.33	420.00	412.00	424.33
I68	384.33	402.33	406.67	380.67	386.00	407.67	405.33	390.00	407.00	415.00	413.67
L68	329.33	378.33	387.67	346.00	349.33	386.00	353.00	363.00	351.00	350.00	369.67
S68	381.33	403.33	399.00	363.33	361.00	393.00	380.00	380.33	356.00	353.67	403.33
T68	411.67	426.00	424.67	409.33	412.00	430.67	422.67	423.67	424.00	423.67	427.67
H68	423.67	438.33	439.33	417.33	426.33	446.67	430.67	436.00	433.67	435.33	441.00
K68	417.00	420.67	422.33	403.33	411.00	426.00	429.33	432.67	433.33	432.00	437.33
B68	421.67	424.33	424.00	411.33	411.00	427.67	427.67	430.33	429.67	429.67	436.33
M67	415.00	415.00	422.67	398.33	401.00	426.00	417.67	422.67	420.00	424.00	433.33

Table G Analysis of Variance Table for Test Weight (gms per pint)
for 16 Lines Replicated 3 Times in 2 Years
and 7 Locations

Source	DF	MS	EMS
Year (Y)	1	3881.2872**	
Location (L)	6	19083.8606**	
Y x L	6	10506.5580**	
Replication Within Y and L (R)	28		
Line (V)	15	4768.9793**	$\sigma_e^2 + 3\sigma_{vly}^2 + 21\sigma_{vy}^2 + 6\sigma_{v1}^2 + 42\sigma_v^2$
V x Y	15	276.6555 N.S.	$\sigma_e^2 + 3\sigma_{vly}^2 + 21\sigma_{vy}^2$
V x L	90	177.5839 N.S.	$\sigma_e^2 + 3\sigma_{vly}^2 + 6\sigma_{v1}^2$
V x Y x L	90	156.7892**	$\sigma_e^2 + 3\sigma_{vly}^2$
V x R within Y & L	420	34.7425	σ_e^2
Total	671		

Table H Analysis of Variance Table for Test Weight (gms per pint)
for 16 Lines Replicated 3 Times in 2 Years
and 5 Locations

Source	DF	MS	EMS
Year (Y)	1	4224.5333**	
Location (L)	4	5462.4500**	
Y x L	4	2727.6687**	
Replication Within Y and L (R)	20		
Line (V)	15	2779.2488**	$\sigma_e^2 + 3\sigma_{vly}^2 + 6\sigma_{vl}^2 + 15\sigma_{vy}^2 + 30\sigma_v^2$
V x Y	15	131.0178 N.S.	$\sigma_e^2 + 3\sigma_{vly}^2 + 15\sigma_{vy}^2$
V x L	60	99.1544 N.S.	$\sigma_e^2 + 3\sigma_{vly}^2 + 6\sigma_{vl}^2$
V x Y x L	60	80.3532**	$\sigma_e^2 + 3\sigma_{vly}^2$
V x R within Y & L	300	22.7597	σ_e^2
Total	479		

Table I Analysis of Variance Table for Packing Efficiency
for 30 Lines Replicated 2 Times
In 3 Locations

Source	DF	MS	EMS
Location (L)	2	213.59896157**	
Rep. (R)	3	0.2010	
Line (V)	29	2.86575644**	$\sigma_e^2 + 2\sigma_{v1}^2 + 6\sigma_v^2$
V x L	58	0.53485603**	$\sigma_e^2 + 2\sigma_{v1}^2$
V x R = Error	87	0.076551	σ_e^2
Total	179		

Table J Analysis of Variance Table for Density
for 30 Lines Replicated 2 Times
In 3 Locations

Source	DF	MS	EMS
Location (L)	2	0.00171554**	
Rep. (R)	3	0.001034	
Line (V)	29	0.00031053**	$\sigma_e^2 + 2\sigma_{v1}^2 + 6\sigma_v^2$
V x L	58	0.00010975**	$\sigma_e^2 + 2\sigma_{v1}^2$
V x R = Error	87	0.00003425	σ_e^2
Total	179		

Table K Analysis of Variance Table for Test Weight
for 30 Lines Replicated 2 Times
in 3 Locations

Source	DF	MS	EMS
Location (L)	2	466.6457**	
Rep. (R)	3		
Line (V)	29	4.8644**	$\sigma_e^2 + 2\sigma_{vl}^2 + 6\sigma_v^2$
V x L	58	1.2007**	$\sigma_e^2 + 2\sigma_{vl}^2$
V x R = Error	87	0.1485	σ_e^2
Total	179		

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