Soft Wheat Milling and Baking Quality in a Soft Red Winter × Hard Red Winter Wheat Population[1]

L. MAY,[2] D. A. VAN SANFORD,[2] and P. L. FINNEY[3]

Cereal Chem. 66(5):378–381

ABSTRACT

A single-cross soft red winter × hard red winter wheat population was evaluated in the F_3, F_4, and F_5 generations for preliminary soft red winter wheat milling and baking quality. Tests conducted included the softness equivalence (SE), adjusted flour yield, grain protein concentration (GPC), alkaline water retention capacity, and cookie diameter. Some of the progeny possessed low alkaline water retention capacity and GPC and high SE and adjusted flour yield, indicating acceptable preliminary soft red winter wheat milling and baking quality. Narrow sense heritability estimates for these traits were low but generally significant, ranging from 0.05 for GPC to 0.47 for SE. The results of the present study suggest that quality constraints may not preclude the use of hard wheat cultivars in soft wheat breeding programs as sources of new germ plasm.

Soft red winter (SRW) and hard red winter (HRW) wheat are distinct market classes having milling and baking properties conditioning each for use in specific products (Yamazaki et al 1981). Hard red winter wheat is noted for high grain protein concentration (GPC) and hard kernel texture, which yields a flour suitable for use in bread. Soft red winter wheat is characterized by low GPC and soft kernel texture making the flour suitable for use in products such as cookies, crackers, and cakes (Barmore and Bequette 1968).

Populations derived from HRW × SRW crosses have not been extensively studied for soft wheat milling and baking quality. Beard and Poehlman (1954), in a study of six HRW × SRW wheat populations, found that 15–35% of the segregates were classified as soft textured. Davis et al (1960) demonstrated gains from selection for soft kernel texture, low GPC, and high grain yield in three HRW × SRW populations. Kernel texture was determined by the pearling index (Taylor et al 1939). Gyawali et al (1968) studied the F_1 generation resulting from crosses between SRW and HRW wheats for milling and baking quality. None of the hybrids possessed acceptable SRW wheat milling and baking quality. More recently, a protein associated with endosperm softness was identified (Greenwell and Schofield 1986). In a study of 100 wheat cultivars, all of the soft wheats possessed this protein, whereas it was lacking or nearly so in the hard wheats. Results of earlier studies also suggested relatively simple inheritance of kernel hardness (Doekes and Belderok 1976, Symes 1965). However, Symes (1965) reported minor genes modifying the action of the major gene controlling kernel hardness.

Several reasons can be cited for introducing HRW wheat genotypes into a SRW wheat breeding program. One is the creation of new gene combinations unavailable through crosses among genetically related SRW wheat genotypes. It is known that the HRW wheat cultivar TAM 105 used as a parent in the present study is genetically distinct from the SRW wheat parent Tyler (Cox et al 1985). Another reason for utilizing HRW × SRW wheat crosses is the potential for the introduction of desirable traits of HRW wheat cultivars such as extreme winter hardiness, which is not found in most SRW wheat cultivars grown in the southeastern United States. Winter hardiness is an important trait for SRW wheat genotypes grown in Kentucky. Because snow cover is frequently lacking in Kentucky winters, the combination of low temperatures and wind may kill unadapted genotypes. However, success in utilizing HRW wheat cultivars in an SRW wheat breeding program ultimately depends on the recovery of progeny with acceptable SRW wheat milling and baking quality.

The objectives of this research were to: 1) determine if a single cross SRW × HRW wheat population could yield any lines with acceptable SRW wheat milling and baking quality, and 2) estimate heritability of milling and baking quality traits.

MATERIALS AND METHODS

Field Experiments

Lines in the F_3, F_4, and F_5 generations from the cross of the SRW wheat cultivar Tyler and the HRW wheat cultivar TAM 105 were evaluated for preliminary milling and baking quality. The experiment was conducted at the Spindletop research farm near Lexington, KY.

Ninety-two F_3 families were planted in rows 0.45 m in length on 7 November 1984. Two F_3 family rows and one row of each parent were planted 0.3-m apart to comprise a range in an experimental design similar to the augmented design of Federer (1961). Nitrogen, as ammonium nitrate, was applied at a rate of 100 kg N/ha in split applications of 33 and 67 kg/ha at Feekes growth stages 6 and 9, respectively (Large 1954). All rows were bulk harvested at maturity. The bulk harvested F_4 seed was planted in the same design as that of the F_3 experiment on 17 October 1985. Similar agronomic practices were followed as in the F_3 experiment. The severe winter of 1986 resulted in the loss of 30 F_4 lines and all but two of the Tyler check rows. Consequently, quality analysis and heritability estimates, which required both parent and offspring data, were based on 62 F_3 and F_4 progeny.

On the basis of superior agronomic performance in the F_4 generation, 27 lines were selected to advance to the F_5 generation. The 27 F_5 lines were seeded at a rate of 100 kg/ha in plots comprised of six rows, 3 m in length, with 0.18 m between rows on 23 October 1986. Similar agronomic practices were followed as in the F_3 and F_4 experiments. Plots were combined for yield at maturity.

Milling and Baking Quality Evaluation

Grain samples of the F_3, F_4, and F_5 lines were submitted to the USDA soft wheat quality lab for preliminary milling and baking quality evaluations. Milling quality was evaluated from the results of the flour yield test as described by Finney and Andrews (1986). In the F_3 and F_4 generations, flour yields were adjusted to reflect wheat ground at 14% moisture and were expressed as percent adjusted flour yield. In the F_5 generation, the wheat was first tempered to 14% moisture, then ground, and the results were expressed as adjusted flour yield. Baking quality was estimated from the results of grain protein, alkaline water retention capacity (AWRC), and softness equivalence (SE). Grain protein concentration was determined by the Kjeldahl method

[1]Contribution from the Dept. of Agronomy, University of Kentucky, Lexington and the USDA-ARS, Wooster, OH. The investigation reported in this paper (88-3-245) is in connection with a project of the Kentucky Agric. Exp. Stn. and is published with the approval of the director.

[2]Graduate research assistant and associate professor, respectively, Dept. of Agronomy, University of Kentucky, Lexington, KY 40546-0091.

[3]Research chemist, USDA-ARS Soft Wheat Quality Lab, OARDC, Wooster, OH 44691.

(Bradstreet 1965). The F_3 and F_4 lines produced less than the 40 g of flour required for the sugar snap cookie test (AACC 1983). Therefore, only the 27 F_5 lines grown in plots in 1987 were evaluated by this test. The AWRC was determined as described by Yamazaki et al (1968). Softness equivalence was determined after Finney and Andrews (1986).

Milling and baking quality scores of experimental lines (F_3, F_4, and F_5 generations) were expressed as a percentage of the score of a standard cultivar in accordance with test procedures of the USDA soft wheat quality lab. In the present study, the standard cultivar was Tyler. The combined quality score was defined as the lesser of the milling and baking quality scores.

Statistical Analysis

Narrow sense heritability of traits was estimated by parent offspring regression and the standard unit method (Frey and Horner 1957). Heritability estimates were subsequently corrected for inbreeding in and coancestry between parents and progeny by the method of Smith and Kinman (1965). Means and standard deviations of traits were also calculated. Relationships among traits of interest within a generation were tested by simple linear correlation. The significance of differences between the progeny and Tyler for milling and baking quality traits was only determined in the F_3 generation. Deviations of the F_3 families from the Tyler mean in 1985 were considered significant where the differences exceeded two standard errors. Due to winter kill in 1986, only two Tyler entries survived to produce sufficient grain for testing. The quality of the grain was poor and was not indicative of superior soft wheat quality. In 1987, only one Tyler entry was tested, hence no standard error could be computed.

RESULTS AND DISCUSSION

Components of Quality

Adjusted flour yield (AY) is the amount of flour produced by a given amount of grain, corrected to 14% moisture, and is thus one measure of milling quality. The AY means of the progeny of Tyler × TAM 105 varied little over the three years of the study (71.0–72.6%, Table I) compared with the range in Tyler (71.1–72.9%). In 1985, 12 F_3 families were not significantly different from Tyler for AY. In 1987, AY in 10 F_5 families was greater than or equal to AY of Tyler (data not shown).

The cookie spread test developed by Finney et al (1950) is an accepted measure of soft wheat baking quality. Increased cookie spread is associated with superior soft wheat baking quality. However, in early generations, grain yields may be insufficient to perform this test. Thus, the AWRC test was developed to measure soft wheat baking quality on small amounts of grain. Alkaline water retention capacity is strongly negatively correlated with cookie spread (Yamazaki 1953, Yamazaki and Donelson 1972) thus, low AWRC values are desirable for an SRW wheat flour. In 1985, five F_3 families were not significantly different from Tyler for AWRC (data not shown). As a result of poor quality grain produced by the Tyler entries in 1986, the AWRC mean of Tyler was 8.4% higher than in 1985 (Table I). This made Tyler a lenient standard for AWRC in 1986. Hence the finding of 56 F_4 families with AWRC values less than the mean Tyler value in 1986 has little significance. In 1987, only three F_5 families had AWRC values similar to Tyler (data not shown).

The softness equivalence (SE) has replaced the particle size index (Worzella and Cutler 1939) as an estimate of kernel hardness (Finney and Andrews 1986). High SE values are associated with superior soft wheat baking quality, thus it was encouraging to find lines with SE values similar to those of Tyler. In 1985, three F_3 families had SE values not significantly different from Tyler (data not shown). Five F_5 lines had SE values similar to Tyler in 1987. Additionally, the distribution of SE was similar in the F_3 and F_4 generations but was skewed in the direction of increased SE in the F_5 generation (Fig. 1).

Low grain protein concentration (GPC) in SRW wheat is associated with tenderness in some finished products (Yamazaki et al 1981). In 1985, five F_3 families had GPC not significantly different from Tyler, while in 1987 13 F_5 lines had GPC less than Tyler (data not shown).

A high combined quality score (CQS) results from superior performance in both the milling and baking quality tests. The value of the CQS is to ensure equal selection pressure in breeding programs for both milling and baking quality. This statistic as well as AY, SE, AWRC, and GPC are guidelines to be used by breeders in the selection of progeny for continued testing. Because the performance in the quality tests of the two Tyler entries in 1986 was poor (Table I), Tyler was a lenient standard. Thus, comparisons with Tyler are not meaningful. The fact remains, however, that in the F_3 and F_5 generations there were progeny with CQS similar to those of Tyler (seven and four lines, respectively).

AY was negatively correlated with SE in 1985 ($r = -0.59$, $P < 0.01$), 1986 ($r = -0.23$, ns), and 1987 ($r = -0.73$, $P < 0.01$) indicating that flour yield decreased as softness of the endosperm increased (Tables II and III). Significant negative correlations between SE and AWRC in 1985 ($r = -0.46$, $P < 0.01$), 1986 ($r = -0.67$, $P < 0.01$), and 1987 ($r = -0.68$; $P < 0.01$) showed that soft kernel texture was associated with low water holding capacity, as expected. Grain protein concentration was not strongly correlated with AY, AWRC, or SE in any year (Tables II and III).

Estimates of Heritability

With few exceptions, heritability values were significantly different from zero (Table IV). A heritability value for a trait indicates the total amount of variation that is under genetic control. A broad sense estimate considers all types of genetic variation, whereas a narrow sense estimate considers only additive genetic variation. For selection purposes, narrow sense estimates are the most valuable, because it is the additive genetic variation that the breeder can utilize. Heritability estimates calculated by parent-offspring regression and the standard unit method were generally similar (Table IV). The standard unit method of Frey and Horner (1957) was proposed to correct for scale differences

TABLE I
Progeny Means and Standard Deviations for Several Milling and Baking Quality Traits in the F_3, F_4, and F_5 Generations of the Tyler × TAM 105 Wheat Population[a]

Trait	1985 Tyler	1985 TAM 105	1985 F_3	1986 Tyler	1986 TAM 105	1986 F_4	1987 Tyler[b]	1987 F_5
Milling quality score	99.9 ± 0.62	101 ± 0.56	98.7 ± 4.04	99.8 ± 3.85	103 ± 0.35	101 ± 3.43	100	95.8 ± 3.80
Baking quality score	99.9 ± 2.2	55.8 ± 2.2	75.2 ± 10.6	100 ± 6.4	93.2 ± 0.77	106 ± 4.59	100	76.5 ± 17.6
Combined quality score	99.9 ± 2.2	55.8 ± 2.2	75.2 ± 10.6	99.8 ± 3.85	93.2 ± 0.77	101 ± 3.43	100	76.5 ± 17.6
Adjusted yield, %	72.9 ± 0.17	73.4 ± 0.17	72.6 ± 1.20	71.1 ± 1.15	71.9 ± 0.11	71.5 ± 1.01	71.6	71.0 ± 1.50
Grain protein, %	9.8 ± 0.12	11.4 ± 0.10	10.7 ± 0.47	10.7 ± 0.20	10.3 ± 0.08	10.5 ± 0.75	8.8	8.86 ± 0.40
AWRC,[c] %	51.2 ± 0.52	57.7 ± 0.45	55.0 ± 1.64	59.6 ± 0.75	60.8 ± 0.16	57.6 ± 1.55	54.6	56.5 ± 1.90
Softness equivalence, %	53.8 ± 0.35	41.7 ± 0.31	47.7 ± 5.15	40.5 ± 2.70	38.0 ± 0.46	47.3 ± 5.71	59.0	56.1 ± 5.24

[a]Milling quality, baking quality, and combined quality scores expressed as percent of the standard cultivar, Tyler.
[b]Only one Tyler entry tested in 1987; no standard error available.
[c]AWRC = Alkaline water retention capacity.

in the expression of traits when the parents and offspring are grown in separate years. The similarity of the standard unit estimates with those obtained by parent-offspring regression indicates that scale differences between any two pairs of years were generally small. Broad sense heritability estimates for GPC (Davis et al 1960) and AWRC (Briggle et al 1968) from studies of SRW × HRW wheat populations are considerably higher than the narrow sense estimates found in the present study. Heritability estimates for flour yield and GPC in an HRW × SRW wheat population reported by Lofgren et al (1968) based on parent-offspring regression and the standard unit method are higher than those found in the present study. However, their estimates were not corrected for inbreeding in the parents. Without correcting a heritability estimate calculated by parent-offspring regression for inbreeding in the parents, the proportion of additive genetic variance is overestimated, thus inflating the heritability value. Sunderman et al (1965), using similar methods to estimate heritability for GPC in an HRW × SRW wheat population, found values similar to those in the present study. Pearson et al (1981) reported a standard unit heritability for GPC in winter × spring wheat populations similar to those of the present study. They also reported a heritability value of 0.57 for flour yield. Considering the low but significant estimates of heritability, the possibility of selecting for low GPC and AWRC and high SE and AY exists in the Tyler × TAM 105 population. These results agree with the findings of Davis et al (1960) but differ from the findings of Gyawali et al (1968). Although the heritability estimates of quality traits in the present study are low to moderate (0.05–0.47), these estimates are in the range of heritability values for many agronomic traits such as grain yield. It should be noted that these genotypes were grown in only one location within a year. Thus, no measure of genotype × location interaction was available to quantify genotypic response to varying locations. However, Baenziger et al (1985) reported that cultivar × environment interaction for soft wheat quality, though significant, was

TABLE II
Simple Correlations Among Milling and Baking Quality Traits in the F_3 Generation (above the diagonal) and F_4 Generation (below the diagonal) of the Tyler × TAM 105 Wheat Population

Trait[a]	AY	GPC	AWRC	SE
AY	1.00	0.08	−0.04	−0.59**
GPC	−0.21	1.00	0.19	−0.26*
AWRC	−0.12	0.33**[b]	1.00	−0.46**
SE	−0.23	−0.12	−0.67**	1.00

[a] AY = Adjusted yield, GPC = grain protein concentration, AWRC = alkaline water retention capacity, SE = softness equivalence. Correlations among 62 lines.
[b] *, ** Significant at $P < 0.05$ and $P < 0.01$, respectively.

TABLE III
Simple Correlations Among Milling and Baking Quality Traits in the F_5 Generation of the Tyler × TAM 105 Wheat Population

Trait[a]	GPC	AWRC	SE	CD
AY	0.18	0.43*[b]	−0.73**	−0.69**
GPC		0.29	−0.48*	−0.43*
AWRC			−0.68**	−0.75**
SE				0.92**

[a] AY = Adjusted yield, GPC = grain protein concentration, AWRC = alkaline water retention capacity, SE = softness equivalence, CD = cookie diameter. Correlations among 27 lines.
[b] *, ** Significant at $P < 0.05$ and $P < 0.01$, respectively.

TABLE IV
Estimates of Parent Offspring Heritability (h^2_{op}) and Standard Unit Heritability (h^2_{su}) for Several Milling and Baking Quality Traits in the Tyler × TAM 105 Wheat Population

	Generation					
	F_3–F_4		F_3–F_5		F_4–F_5	
Trait	(h^2_{op})	(h^2_{su})	(h^2_{op})	(h^2_{su})	(h^2_{op})	(h^2_{su})
AWRC,[a] %	0.25**[b]	0.26**	0.37**	0.32**	0.40**	0.35**
Grain protein, %	0.23*	0.14	0.05	0.05	0.12*	0.22*
Softness equivalence, %	0.40**	0.36**	0.47**	0.46**	0.28**	0.30**
Adjusted flour yield, %	0.20**	0.23**	0.41**	0.32**	0.44*	0.24*

[a] Alkaline water retention capacity.
[b] *, ** Significant at $P < 0.05$ and $P < 0.01$, respectively.

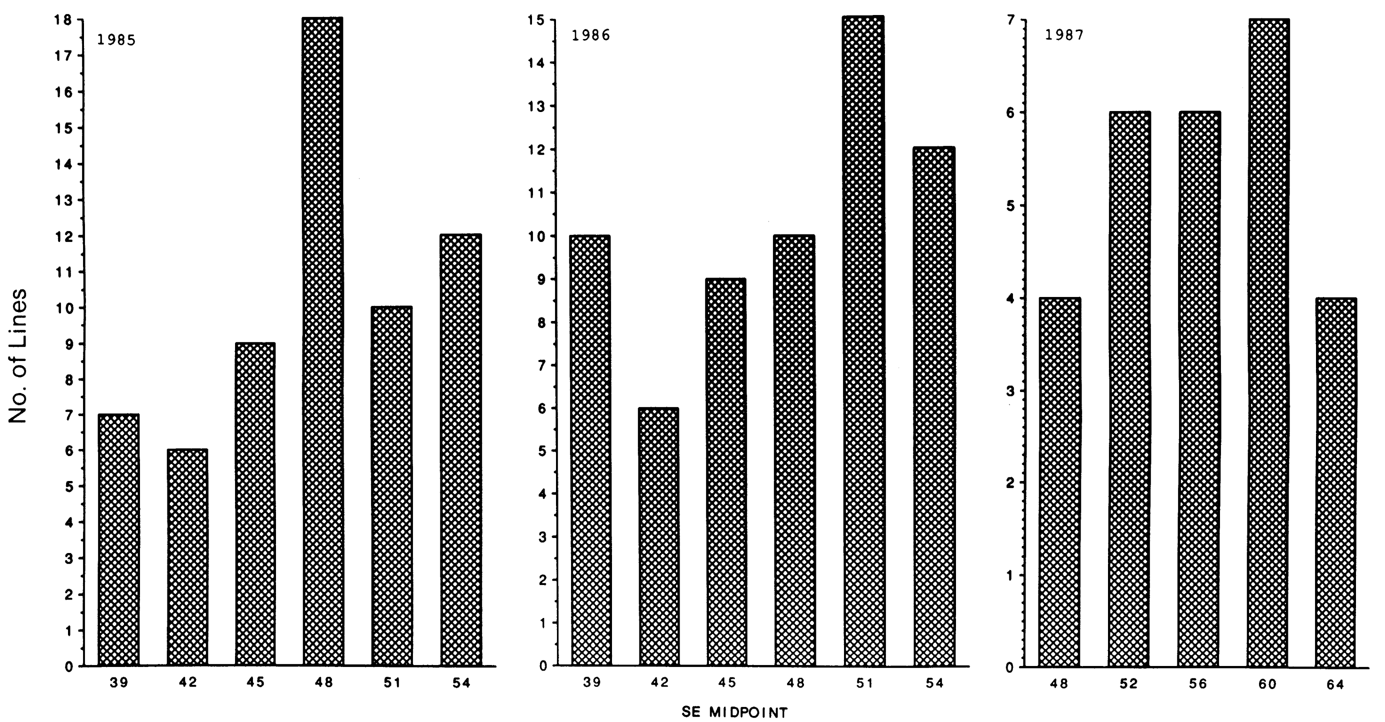

Fig. 1. Distribution of softness equivalence (SE) in the F_3 generation in 1985, F_4 generation in 1986, and the F_5 generation in 1987 of the Tyler × TAM 105 wheat population. Tyler values: 1985, 53.8%; 1986, 40.5%; 1987, 59.0%.

of a relatively small magnitude and concluded that evaluations conducted in one environment were sufficient to evaluate early generation progeny for preliminary milling and baking quality.

CONCLUSIONS

Certain F_3, F_4, and F_5 progeny possessed AY, GPC, AWRC, and SE values similar to those of Tyler. In addition, three lines in 1987 had cookie diameters similar to Tyler (data not shown). Because Tyler was represented by only two rows in the 1986 quality analysis, it is likely that the progeny were subjected to a less critical comparative quality evaluation in 1986. In addition to the possible bias introduced by the small number of Tyler checks in 1986, there were clearly differences between 1985 and 1986. The mean values for TAM 105 for several quality traits were more in the direction of soft wheat quality in 1986 than in 1985 (Table I). Nonetheless, the 1985 and 1987 data indicate that several lines could be identified that had acceptable preliminary soft wheat quality. The term preliminary should be emphasized, however. The fact that some lines had test values greater than or equal to Tyler does not imply that these lines have better milling and baking quality. However, such lines are candidates for further testing. On the basis of acceptable performance in the milling and baking quality tests in the F_3, F_4, and F_5 generations, one line was selected for testing in a yield trial at two locations in 1989.

Because only one cross was evaluated, the results of the present study cannot be used to assess the general utility of HRW wheat genotypes in an SRW wheat breeding program. Additionally, although only a very small portion of the lines tested had acceptable preliminary soft wheat milling and baking quality, it is not unreasonable to expect that other HRW $\times$ SRW wheat crosses might yield segregates with suitable soft wheat quality.

LITERATURE CITED

AMERICAN ASSOCIATION OF CEREAL CHEMISTS. 1983. Approved Methods of the AACC. Method 10-52, approved September 1985. The Association: St. Paul, MN.

BAENZIGER, P. S., CLEMENTS, R. L., McINTOSH, M. S., YAMAZAKI, W. T., STARLING, T. M., SAMMONS, D. J., and JOHNSON, J. W. 1985. Effect of cultivar, environment, and their interaction and stability analysis on milling and baking quality of soft red winter wheat. Crop Sci. 25:5-8.

BARMORE, M. A., and BEQUETTE, R. K. 1968. Kernel color and shape as guides to potential flour performance in wheat marketing. Agron. J. 60:223-228.

BEARD, B. H., and POEHLMAN, J. M. 1954. A study of quality as measured by the pearling test in crosses between hard and soft wheats. Agron. J. 46:220-223.

BRADSTREET, R. B. 1965. The Kjeldahl method for organic nitrogen. Academic Press: New York.

BRIGGLE, L. W., YAMAZAKI, W. T., and HANSON, W. D. 1968. Heritability of three soft wheat quality characters in the F_2 and F_3 generations. Crop Sci. 8:283-285.

COX, T. S., MURPHY, J. and RODGERS, D. M. 1985. Coefficients of Parentage for 400 Winter Wheat Cultivars. Dept. Rep. Agron. Agric. Exp. Stn. Kansas State University: Manhattan.

DAVIS, W. H., MIDDLETON, G. K., and HEBERT, T. T. 1960. Inheritance of protein, texture, and yield in wheat. Crop Sci. 1:235-238.

DOEKES, G. J., and BELDEROK, B. 1976. Kernel hardness and baking quality of wheat—A genetic analysis using chromosome substitution lines. Euphytica 25:565-576.

FEDERER, W. T. 1961. Augmented designs with one way elimination of heterogeneity. Biometrics 17:447-473.

FINNEY, K. F., MORRIS, V. H., and YAMAZAKI, W. T. 1950. Micro versus macro cookie baking procedures for evaluating the cookie quality of wheat varieties. Cereal Chem. 27:42-49.

FINNEY, P. L., and ANDREWS, L. C. 1986. Revised micro-testing for soft wheat quality evaluation. Cereal Chem. 63:177-182.

FREY, K. J., and HORNER, T. 1957. Heritability in standard units. Agron. J. 49:59-62.

GREENWELL, P., and SCHOFIELD, J. D. 1986. A starch granule protein associated with endosperm softness in wheat. Cereal Chem. 63:379-380.

GYAWALI, K. K., QUALSET, C. O., and YAMAZAKI, W. T. 1968. Estimates of heterosis and combining ability in winter wheat. Crop Sci. 8:322-324.

LARGE, E. C. 1954. Growth stages in cereals. Plant Pathol. 3:128-129.

LOFGREN, J. R., FINNEY, K. F., HEYNE, E. G., BOLTE, L. C., HOSENEY, R. C., and SHOGREN, M. D. 1968. Heritability estimates of protein content and certain quality and agronomic properties in bread wheat (*Triticum aestivum* L.). Crop Sci. 8:563-568.

PEARSON, D. C., ROSIELLE, A. A., and BOYD, W. J. R. 1981. Heritabilities of five wheat quality traits for early generation selection. Aust. J. Exp. Agric. Anim. Husb. 21:512-515.

SMITH, J. D., and KINMAN, M. L. 1965. The use of parent-offspring regression as an estimator of heritability. Crop Sci. 5:595-596.

SUNDERMAN, D. W., WISE, M., and SNEED, E. M. 1965. Interrelationships of wheat protein content, flour sedimentation value, farinograph peak time, and dough mixing and baking characteristics in the F_2 and F_3 generations of winter wheat (*Triticum aestivum* L.). Crop Sci. 5:537-540.

SYMES, K. J. 1965. The inheritance of grain hardness in wheat as measured by the particle size index. Aust. J. Agric. Res. 16:113-123.

TAYLOR, J. W., BAYLES, B. B., and FIFIELD, C. C. 1939. A simple measure of kernel hardness in wheat J. Am. Soc. Agron. 31:775- 784.

WORZELLA, W. W., and CUTLER, G. H. 1939. A critical study of techniques for measuring granulation in wheat meal. J. Agric. Res. 58;329-341.

YAMAZAKI, W. T. 1953. An alkaline water retention capacity test for the evaluation of cookie baking potentialities for soft winter wheat flours. Cereal Chem. 30:242-246.

YAMAZAKI, W. T., and DONELSON, J. R. 1972. Evaluating soft wheat quality of early generation progenies. Crop Sci. 12:374-375.

YAMAZAKI, W. T., DONELSON, J. R., and BRIGGLE, L. W. 1968. Micro-tests for soft wheat quality evaluation. Crop Sci. 8:199-201.

YAMAZAKI, W. T., FORD, M., KINGSWOOD, K. W., and GREENWOOD, C. T. 1981. Soft wheat production. Pages 1-32 in Soft Wheat: Production, Breeding, Milling, and Uses. W. T. Yamazaki and C. T. Greenwood, eds. Am. Assoc. Cereal Chem.: St. Paul, MN.

[Received September 26, 1988. Accepted April 14, 1989.]