Associations Among Quality Attributes of Red and White Soft Wheat Cultivars Across Locations and Crop Years

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ABSTRACT

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The means and distributions of correlation coefficients among seven principal wheat and flour quality attributes (test weight, break flour yield, straight-grade flour yield, flour protein content, sugar-snap cookie diameter, white layer cake volume, and alkaline water retention capacity) of 53 soft wheat cultivars grown in the eastern United States were compared relative to pericarp color (red or white). Quality attributes of red wheat cultivars usually were adversely affected by protein content. Quality attributes of white wheat cultivars were relatively unaffected by protein content. Among most red wheats, but not among most white wheats, high protein content was correlated with harder kernel texture. Break flour yield was correlated with alkaline water retention capacity for most white wheats, but not for red wheats. Within each color class, individual cultivars varied greatly in correlations among quality tests.

The fact that more soft wheat cultivars are being grown commercially (Finney et al 1987) has implications for overall crop end-use stability. Because each cultivar is unique in some way, the larger number of cultivars raises concerns about whether the milling and baking industry can accommodate the expected variations in quality among the cultivars.

Crop year, location, cultivation customs, and environmental and climatic conditions profoundly affect cultivar protein content and kernel texture. In addition, protein content and quality and kernel texture are, to varying extents, genetically controlled. Those attributes in turn affect practically all milling and baking qualities of wheat.

Wheat is commonly classified by the color, red or white, of the pericarp (bran). Soft red winter wheat is grown in most of the eastern United States. Soft white winter wheat is produced predominantly in Michigan and New York and in adjacent areas of southern Ontario, Canada (Patterson and Allan 1981). Soft red and white wheats produced in the United States are used for similar types of products. White wheat bran is often preferred for its milder taste in the production of breakfast cereals.

At the Soft Wheat Quality Laboratory in Wooster, OH, the quality of soft wheat cultivars is predicted from small samples. The same laboratory tests are used for both red and white wheats. Commonly used tests for predicting wheat and flour quality include test weight, break flour yield, straight-grade flour yield, flour protein content, sugar-snap cookie diameter, white layer cake volume, and alkaline water retention capacity (AWRC). Data from those tests are inserted into mathematical equations to predict end-use qualities. However, the equations were also generated for soft wheat without regard to kernel color class. The present study was undertaken to analyze the relationship between quality test data and kernel color.

Correlations among seven soft wheat quality attributes were analyzed relative to kernel color class to determine differences between the classes and among the 53 cultivars studied within the classes. The wheats evaluated represent most of the eastern U.S. wheats currently used in commerce. Data were taken from at least eight locations and for up to seven crop years for each cultivar. The objectives of the study were 1) to determine differences between the red and white wheat classes in genetically associated qualities, 2) to identify the end-use attributes that work best in regression equations for predicting milling and baking qualities, 3) to analyze the effects of environmental variation on quality attributes, 4) to explore the extent of genetic linkage of the quality attributes, and 5) to identify the cultivars that, in this study, were environmentally stable, as evidenced by low correlations among certain attributes, such as protein content, break flour yield, and cookie spread.

MATERIALS AND METHODS

Wheats and Flours

Samples of 53 wheat cultivars were cleaned by air and by hand to remove shriveled and broken kernels and were milled into straight-grade flours (Yamazaki and Andrews 1982). The 41 red wheat cultivars were Abe, Adena, Argee, Arthur, Arthur 71, Beau, Becker, Caldwell, Cardinal, Charmany, Coker 747, Coker 797, Coker 916, Downy, Fillmore, Florida 301, Florida 302, GR-855, Hart, Hillsdale, Kenosha, Knox 62, Logan, Magnum, McNair 1003, Monon, Oasis, Omega 78, Pike, Pioneer 576, Pioneer 2550, Pioneer 2551, Roland, Ruler, Saluda, Scotty, Stacy, Sullivan, Titan, Trumbull, and Tyler. The 12 white wheat cultivars were Augusta, Favor, Frankenmuth, Fredrick, Genesee, Geneva, Houser, Ionia, NY 6432, Purcell, Tecumseh, and Yorkstar. Wheats were grown in breeders' nurseries at many locations throughout the eastern United States during 1981–1987. At least eight samples of each of the 53 wheats were cleaned, milled, and evaluated.

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Evaluations and Analyses

Cultivars were evaluated for test weight (after cleaning), break flour yield (Yamazaki and Andrews 1982), and straight-grade flour yield. Flours were tested for cookie diameter, cake volume, AWRC, and protein content (AACC 1983). Correlations among all attributes were calculated for each cultivar. Individual cultivar correlations were derived from varying numbers of samples (eight to 43). Means and two standard deviations (68.3% of the sample population) of the correlation coefficients for the red and white wheat classes were then calculated. Two standard deviations were used to compare the widths of the distributions of the coefficients for each kernel color class. Each cultivar had equal influence on the mean and distribution of class coefficients. The means and standard deviations of all correlation coefficients (except those involving cake volume) were calculated from data for all 41 red wheat cultivars and 12 white wheat cultivars. Means and standard deviations of coefficients involving cake volume were calculated from data for 13 red and six white wheat cultivars. Levels of probability for differences between the means of the two classes for each correlation were determined by analysis of variance.

RESULTS AND DISCUSSION

A correlation coefficient between two quality attributes that is unusually high for most cultivars or a narrow distribution of coefficients around the class mean suggests a strongly heritable association and possibly a narrow gene base. A low correlation or a wide distribution of coefficients suggests a nonheritable association or less complementary gene action, a more general rather than narrow combinability, or less F_1 hybrid vigor of germ plasm selections. Selection of germ plasm from cultivars with low correlations among quality data could produce progeny with greater environmental stability. The larger standard deviations of correlation coefficients for red wheat cultivars usually reflect the greater diversity and larger number of red wheats studied here (and used in commerce) and the wider range of growing environments for red wheats compared with white wheats.

Test Weight

Test weights of most red wheat cultivars were positively correlated with straight-grade flour yield (Table I), but on average, test weights of white wheats were not correlated with flour yield. The double standard deviations of the distributions of the correlation coefficients show that the degree of correlation between test weight and flour yield varied greatly among cultivars, especially for red wheats.

For both red and white wheats, cultivars with higher test weights produced less break flour (i.e., had harder kernel texture). No positive correlation was observed for any cultivar in either class.

The mean correlation coefficients for test weight versus protein content were essentially zero for both classes (Table I). The wide distributions of these coefficients show that both classes included cultivars whose protein contents were positively correlated with test weight and other cultivars whose protein contents were negatively correlated with test weight. For a few red wheat cultivars, the correlation was strong.

Sugar-snap cookie diameters and white layer cake volumes of red and white wheats were not correlated with cleaned test weights when the correlation coefficients were averaged across cultivars (Table I). The large double standard deviations for red wheats show that the baking qualities of some red wheat cultivars were correlated positively with test weight, whereas for others, the correlation was negative. This is not surprising because test weight can be associated either positively or negatively with protein content, as shown above.

Test weight can be viewed as a yardstick of environmental influences. Cake volume (like test weight) varies considerably between and among cultivars (*unpublished data*), depending on environmental growing conditions. The above data indicate that the baking qualities of some cultivars are more environmentally stable (less correlated with test weight and protein content) than are those of other cultivars. Table II lists the cultivars whose correlation coefficients between test weight and any of the quality parameters studied were less than ± 0.2.

Break Flour

The mean correlation between break flour yield and flour protein content for red wheats was negative and significantly different from that for white wheats (Table III). However, the double standard deviation shows that for some white wheats, break flour and protein content were positively correlated. In

TABLE I
Correlation Coefficients of Test Weight of Red and White Wheats with Straight-Grade Flour Yield, Break Flour Yield, Protein Content, Sugar-Snap Cookie Diameter, and White Layer Cake Volume

	Correlation Coefficients				
	Red Wheats		White Wheats		
Correlation[a]	Mean	2SD[b]	Mean	2SD[b]	Level of Probability[c]
Flour yield	0.32	0.70	0.09	0.46	0.0411
Break flour	−0.61	0.36	−0.51	0.38	0.1156
Protein content	0.13	0.84	−0.03	0.66	0.2247
Cookie diameter	−0.14	0.64	−0.08	0.40	0.6018
Cake volume	−0.25	0.90	0.02	0.46	0.1801

[a] Test weight versus the indicated variable.
[b] Twice the standard deviation.
[a] For differences between the means.

TABLE II
Soft Wheat Cultivars with Correlation Coefficients Less than ±0.2 for Five Quality Parameters Correlated with Test Weight

Flour Yield	Break Flour Yield	Protein Content	Cookie Diameter	Cake Volume
		Red Wheats		
Argee	Monon	Beau	Abe	Arthur
Downy		Charmany	Argee	Saluda
Florida 302		Downy	Charmany	Titan
Magnum		Florida 302	Coker 797	
Pioneer S76		Monon	Fillmore	
Pioneer 2550			Logan	
Roland			Monon	
Saluda			Omega 78	
			Pioneer S76	
			Pioneer 2550	
		White Wheats		
Frankenmuth	NY 6432	Favor	Augusta	Augusta
Ionia		Genesee	Frankenmuth	Fredrick
Purcell		Houser	Fredrick	Yorkstar
Tecumseh		NY 6432	Genesee	
Yorkstar		Purcell	Geneva	
		Yorkstar	Houser	
			NY 6432	
			Purcel	
			Tecumseh	

TABLE III
Correlation Coefficients of Break Flour Yield of Red and White Wheats with Protein Content, Alkaline Water Retention Capacity (AWRC), Sugar-Snap Cookie Diameter, and White Layer Cake Volume

	Correlation Coefficients				
	Red Wheats		White Wheats		
Correlation[a]	Mean	2SD[b]	Mean	2SD[b]	Level of Probability[c]
Protein content	−0.42	0.64	0.00	0.72	0.0003
AWRC	−0.08	0.74	−0.35	0.64	0.0241
Cookie diameter	0.31	0.66	−0.04	0.42	0.0011
Cake volume	0.20	0.76	0.12	0.25	0.6606

[a] Break flour yield versus the indicated variable.
[b] Twice the standard deviation.
[c] For differences between the means.

general among red wheats, higher break flour yield results from softer textured wheats, which usually results from lower protein soft wheat. Therefore, it was surprising that some white wheats in this study had softer kernel texture at increased levels of protein.

The mean correlation between AWRC and break flour yield was zero for red wheats and negative for white wheats (Table III). Again, the correlation coefficients were positive for several individual cultivars of both classes and negative for others. The lack of correlation for red wheats and the wide distributions suggest that AWRC and break flour yield both contribute uniquely to the prediction of baking quality.

The mean correlation between break flour yield and cookie diameter was positive for red wheats and zero for white wheats. Gaines (1985) calculated a correlation coefficient of 0.30 between break flour yield and cookie spread for individual observations of 83 red wheats. However, the present results show that break flour yield and cookie spread are less correlated for white wheat cultivars. Because protein content is correlated with baking quality across cultivars, the association between break flour yield and protein content probably also explains the various correlations between cookie diameter and break flour yield.

TABLE IV
Soft Wheat Cultivars with Correlation Coefficients Less than ±0.2 for Four Quality Parameters Correlated with Break Flour Yield

Protein Content	AWRC[a]	Cookie Diameter	Cake Volume
	Red Wheats		
Argee	Abe	Argee	Abe
Coker 747	Caldwell	Arthur 71	Arthur
Coker 797	Florida 301	Beau	Florida 301
Florida 301	GR-855	Florida 301	Pioneer S76
Kenosha	Kenosha	GR-855	Saluda
Knox 62	Knox 62	Logan	Sullivan
McNair 1003	Logan	Magnum	
Oasis	Omega 78	McNair 1003	
Omega 78	Pioneer S76	Oasis	
Stacy	Pioneer 2550	Omega 78	
	Pioneer 2551	Ruler	
	Saluda	Trumbull	
	White Wheats		
Frankenmuth	Fredrick	Frankenmuth	Fredrick
Fredrick	Tecumseh	Fredrick	Genesee
Ionia		Genesee	Houser
Purcell		Geneva	
		Houser	
		Purcell	
		Tecumseh	
		Yorkstar	

[a] Alkaline water retention capacity.

TABLE V
Coefficients of Correlations Among Sugar-Snap Cookie Spread, White Layer Cake Volume, Protein Content, and Alkaline Water Retention Capacity (AWRC) of Red and White Wheats

	Correlation Coefficients				
	Red Wheats		White Wheats		
Correlation	Mean	2SD[a]	Mean	2SD[a]	Level of Probability[b]
Cookie diameter vs.					
Protein content	−0.41	0.46	0.11	0.62	0.0000
AWRC	−0.20	0.58	−0.14	0.62	0.5289
Cake volume	0.10	0.64	0.46	0.44	0.0253
Cake volume vs.					
AWRC	0.15	0.60	−0.40	0.36	0.0008
Protein content	−0.32	0.58	0.06	0.74	0.0247
AWRC vs.					
Protein content	0.01	0.72	−0.04	0.92	0.7200

[a] Twice the standard deviation.
[b] For differences between the means.

The mean correlation coefficient between break flour yield and cake volume was positive but small for both red and white wheats. The standard deviation of the correlation coefficients was fairly large for the red wheats and relatively small for the white wheats. In general (except for some white wheats), cultivars that produced more break flour (i.e., had softer kernel texture) also had better baking quality. Table IV lists the cultivars whose correlation coefficients between break flour yield and any of the quality parameters studied were less than ± 0.2.

Cookie and Cake Size

The mean correlation coefficient between cookie diameter and flour protein content was negative for red wheats and slightly positive for white wheats (Table V). The double standard deviation of these coefficients was relatively small for red wheats. It is well known that cookie diameter decreases as the protein content of a cultivar increases (Yamazaki 1954, Yamazaki and Lamb 1962); in this study, however, the relationship was positive for seven white wheat cultivars.

The mean coefficients for the correlation between cookie diameter and AWRC were low and negative for both red and white wheats. At one time, the relationship between AWRC and sugar-snap cookie spread was stronger (Yamazaki 1953, 1954). The AWRC test was developed to screen for soft wheats with hard wheat tendencies for water retention at alkaline pH (Yamazaki 1953). However, the class means and distributions of the correlation coefficients show that cultivar breeding and selection have diminished the once strong relationship between sugar-snap cookie spread and AWRC (many cultivars in this study had a slightly positive relationship).

Gaines (1985) showed that cake volume and sugar-snap cookie spread were not correlated across individual observations of 83 red wheat cultivars. However, in the present study those two attributes were positively correlated for the white wheat cultivars studied (Table V). A similar relationship was observed between cake volume and AWRC. AWRC is not usually used as a predictor of cake volume; however, the greater correlation and narrow distribution among the white wheat cultivars studied here suggest that it may be useful as such.

The mean correlation coefficient between cake volume and protein content was negative for red wheats. Among white wheats, however, the correlation coefficients were widely distributed around a mean of zero. Again, a baking quality attribute (class mean cake volume) of the white wheats studied was not correlated with flour protein content.

Correlation coefficients between protein content and AWRC were widely distributed around means of zero for both red and white classes. Protein content of individual cultivars can be positively or negatively correlated with AWRC, cake volume, cookie diameter, break flour yield, and test weight. A common requirement in both cultivar breeding and commercial flour specifications is that a narrow range of low-protein flours be used for most soft wheat products. As protein content increases, variability in quality parameters becomes increasingly unpredictable, especially among most white wheat cultivars. Table VI lists the cultivars whose correlation coefficients for three quality parameters correlated with cookie diameter, two quality parameters correlated with white layer cake volume, or protein content correlated with AWRC are less than ± 0.2.

CONCLUSIONS

The red and white soft wheats evaluated in this study differ in the correlation between flour protein content and other quality tests. The main differences result from the relationship of protein content and kernel texture. Among red wheats, higher protein content is associated with harder kernel texture and smaller cookies. Among white wheats, these correlations are usually low or zero. Depending on the cultivar, protein content may be positively or negatively correlated with other quality parameters. Correlations of test weight with straight-grade flour yield and baking quality are highly variable and depend on the cultivar. Both kernel

TABLE VI

Soft Wheat Cultivars with Correlation Coefficients Less than ±0.2 for Three Quality Parameters Correlated with Cookie Diameter, Two Quality Parameters Correlated with White Layer Cake Volume, and Protein Content Correlated with Alkaline Water Retention Capacity (AWRC)

Cookie Diameter vs.			Cake Volume vs.		AWRC vs.
Protein Content	AWRC	Cake Volume	AWRC	Protein Content	Protein Content
		Red Wheats			
Becker	Abe	Abe	Pioneer S76	Arthur 71	Arthur 71
Caldwell	Arthur 71	Adena	Sullivan	Florida 301	Knox 62
Kenosha	Charmany	Beau		Knox 62	Pioneer S76
Knox 62	Coker 747	Becker		Oasis	Saluda
Ruler	Downy	Charmany		Pioneer 2551	Titan
Stacy	Florida 302	Coker 916		Saluda	
	Logan	Downy			
	McNair 1003	Knox 62			
	Pioneer 2550	Logan			
	Roland	Magnum			
	Saluda	McNair 1003			
	Titan	Monon			
	Trumbull	Oasis			
		Omega 78			
		Pike			
		Ruler			
		Saluda			
		Sullivan			
		Titan			
		Tyler			
		White Wheats			
Augusta	Genesee	Yorkstar	Houser	Augusta	Augusta
Favor	Ionia			Frankenmuth	Fredrick
Genesee	NY 6432			Houser	Genesee
Geneva	Tecumseh				Ionia
Purcell					
Tecumseh					

texture and AWRC should be included in quality prediction models.

This study shows, in part, why different environments cause unpredictable variability in wheat quality. Selection of germ plasm from cultivars with low correlation coefficients among most quality attributes (especially with kernel texture and protein content) could yield progeny that are more environmentally stable than currently available cultivars.

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