Statistical Correlations Between Quality Attributes and Grain-Protein Composition for 60 Advanced Lines of Crossbred Wheat

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ABSTRACT

Grain of advanced lines from New Zealand breeding programs was milled and analyzed for dough quality (extensigraph, farinograph, mechanical development), baking quality, grain hardness, and protein composition (gel electrophoresis at pH 3 and in sodium dodecyl sulfate) and by small-scale tests (sedimentation, residue). Very highly significant correlations ($P < 0.001$) were found between many of these measures of grain quality (especially resistance of dough to extension) and the presence of specific gliadins and high molecular weight glutenin subunits (particularly 5 and 10, or 2 and 12). Segregation of the lines according to the presence of these glutenins and of gliadins 58 and 59 successfully identified a group of lines with mean dough resistance to extension well above ($P < 0.001$) that of the others.

As described in a companion paper (Campbell et al 1987), evidence is accumulating to indicate that specific gluten proteins are statistically correlated with genetic aspects of wheat grain quality, particularly resistance to dough stretching. Because such information would be valuable in planning a wheat breeding program and in selecting for grain quality, the validity of the conclusions from that study (of 71 diverse breeding-parent lines) was tested by performing a parallel evaluation of progeny from a range of crosses, involving a diversity of wheat genotypes quite different from the parents used in the other study.

The conclusions in general were found to agree with those of the parallel study, indicating that selection of progeny according to the presence of only a few protein components provides excellent segregation of strongest from weakest dough types.

MATERIALS AND METHODS

Grain Samples

Sixty advanced lines of hexaploid wheat (F7-F8) from four breeding programs were each grown in the same year and at one site in New Zealand (Lincoln), to give in excess of 1 kg of grain. These lines resulted from a wide range of crosses made in New Zealand, France, Sweden, and the Netherlands for growing in those countries. Two were sister lines from the same original cross, but all others came from different crosses. A wide diversity of parents had been used in making the crosses, and in only a few cases had the same parent been used more than once. These lines had been selected mainly on the basis of agronomic performance, with little attention to quality characteristics at this stage of selection. Most were well adapted to the growth site.

Analyses for protein content and falling number (to test for sprouting), were previously used to exclude samples for which genetic effects might be masked or complicated by environmental factors.

Grain Quality and Protein Composition

Grain of these 60 lines was milled to 72% flour yield on a Buhler laboratory mill. Quality attributes, protein composition (gliadins and high molecular weight glutenin subunits), and statisical relationships were determined by procedures described in the companion paper (Campbell et al 1987).

TABLE I
Range of Grain Quality Values for 60 Breeding Lines

Attribute	Units	Range	Mean	Standard Deviation
Resistance (5 cm)	BU	115-480	215	68
Resistance (max)	BU	115-625	316	125
Extensibility	cm	14.7-28.5	21.6	2.8
Development time	min	2.0-9.2	5.6	2.0
Loaf volume	ml	648-918	773	55
Work input	Whr/kg	4.5-18.1	9.4	3.3
SDS[a] volume	ml	42-91	70.5	11.7
Residue protein	%	19.8-40.5	30.3	4.8
Particle size	···	12-28	17.4	4.4
Water retention capacity	%	58.4-82.0	69.8	4.7
Water absorption	%	51.2-67.0	58.9	3.3
Color grade	···	0.3-6.4[b]	2.6	1.2
Protein content	%	9.1-15.5	12.0	1.3

[a] SDS = Sodium dodecyl sulfate.
[b] High value from a purple wheat.

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TABLE II
Correlation Coefficients Relating Quality Attributes for 60 Breeding Lines[a]

Attribute	R5	Rmax	Ext	DT	LV	WI	SDS	Res	PSI
Resistance (5 cm), R5	1.00	...							
Resistance (max), Rmax	*0.92*	1.00	...						
Extensibility, Ext	−0.32	−0.03	1.00	...					
Development time, DT	0.30	*0.55*	0.37	1.00	...				
Loaf volume, LV	0.14	0.28	0.37	0.41	1.00	...			
Work input, WI	0.47	*0.67*	0.31	*0.78*	*0.54*	1.00	...		
SDS volume, SDS	0.46	*0.67*	0.35	*0.75*	0.50	*0.78*	1.00	...	
Residue protein, Res	0.50	*0.67*	0.10	*0.64*	0.21	*0.62*	*0.66*	1.00	...
Particle size, PSI	−0.25	−0.33	−0.04	−0.45	−0.17	−0.49	−0.49	−0.29	1.00
Protein content, Prot	−0.13	0.08	*0.58*	*0.51*	0.39	0.44	0.30	0.18	−0.17

[a] Correlation coefficients above 0.50 are italicized as being very highly significant (*** $P<0.001$), those over 0.44 are highly significant (** $P<0.01$), and those over 0.40 are significant (* $P<0.05$).

TABLE III
Frequencies of Occurrence of Allelic Variants of High Molecular Weight Glutenin Subunits in the 60 Lines Studied

Allele	Number
Glu A1 locus	
1	13
2*	27
Null	20
Glu B1 locus	
6 + 8	12
7	18
7 + 8	6
7 + 9	20
17 + 18	2
13 + 19	4
13 + 16	1
21	1
Glu D1 locus	
5 + 10	29
2 + 12	31

RESULTS AND DISCUSSION

The spread of quality values for the set of 60 lines was quite broad (Table I). Correlation coefficients relating these attributes (Table II) showed close associations between the two measures of dough resistance from the extensigram (resistance at 5 cm and at maximum height of the extensigram) but much poorer correlation of either to extensigram length. There were minor differences in the pattern of correlations for these samples compared to those in the paper by Campbell et al (1987), reflecting the different genetic sources and the different growth environments for the two sets. The frequencies of high molecular weight glutenin subunits (Table III) differed from those in the other set of genotypes mainly in the B genome; none had bands 14 and 15 or 20.

Table IV lists the protein components indicated to be associated with each quality attribute according to a similarity matrix (constructed to include all proteins and all the quality attributes in Table II). The degree of significance of association between each band in Table IV with quality is indicated, based on chi-squared analysis.

Glutenin subunits 5+10 and 2+12 showed the same very strong associations with resistance to extension as they had shown for the 71 parent lines studied similarly by Campbell et al (1987), but these components were not so prominent in the lists for other aspects of quality. If this is mainly because the other measures of quality were less correlated with resistance (Table II), the result may show that these protein components primarily indicate this property of dough.

As might thus be expected, classification of the lines according to Glu 5+10/Glu 2+12 segregated high-resistance lines from low ones, but not on the basis of other qualities, as shown in Figure 1. The influence of protein content in these associations was not significant. The lines with 5+10 bands had a mean protein content of 12.0±1.5% and those with 2+12 bands averaged 12.1±1.2% protein.

TABLE IV
Electrophoretic Components that Correlate Best with Quality Attributes in 60 Breeding Lines, when the Attribute is at a High or Low Value

Attribute	Value	Electrophoretic Components in Decreasing Order of Significance[c]
Resistance (5 cm)	High	Glu 5+10***, Gli 31***, Gli 59*, Gli 47*, Gli 37*
	Low	Glu 2+12***, Gli 28**, Gli 58*
Resitance (max)	High	Gli 31**, Glu 5+10**, Gli 59**, Gli 37**, Gli 35*, Gli 47*
	Low	Gli 29**, Glu 2+12**, Gli 58*, Glu null*, Gli 34*
Extensibility	High	Glu 7+9**, Glu 2+12*, Glu 13+19*
	Low	Glu 5+10*, Glu 7*
Development time	High	Gli 35***, Glu 2 star**, Gli 37**, Glu 13+19*, Gli 31*, Gli 43*, Glu 7+9*
	Low	Glu null ***, GLi 34***, Gli 40**, Glu 7**, Gli 29**, Gli 69**, Gli 48*, GLi 44*
Loaf volume	High	Gli 50**, Glu 5+10*, Gli 68*
	Low	Glu null**, Glu 2+12*
Work input	High	Glu 13+19*, Glu 5+10, Gli 37*, Glu 2 star*, Gli 59*
	Low	Glu null ***, Glu 7**, Gli 34**, Gli 29**, Gli 69*, Glu 2+12*
SDS volume	High	Gli 35**, Gli 51**, Gli 37**, Glu 13+19*, Gli 59*, Glu 2 star*, Glu 7+9*, Gli 21*, Gli 31*
	Low	Glu 7***, Glu null***, Gli 34**, Gli 29**, Gli 52*
Residue protein	High	Gli 37***, Gli 51***, Gli 31**, Gli 35**, Gli 21**, Glu 2 star *, Glu 5+10*, Glu 13+19*
	Low	Gli 34**, Gli 52**, Gli 28**, Glu null**, Glu 7*, Gli 40*, Glu 2+12*
Particle size	High	Glu 7***, Glu null**, Gli 69**
	Low	Glu 2 star**, Gli 68**

[a] Extent of correlation shown by number of asterisks: * $P<0.05$, ** $P<0.01$, and *** $P<0.001$.

Many other high molecular weight glutenin subunits showed associations with various aspects of quality. In general, these were consistent with the results of others (e.g., Payne et al 1981, Branlard and Dardevet 1985b).

A large number of gliadin components (Table IV) appears implicated in quality associations. Some, but not all, were similarly involved in the parallel study by Campbell et al (1987). Gliadins 20+25, 23, 35.5, 40, and 48, which feature prominently in the parallel study, were not apparent in this case because of their low frequencies in the set of breeding lines. On the other hand, Gli 35 appears in Table IV but not in associations of Campbell et al (1987). It is probably equivalent to gliadin components associated with quality in several other studies (block IBI in Sozinov and Poperelya 1980, band 14 in Wrigley et al 1982, and band 30 in Branlard and Dardevet 1985a).

Gli 58 and Gli 59 were again significantly associated with low

A. First split according to glutenins.

	Glu 2+12		Glu 5+10
No. wheats	30		25
R5	188.5 ± 49.8	***	250.4 ± 72.8
Rmax	275.0 ± 119	**	370.0 ± 114
LV	754.2 ± 56.2	*	787.0 ± 48.1
EXT	22.1 ± 2.1	NS	20.7 ± 3.3
SDS	68.0 ± 13.4	NS	72.2 ± 9.3

	Gli 58		Gli 59		Gli 58		Gli 59
No. wheats	11		13		12		19
R5	175.0 ± 57.0	NS	196.3 ± 45.0		210.8 ± 41.8	**	286.9 ± 77.4
Rmax	230.0 ± 116	NS	301.0 ± 115		296.7 ± 64.6	***	437.0 ± 109
LV	728.1 ± 51.8	NS	769.3 ± 54.4		786.1 ± 43.6	NS	787.9 ± 53.6
EXT	20.9 ± 2.4	*	22.8 ± 1.7		20.9 ± 2.4	NS	20.6 ± 4.0
SDS	63.9 ± 12.5	NS	70.3 ± 13.6		68.3 ± 8.4	*	75.9 ± 8.9

B. First split according to gliadins.

	Gli 58		Gli 59
No. wheats	23		32
R5	193.7 ± 51.8	*	233.1 ± 74.4
Rmax	264.6 ± 96.6	**	356.0 ± 130
LV	758.3 ± 55.1	NS	776.9 ± 54.0
EXT	20.9 ± 2.4	NS	21.9 ± 3.0
SDS	66.2 ± 10.5	*	72.6 ± 12.1

	Glu 2+12		Glu 5+10		Glu 2+12		Glu 5+10
No. wheats	11		12		13		19
R5	175.0 ± 57.0	NS	210.8 ± 41.8		196.3 ± 45.0	**	286.9 ± 77.4
Rmax	230.0 ± 116	NS	296.7 ± 64.6		301.0 ± 115	**	437.0 ± 109
LV	728.1 ± 51.8	**	786.1 ± 43.6		769.3 ± 54.4	NS	787.9 ± 53.6
EXT	20.9 ± 2.4	NS	20.9 ± 2.4		22.8 ± 1.7	NS	20.6 ± 4.0
SDS	63.9 ± 12.5	NS	68.4 ± 8.4		70.3 ± 13.6	NS	75.9 ± 8.9

Fig. 1. Classification of 55 of the 60 breeding lines according to the presence of Glu 2+12/Glu 5+10 and of Gli 58/59, giving means for the qualities of resulting subgroups and indicating the degree of significance (*t* test) of differences in quality between groups. Five lines were excluded because they had neither or both gliadins 58 and 59. **R5** = Extensigram resistance at 5 cm on extensigram, **Rmax** = resistance at maximum height of extensigram, **LV** = loaf volume (by mechanical dough development), **EXT** = extensibility (length of extensigram), **SDS** = sodium dodecyl sulfate (sedimentation volume). Levels of significance are indicated by asterisks: * $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$, and NS, not significant.

and high resistance to extension. Classification of these lines according to their presence provided useful selection according to resistance (Figure 1), even after preliminary classification on the basis of high molecular weight glutenins 5+10 and 2+12.

CONCLUSION

This study provided general validation for the possibility (described by Campbell et al 1987) of selecting for resistance to extension (high or low) in a breeding program according to the presence of a few specific proteins. Glutenins 5+10 and 2+12 appeared to be more effective than gliadins 58 and 59 if only one combination of protein components were to be used. Classification on the presence of all these proteins was most effective, however, especially for selecting lines with greatest resistance. Presumably these proteins indicate major genes that can be used to select for larger quality differences; other proteins associated with more minor effects (Table IV) could serve for "fine tuning" of quality in breeding.

The study indicated that segregation at least for dough resistance can be effectively performed using these (and possibly other) proteins as markers. They are also identified as targets for attention in the production of specific probes, such as monoclonal antibodies or complementary DNA (Wrigley 1986).

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LITERATURE CITED

BRANLARD, G., and DARDEVET, M. 1985a. Diversity of grain proteins and bread wheat quality. I. Correlation between gliadin bands and flour quality characteristics. J. Cereal Sci. 3:329.

BRANLARD, G., and DARDEVET, M. 1985b. Diversity of grain proteins and bread wheat quality. II. Correlation between high molecular weight subunits of glutenin and flour quality characteristics. J. Cereal Sci. 3:345.

CAMPBELL, W. P., WRIGLEY, C. W., CRESSEY, P. J., and SLACK, C. R. 1987. Statistical correlations between quality attributes and grain-protein composition for 71 hexaploid wheats used as breeding parents. Cereal Chem. (In press).

PAYNE, P. I., CORFIELD, K. G., HOLT, L. M., and BLACKMAN, J. A. 1981. Correlations between the inheritance of certain high molecular weight subunits of glutenin and bread-making quality in progenies of six crosses of bread wheat. J. Sci. Food Agric. 32:51.

SOZINOV, A. A., and POPERELYA, F. A. 1980. Genetic classification of prolamines and its use for plant breeding. Ann. Technol. Agric. 29:229.

WRIGLEY, C. W. 1986. Engineering wheat grain proteins to suit processing requirements: Studies on wheat quality in the CSIRO Wheat Research Unit. CSIRO Food Res. Q. 46:73.

WRIGLEY, C. W., LAWRENCE, G. J., and SHEPHERD, K. W. 1982. Association of glutenin subunits with gliadin composition and grain quality in wheat. Aust. J. Plant Physiol. 9:15.

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