NOTE

The Influence of Chromosome Number and Species on Wheat Hardness[1]

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ABSTRACT

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Cereals of different species, varieties, and genotypes of diploid, tetraploid, or hexaploid genetic constitution were tested for hardness using an established grinding/sieving method, the particle size index test. Diploid types were all very soft, tetraploid wheats all very hard, and the combination of AABB with the DD genome in hexaploid wheats resulted in a complete spectrum of hardness, from very hard to very soft. A similar range of hardness was found in hexaploid triticales, whereas the diploid *Secale* (rye) lines were similar to diploid wheats in kernel softness.

Key words: Chromosome number, Hardness

A complete set of genes and the chromosomes carrying them constitute a genome. The smallest number of genes necessary to the functioning of a wheat plant is carried on seven chromosomes; and the simplest forms of wheat carry seven chromosomes in the nuclei of their reproductive cells, and paired sets, or 14 chromosomes, in their vegetative cells. These plants with 14-chromosomes (2 × 7) are referred to as the diploid, or Einkorn, series. The most commonly encountered forms of wheat are the diploid (Einkorn), tetraploid (Emmer), and the three-genome hexaploid (Dinkel) series, which respectively carry (2 × 7), (2 × 14), and (2 × 21) chromosomes. Other forms of wheat carry three, five, eight, 10, and 12 sets of chromosomes, but these are rare and generally unstable forms.

The three genomes of common wheat, *Triticum aestivum*, have been designated as the A, B, and D genomes, and the nuclei of their vegetative cells have the AABBDD conformation. The A genome is believed to have originated in the primitive species *T. boeoticum*, the B genome from *Aegilops speltoides*, and the D genome from *A. squarrosa*. All three of these species are indigenous to the eastern Mediterranean area, including Turkey, Syria, Iraq, and Iran. *T. aestivum* itself is thought to be the result of a single gene mutation of another hexaploid *T. spelta*, which in turn was the progeny of a natural cross between *T. dicoccoides* and *A. squarrosa* (Peterson 1965).

Hard wheats have kernels that are difficult to penetrate or reduce to small fragments. The physical hardness of wheat has been shown to have a direct influence on its milling performance, and on water absorption, damaged starch content, and fermentation capacity of flours (Williams 1967). This note draws attention to the influence of chromosome number, species, and differing combinations of the same chromosome number on wheat hardness.

Several workers (e.g., Aamodt et al 1935; Worzella 1942; Beard and Poehlman 1954; Symes 1961, 1965; Mattern et al 1973; Baker 1977) have commented on the degree to which wheat hardness is controlled by genetics. This subject was reviewed by Yamazaki and Donelson (1983), who reported a general agreement among workers in this field that wheat hardness is controlled by one major gene with others supplying a modifying influence. An obstacle to earlier work on the genetics of wheat kernel texture was the absence of a precise method for measuring wheat hardness. The development of the particle size index (PSI) method by Cutler and Brinson (1935) and its refinements by Symes (1961) enabled a more definitive study of wheat hardness. Symes (1969) suggested that two major genes existed (the "Falcon" type and the "Spica" type) for the genetic control of wheat hardness. Hardness of the Spica type is similar to that of North American and Eastern European hard red spring and winter wheats. The Falcon type of hardness is expressed as a much harder type of wheat, which is closer to that of tetraploid wheat. The Spica type hardness is more "mellow," and in

TABLE I
Range of Wheat Hardness (Particle Size Index)

Particle Size Index	Classification
5–10	Very hard
10–15	Hard
15–20	Medium hard
20–25	Medium soft
25–30	Soft
30–40	Very soft
40–45	Extra soft

TABLE II
Precision of Particle Size Index (PSI) Test

	Durum	Hard Red Spring	Soft White Winter
Number of tests	21	39	27
Mean PSI (%)	8.0	19.9	43.6
Standard deviation	0.12	0.45	1.04
Coefficient of variability (%)	1.5	2.2	2.4

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TABLE III
Hardness of Pure Species and Varieties of Wheats

Type	Genome	Species	Variety	Line	Hardness (PSI) (%)
Hexaploid	ABD	*Triticum aestivum*	KB	HWS[a]	
			Curlew	HWS	10.7
			Falcon	HWS	11.5
			Glenlea	HRS	12.2
			Garnet	HRS	14.0
			Thatcher	HRS	16.5
			Park	HRS	17.9
			Selkirk	HRS	18.0
			Neepawa	HRS	18.6
			Manitou	HRS	19.5
			Wichita	HRW	21.5
			Winalta	HRW	21.6
		T. sphaerococcum	6B438		22.6
		T. spelta	Line 101		22.6
		T. aestivum	Scout	HRW	23.3
		T. sphaerococcum	6B437		24.6
			Indian 4		24.6
		T. spelta	Line 109		24.7
		T. aestivum	Lemhi 66	SWS	27.2
		T. compactum	6B393		30.9
			Little Club 50		32.0
		T. aestivum	Gaines	SWW	34.7
			Idaed 59	SWS	35.2
			Seneca	SRW	36.4
			Knox	SRW	38.4
			Thorne	SRW	39.7
		T. compactum	Poso 48		41.2
		T. aestivum	Genesee	SWW	41.7
Tetraploid	AB	*T. durum*	4B148		7.7
		T. polonicum	4B254		8.2
			Line 126		8.6
		T. durum	Wells		8.7
			Duro Bari 39		8.9
		T. persicum	4B280		8.9
		T. durum	Pelissier		8.9
			Stewart 63		9.1
			Ramsey		9.4
		T. dicoccum	4B94		9.9
		T. durum	Senator Cappelli		10.0
		T. turgidum	4B117		10.2
			4B118		10.5
		T. durum	4B233		11.1
		T. dococcum	4B90		13.1
Diploid	A	*T. monococcum*	2B29		37.2
	A		2B34		42.0
	R	*Secale cereale*			42.6
	A	*T. monococcum*	2B24		43.1
	D	*Aegilops squarrosa*	Strangulata I		43.6
	R	*S. cereale*			44.7
	D	*A. squarrosa*	Typica		46.0
	D		Strangulata II		46.9
	R	*S. cereale*			46.9

[a] HWS = Hard white spring, HRS = hard red spring, HRW = hard red winter, SRW = soft red winter, SWS = soft white spring, SWW = soft white winter.

TABLE IV
Variability in Hardness of Wheat Types and Varieties

	Mean Statistical Data for Wheat Types			Mean Statistical Data for Varieties Within a Type		
	Diploid	Tetra-ploid	Hexa-ploid	Diploid	Tetra-ploid	Hexa-ploid
Number of observations	9	15	28	3	4	7
Mean PSI (%)	43.7	9.8	24.6	43.6	9.0	24.6
Standard deviation	3.0	1.4	9.8	2.3	0.9	8.5
Coefficient of variability (%)	6.9	14.2	40.0	5.3	10.0	34.7

general appears to result in hard wheats with higher milling quality (as assessed by extraction, flour color, and ash) than does the Falcon type of hardness, which can be expressed in wheats approaching durum consistency. The soft counterparts of wheat in both categories of hardness defined by Symes in this study were of the same degrees of softness.

MATERIALS AND METHODS

To investigate the degree to which chromosome number itself directly affected grain hardness, a series of pure cultivars of wheats were assembled. The series comprised specimens of wheats of diploid, tetraploid, and hexaploid chromosome number. At least two species and two cultivars within a species were included.

The wheats were all grown under field conditions at Glenlea, Manitoba. Hardness was assessed by the PSI test using a LabConco model 900 burr mill. The ground meals (10 g) were sifted for 10 min through U.S. standard 200-mesh (74 μm) sieves, using a Ro-tap sieve shaker. The throughs were weighed and recorded as PSI percentage. By this test the softer wheats, because they more readily disintegrate, give more fine particles, so that higher proportions of throughs indicate softer wheats. Three genera of diploids were studied, including two wheats (*Triticum* and *Aegilops*) and one rye (*Secale cereale*); three cultivars of each species were tested. Five species of tetraploid wheats were studied. Within the species, up to eight cultivars were studied. Hexaploid wheats included four species. Of these, *T. compactum*, *T. sphaerococcum*, and *T. spelta* were represented by two or three cultivars. Over 20 cultivars of *T. aestivum*, the most common wheat, were tested. These originated in Canada, the United States, and Australia. All tests were carried out in duplicate.

RESULTS AND DISCUSSION

Hardness in wheat can be classified on the basis of the PSI test as summarized in Table I. A recent extensive collaborative study revealed that all 10 collaborators were able to distinguish between wheats of different hardness with an average correlation coefficient of 0.995 (Christensen 1983). Precision of PSI testing in the present study was verified by grinding and sieving three different check samples of hard red spring, durum, and soft white winter wheats. Results of precision testing are summarized in Table II.

The results of testing over 50 wheats for hardness are summarized in Table III. All of the diploid wheats were very soft, whereas all of the tetraploids were very hard. A complete spectrum of hardness was displayed by the hexaploid lines. The indications were that: 1) Both the DD and AABB chromosome assemblages result in a kernel texture with a small range in hardness. Cultivars with the DD chromosomes were all soft, including the two *Secale* lines, whereas the AABB tetraploids all ranged from very hard to hard. 2) The combination of the DD chromosomes with the AABB chromosome assemblage resulted in a breakdown or "unlocking" of the restrictions in hardness displayed by diploid and tetraploid wheats, with the result that hexaploid wheats with the full range of hardness can be encountered in a wheat-breeding program. These observations are summarized by the coefficients of variability data in Table IV.

The effect of combinations between diploid and tetraploid wheats is also apparent with hexaploid triticales. The rye varieties tested were all soft, with a very low range of hardness. A series of 280 triticale cultivars, all of which represented crosses between *S. cereale* and *T. durum* varieties, were recently tested at ICARDA, the International Centre for Agricultural Research in the Dry Areas at Aleppo, Syria. The series showed a range of 7.8–34.6 in PSI, and a coefficient of variation of 35%.

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