Breadmaking Quality of Einkorn Wheat (*Triticum monococcum* ssp. *monococcum*)

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ABSTRACT

Cereal Chem. 73(2):208-214

Twenty-five Einkorn lines (*Triticum monococcum* ssp. *monococcum*) were evaluated for their agronomic performance in Italy and Germany. Seeds produced in 1993 in the two locations were used for breadmaking quality tests. Flour was produced (after dehulling) with an experimental mill. Flour yield and the percentage of fine particles of all Einkorn lines were similar to the bread wheat standard. The protein content (N × 5.7) of Einkorn lines ranged from 13.2 to 22.8%, values higher than those found for bread wheat (10.8–13.3%). SDS sedimentation volume of Einkorn genotypes ranged from 11 to 93 ml. Seven Einkorn lines had acceptable gluten strength that yielded alveograph values and farinograph stability indices similar to those of bread wheat. Most Einkorn flours produced sticky dough; however, about one-third gave an acceptable dough and produced breads with a bright yellow color with volumes similar to, or better than, bread wheat. Rheological parameters and bread volume correlated positively with SDS sedimentation volume. About 16% of the 1,099 accessions screened for SDS sedimentation volume gave values above 60 ml, the threshold value for considering a genotype potentially suitable for breadmaking. Einkorn could become an important crop for the production of baked foods rich in carotenoids and proteins.

Einkorn (*Triticum monococcum* ssp. *monococcum*), a diploid wheat carrying the A genome ($2n=2x=14$), was among the crops that founded agriculture in the Near East. During the Bronze Age, Einkorn was gradually replaced by tetraploid and hexaploid wheats and today is cultivated only sporadically (Kimber and Feldman 1987). Because of its variability for several yield and resistance traits and the diploid state of its genome, which supports higher genetic gains during selection, Einkorn has been recently reconsidered as potentially interesting for future cultivation (Waines 1983, Vallega 1992).

Several authors have evaluated the genetic variability for agronomic traits (Sharma et al 1981; Waines et al 1987; Guzy et al 1989; Rafi et al 1992; Vallega 1979, 1992; Castagna et al 1995), while the quality related traits of this species have been considered in only a few reports. According to D'Egidio et al (1993), the first report on Einkorn quality goes back to LeClerc et al (1918), who reported high ash and gluten content in one Einkorn line. Schiemann (1948) described the Einkorn flour as very fine, rich in gluten, and with a pronounced yellow color. Yamashita et al (1957) pointed to the sticky dough of some Einkorn genotypes, which nevertheless produced an acceptable bread volume. According to Williams (1986), the softness of Einkorn flour equals that of the softest bread wheat cultivars. High values for wet gluten content, associated with Phelshenke test values close to that of the hexaploid wheat and low Berliner test values, were observed by Mettin (1964). D'Egidio et al (1993) found, in 12 lines, flour yields similar to those of bread wheat associated with fine particles. In the same experiment, the rheological properties measured with the Chopin alveograph showed W values variable between 24 and 65 × 10^{-4} J.

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Publication no. C-1996-0223-01R.

Recently, Blanco et al (1994) described Einkorn having a mean protein content of 15.5% and mean SDS sedimentation volumes two times higher than those reported by D'Egidio et al (1993). Genetic variability for storage protein and their inheritance were studied in *T. monococcum* by Waines and Payne (1987), Galili et al (1988), and Metakovsky and Baboev (1992). A first attempt to associate the presence of certain alleles and breadmaking quality evaluated with SDS sedimentation test among genotypes was recently made by Saponaro et al (1995).

In spite of the fact that Einkorn breadmaking quality has been considered by the articles cited above, still the need exists to perform a broader study using a large set of different Einkorn genotypes and determining all bread quality traits simultaneously. We report on the breadmaking quality of 25 Einkorn lines. Moreover, having verified the existence of a correlation between SDS volume and breadmaking itself, we have also screened 1,099 samples of cultivated and wild Einkorns based on the SDS volume of their flour.

MATERIALS AND METHODS

Seventeen Einkorns were obtained from different gene banks, and eight lines were selected out of the German "Winterform" population (1–8 and 22–24). All 25 lines were evaluated for their agronomic performance for two years in Germany and Italy (Castagna et al 1995). The 1993 seed harvested at Milan (MI) and Cologne (COL) were used for quality tests. The two bread wheat cultivars used as standards were grown at MI in the same field. For comparison, one of the best commercial flours available for breadmaking was also used.

All Einkorns were tenacious-glumed and were mechanically dehulled with the Otake FC4S apparatus (Satake, Japan). The glumes of 10 g of grain produced at MI were removed by hand and the ratio between grain weight, free of adhering structures, and the weight of husked grain was calculated (net/gross). Seeds from the four replications of each location were blended. About 3 kg of seed per line from MI and 1 kg from COL were tempered overnight (at 15% moisture) and milled with the experimental mill Bona-GRB (Bona, Italy).

For some lines, the amount of flour obtained in COL was insufficient to carry out the baking test. Particle size was calculated from flour samples of 200 g using sieves with a diameter of 30 cm and mesh apertures of 125 and 80 μm. The sieves were mechanically shaken (200 times per min) for 5 min. Flour protein content (N × 5.7 in dry matter) was determined photometrically after microKjeldahl digestion using the indophenol method performed automatically by a Carlo Erba autoanalyzer (Carlo Erba, Italy) as described by Corbellini and Borghi (1985). Sedimentation volume with a solution of 3% sodium dodecyl sulfate (SDS) was carried out according to Preston et al (1982) with minor modifications. Specific sedimentation volume, i.e., the SDS sedimentation volume per unit of protein, was calculated by dividing the sedimentation volume by the protein content. The falling number test was performed according to the ISO method 3093-1982 with the Falling Number 1400 apparatus (Falling Number AB Stockholm, Sweden). Pigments, expressed as carotenoids in ppm, were determined according to AACC method 14-50. Rheological evaluation was performed with the Chopin alveograph according to ICC method 121-1992 and with the Brabender farinograph using a 50-g mixer according to ICC 115-D-1972.

Bread was baked according to AACC method 10-10 with some modifications (Borghi 1979) introduced to render the procedure more similar to the one traditionally used in Italy. The basic ingredients were flour at 14% moisture (200 g) with added fresh compressed yeast (3%), salt (sodium chloride 1.5%), sucrose (6%), pork fat (3%), and ascorbic acid (8 mg). The quantity of water was determined according to farinograph water absorption at 500 Brabender units (BU). Doughs were scaled to constant flour weight (100 g of flour on 14% m.b.) and were proofed for a constant time of 50 min at 29°C. At least two baking tests were done per each entry. Bread volume was measured with a rapeseed displacement and referred to 100 g of flour on 14% m.b. Crumb texture was scored on the Mosh (1–8) scale (Dallmann 1981). Standard ANOVA (analysis of variance) and correlation analysis between traits were performed with the MSTAT-C (1990) software package. The level of significance of the coefficients of correlation (r) has been indicated with one (*) or two (**) asterisks for $P \leq 0.05$ and ≤ 0.01, respectively.

RESULTS

Yield and Yield-Related Traits

Detailed results concerning grain yield and other agronomic characteristics have been published elsewhere (Castagna et al 1995). Mean gross grain yield was 2.84 t/ha at MI and 4.63 t/ha at COL (Table I). In both locations, kernel weight of *T. monococcum* was about 50% less than that of bread wheat. Net grain yield, on average, represented 77% of gross yield, with a wide variation (63–92%) among lines. Gross grain yield was associated positively with kernel weight only at MI (r = 0.41*), whereas kernel size did not affect either net-gross grain yield or flour yield.

Flour Characteristics

Flour yield of the 25 Einkorn lines was similar to that of the soft texture bread wheat Centauro and higher than in the hexa-

TABLE I
Grain Yield, Kernel Weight, and Milling Yields of 25 Einkorn Lines Grown at Two Locations: Milan (MI), Italy, and Cologne (COL), Germany, in 1993 Compared with Bread Wheat

	Gross Grain Yield (t/ha)		Net-Gross (%)	Kernel Weight (mg)		Milling Yields, %						Flour Particle Size, μm	
						Flour		Fine Bran		Bran		% <125	% <80
Entry	MI	COL	MI	MI	COL	MI	COL	MI	COL	MI	COL	MI	MI
1 WP-1 ISC	2.46	3.39	82	27.8	34.0	61.1	57.9	24.6	31.3	13.8	10.9	87.3	51.3
2 WP-2 ISC	2.12	4.04	71	22.5	24.1	63.7	60.2	24.5	30.1	11.8	9.6	90.8	68.0
3 WP-7 ISC	3.35	5.39	80	25.1	26.4	60.9	59.8	23.4	28.8	15.7	11.4	88.6	55.2
4 WP-31 ISC	2.40	4.73	82	24.9	26.8	62.2	64.2	22.7	25.6	15.1	10.2	89.3	60.1
5 WP-48 ISC	2.32	5.47	77	20.4	26.3	61.5	58.9	26.5	30.5	12.0	10.6	91.4	63.6
6 WP-67 ISC	3.09	5.23	79	22.1	25.3	60.2	58.8	24.4	29.1	15.4	12.1	89.0	55.3
7 WP-70 ISC	2.25	3.95	76	22.9	22.1	63.4	60.8	24.3	23.2	12.3	16.0	89.8	62.4
8 WP-72 ISC	2.41	4.18	71	18.3	26.6	63.0	57.8	22.4	29.5	14.6	12.7	89.0	54.2
9 MG-4276 IDG	2.91	4.83	88	25.8	27.1	63.7	65.3	21.1	25.1	15.2	9.6	89.9	58.5
10 MG-4278 IDG	2.73	4.61	91	23.3	25.8	62.1	62.8	22.4	26.4	15.5	10.8	87.4	63.7
11 MG-4280 IDG	2.85	4.79	70	27.1	29.8	64.3	63.9	22.6	26.1	13.1	10.0	91.7	62.3
12 IDG-4232 IDG	3.05	4.50	85	24.1	23.3	64.1	62.4	21.2	24.7	14.7	12.9	88.9	57.6
13 IDG-4242 IDG	2.93	4.41	71	27.1	35.3	62.9	61.4	23.4	28.2	13.7	10.4	86.9	51.5
14 IDG-4515 IDG	3.19	4.39	81	24.5	28.6	64.4	65.2	20.0	24.1	15.6	10.7	89.5	59.4
15 EINKORN MPI	2.71	4.93	69	20.8	28.3	61.9	58.0	24.7	29.3	13.4	12.7	88.2	60.2
16 486 RAC	2.64	4.75	78	22.2	24.9	62.4	59.4	22.4	28.9	15.2	11.7	89.1	62.4
17 1496-1 RAC	2.95	4.49	85	23.2	22.1	62.6	60.5	25.0	25.6	12.4	13.9	89.9	53.3
18 1496-2 RAC	3.22	5.23	78	21.7	28.3	61.7	63.9	25.8	26.1	12.5	10.0	91.1	56.3
19 1497 RAC	3.31	5.06	92	27.2	32.4	61.2	54.8	22.5	36.5	16.3	8.7	84.9	49.3
20 1498 RAC	3.45	5.06	66	25.6	31.9	62.6	60.3	22.0	30.3	15.4	9.4	86.7	52.8
21 2372 RAC	3.33	4.88	82	24.4	33.7	64.4	60.9	22.7	25.7	12.9	13.4	90.1	54.8
22 WP-44 ISC	2.47	3.84	63	21.1	25.3	63.3	57.3	28.1	24.9	8.6	17.8	90.1	54.5
23 WP-63 ISC	2.86	4.36	67	23.0	23.8	61.9	59.8	23.7	24.8	14.4	15.4	89.2	43.6
24 WP-65 ISC	2.92	–[a]	70	26.1	–	60.8	–	25.1	–	14.1	–	89.2	61.2
25 Winterform MPI	3.02	–	69	26.2	–	62.7	–	22.9	–	14.4	–	88.4	51.0
Mean	2.84	4.63	77	23.9	27.5	62.5	60.6	23.5	27.6	13.9	11.8	89.1	56.9
LSD (P = 0.05)	0.57	0.49	6	5.1	6.2								
SE	0.08	0.11	1.6	0.5	0.8	0.2	0.6	0.4	0.6	0.3	0.5	0.3	1.1
Bread wheat	8.19[b]	9.55[b]										72.3[c]	39.0[c]
Centauro	7.11	–	–	39.1	–	60.6	–	28.8	–	10.6	–	84.4	58.9
Pandas	6.96	–	–	46.4	–	52.6	–	30.0	–	17.4	–	76.1	38.9

[a] Missing data.
[b] Mean value of the best five bread wheat cultivars.
[c] Commercial flour.

ploid wheat variety Pandas, which has a harder texture (Table I). Variability between lines was in the range of 3–4%. The lower percentage of bran found in the location of COL compared to MI can likely be related to the larger kernel size found in this location. This positive characteristic was associated with a higher percentage of fine bran, which in COL was correlated to a lower flour yield. Einkorn yielded a percentage of fine (<125 μm) and very fine (<80 μm) flour similar to those of the soft wheat variety Centauro. The variability found in Einkorn genotypes for percentage of very fine particles (<80 μm) was high, and values close to that of the hard texture bread wheat Pandas were recorded.

Qualitative Characteristics

The average carotenoids content of the Einkorn lines grown at MI (Table II) ranged from 12.7 to 28.3 ppm and, on the average, was five times higher than the value of the bread wheat standard. The highest Einkorn value was nine times higher than that of bread wheat control flours. In both locations, protein content was also higher in Einkorns than in bread wheat. A large variability among lines for protein and gluten content was noted. Lines 13 and 20 did not form gluten at MI, while in COL, five out of the 13 lines tested behaved similarly to lines 13 and 20 at MI (note that the protein content in COL was lower than in MI). Dry and wet gluten were highly correlated ($r = 0.97^{**}$). At COL, gluten occurred at higher percentages (of the total protein content) in the gluten-producing lines, when compared with the values observed for the same lines cultivated at MI.

Concerning the SDS sedimentation volume, the difference between the two locations were reflected by the differences in total protein content. The variability in SDS sedimentation volumes among Einkorn lines were largely independent from total protein content, while a high correlation was found between SDS sedimentation volume and specific sedimentation volume ($r = 0.98^{**}$ at both locations). Four lines (1, 5, 13, and 20) gave SDS sedimentation volumes below 20 ml at both locations with specific sedimentation volumes below 1.2 ml; five Einkorn lines had an SDS sedimentation volume between 20 and 40 ml and another five between 40 and 60 ml. The remaining 11 Einkorns gave specific sedimentation volumes up to 6.6 ml and SDS sedimentation volumes as high as those of the hexaploid bread wheats. The falling number values were in the range of 280–350 sec at MI and 126–356 sec at COL (values below 200 sec are usually correlated to kernel sprouting).

Rheological Properties

The results of the alveograph and farinograph tests are reported in Tables III and IV for MI and COL, respectively. Einkorn doughs were often sticky but not to the point to make impossible the production of readable alveograms and farinograms. At MI, accessions 2, 4, 6, 10, 11, and 16 gave an acceptable gluten strength with W values above 100×10^{-4} J. Ten lines (1, 5, 13, 14, 15, 18, 20, 21, 24, and 25) gave W values below 50×10^{-4} J. Considering the components of dough strength, i.e., tenacity (evaluated by the P parameter) and extensibility (measured by the

TABLE II
Flour Characteristics of 25 Einkorn Lines Grown at Two Locations: Milan (MI), Italy, and Cologne (COL), Germany, in 1993 Compared with Bread Wheat

	Carotenoids[a] (ppm)	Protein Content[b] (%)		Gluten[a] (%) Dry		Gluten[a] (%) Protein		SDS Sed. Vol[a] (ml)		SDS Sed. Vol/Protein (ml)		Falling Number[a] (sec)	
Entry	MI	MI	COL	MI	COL	MI	COL	MI	COL	MI	COL	MI	COL
1 WP-1 ISC	12.7	22.8	22.9	13.9	nf[c]	60.7	nf	18	16	0.8	0.7	280	–[d]
2 WP-2 ISC	19.4	22.3	18.9	14.9	16.7	66.8	88.4	70	67	3.1	3.5	319	15
3 WP-7 ISC	22.1	19.9	15.9	14.7	–	73.9	–	53	18	2.7	1.1	303	–
4 WP-31 ISC	16.8	16.6	14.4	11.6	–	69.9	–	90	93	5.4	6.5	344	–
5 WP-48 ISC	18.4	22.1	14.4	13.9	nf	62.9	nf	13	13	0.6	0.9	307	313
6 WP-67 ISC	24.3	22.0	15.3	15.1	14.5	68.6	94.7	67	28	3.0	1.8	327	356
7 WP-70 ISC	25.6	20.8	17.3	11.5	–	55.3	–	46	27	2.2	1.6	298	188
8 WP-72 ISC	28.3	21.7	16.4	14.2	12.9	65.4	78.7	46	24	2.1	1.5	303	332
9 MG-4276 IDG	16.9	18.1	16.0	12.4	15.1	68.5	94.4	80	71	4.4	4.4	313	155
10 MG-4278 IDG	21.7	18.9	15.1	13.6	–	72.0	–	86	79	4.6	5.2	340	–
11 MG-4280 IDG	19.4	19.3	15.7	12.1	–	62.7	–	72	60	3.7	3.8	314	–
12 IDG-4232 IDG	20.7	18.2	14.5	12.7	13.8	69.8	95.2	63	76	3.5	5.2	307	219
13 IDG-4242 IDG	19.4	18.7	16.2	nf	nf	nf	nf	11	11	0.6	0.7	317	176
14 IDG-4515 IDG	17.8	20.2	16.6	13.9	nf	68.8	nf	27	14	1.3	0.8	293	158
15 EINKORN MPI	20.0	21.1	14.6	13.9	11.6	65.9	79.5	35	20	1.7	1.4	282	236
16 486 RAC	22.7	18.8	14.3	12.5	12.2	66.5	85.3	90	95	4.8	6.6	350	267
17 1496-1 RAC	20.4	19.9	17.6	13.2	–	66.3	–	55	72	2.8	4.1	304	164
18 1496-2 RAC	23.3	18.4	14.7	13.5	–	73.4	–	25	34	1.4	2.3	306	–
19 1497 RAC	19.9	16.5	13.2	9.7	nf	58.8	nf	65	31	3.9	2.3	335	236
20 1498 RAC	25.7	16.6	14.5	nf	–	nf	–	15	18	0.9	1.2	317	–
21 2372 RAC	24.0	20.2	15.6	14.1	–	69.8	–	23	41	1.1	2.6	302	–
22 WP-44 ISC	21.1	20.4	16.3	14.5	–	71.1	–	69	32	3.4	2.0	296	126
23 WP-63 ISC	21.0	19.4	16.0	13.4	14.3	69.1	89.4	52	46	2.7	2.9	308	143
24 WP-65 ISC	20.6	18.5	–	12.0	–	64.9	–	31	–	1.7	-	320	–
25 Winterform MPI	16.2	17.9	–	11.8	–	65.9	–	42	–	2.3	–	312	–
Mean	20.7	19.6	15.9	13.2	13.9	66.8	88.2	50	43	2.58	2.7	311	215
SE	0.7	0.4	0.4	0.3	0.6	10.0	2.3	5.0	5.7	0.3	0.4	3.6	18.9
Bread wheat[e]	3.2			10.9		12.5		89				285	
Centauro	3.7	10.8	–	8.1	–	75.0	–	69	–	6.3	–	302	–
Pandas	3.3	13.3	–	13.0	–	97.7	–	87	–	6.5	–	384	–

[a] Mean value of two replicates.
[b] Mean value of four replicates.
[c] Not formed.
[d] Missing data.
[e] Commercial flour.

L parameter), it was evident that the two groups of lines differed remarkably in extensibility. The *L* value of the best line was 121 mm but for the poorest Einkorn only 36 mm, whereas the *P* value decreased from 58 to 39 mm, respectively, in the two groups of genotypes. Farinograph water absorption ranged from 53 to 60% and was positively correlated with protein content ($r = 0.67^{**}$). Lines 5, 13, 14, 15, and 21 had development times shorter than 75 sec, associated with a reduced farinographic stability and a high degree of softening. The best farinograms were obtained with lines 4, 6, 9, 10, 16, and 19, characterized by a degree of softening of 90–170 BU and by stability indices of 120–270 sec. At COL (Table IV), only line 16 gave an alveograph *W* value higher than 100×10^{-4} J. Lines 8, 16, and 18 gave outstanding farinograms with good stability times. Their degree of softening was intermediate between those of the two bread wheats.

Baking Test

The baking results are reported for the MI location in the last three columns of Table III. Due to the shortage of flours from COL, the baking test was carried out on only five lines and the results are shown in Figure 1. Optimal mixing time, judged by the manual evaluation of the developing dough, was shorter than the development time recorded with the farinograph. Lines 1, 7, 8, 13, 15, 18, 20, 21, and 25 grown at MI and lines 13 and 15 from COL gave unacceptable sticky doughs. For these lines, it was impossible to transfer the dough to the fermentation bowl for the successive punching. Doughs were therefore transferred directly to the baking pan. Bread volumes of these lines were less than 350 cm^3 and had a texture score below 3. Among the remaining lines, 10 from MI and one from COL gave bread volumes similar to or higher than the one recorded for Pandas, a bread wheat of high baking quality. Lines 4, 10 (tested only at MI), and 16 (the best from COL) had medium to long mixing times and crumb texture scores close to those of bread wheats. Line 10 (from MI) had a bread volume higher than the one observed for the commercial flour.

Associations Between Qualitative Traits

Protein content was correlated with dry gluten content ($r = 0.75^{**}$ at MI and $r = 0.78^{**}$ at COL) and with farinograph water absorption ($r = 0.71^{**}$ at MI and $r = 0.51^{*}$ at COL). SDS sedimentation volume did not correlate with the protein content, nor with the percentage of gluten in total protein. All rheological parameters were, at both locations, significantly correlated with SDS sedimentation volume, the highest values being obtained at MI with alveograph *W* ($r = 0.88^{**}$), bread volume ($r = 0.82^{**}$), and alveograph *L* ($r = 0.80^{**}$). Bread volume was significantly correlated with alveograph *W* ($r = 0.73^{**}$) and *L* ($r = 0.64^{**}$), with farinograph stability ($r = 0.58^{*}$) and with the degree of softening ($r = 0.63^{**}$), but the largest correlation was found with SDS sedimentation volume (see above).

No significant associations were found between the specific sedimentation volume and the rheological parameters or the bread volume.

TABLE III
Chopin Alveograph, Brabender Farinograph Parameters, and Results of Baking Test of 25 Einkorn Lines Grown at Milan (Italy) in 1993 Compared with Bread Wheat

	Alveograph[a]				Farinograph				Baking Test[b]		
Entry	*W* ($\times 10^{-4}$ J)	*P* (mm)	*L* (mm)	*P/L*	Water Absorption (%)	Development Time (sec)	Stability (sec)	Degree of Softness (BU)	Mixing Time (sec)	Crumb Texture Score (1–8)	Bread Volume (cm^3)
1 WP-1 ISC	44	52	22	2.39	58	90	45	210	50	2	295
2 WP-2 ISC	112	52	100	0.52	59	120	75	170	60	3	551
3 WP-7 ISC	67	45	70	0.65	59	90	60	170	60	5	520
4 WP-31 ISC	101	42	152	0.28	53	90	180	120	90	5	678
5 WP-48 ISC	39	39	38	1.03	58	75	60	200	45	2	415
6 WP-67 ISC	116	51	115	0.45	60	120	120	160	60	2	676
7 WP-70 ISC	61	42	76	0.55	60	90	60	210	60	2	384
8 WP-72 ISC	72	34	122	0.30	58	120	75	180	60	1	436
9 MG-4276 IDG	93	51	90	0.56	57	90	120	170	75	3	790
10 MG-4278 IDG	120	44	205	0.21	55	120	120	150	90	5	814
11 MG-4280 IDG	103	54	90	0.61	57	105	60	190	55	3	838
12 IDG-4232 IDG	52	36	58	0.61	57	120	60	190	60	3	550
13 IDG-4242 IDG	14	30	10	3.03	53	45	45	260	40	3	359
14 IDG-4515 IDG	14	23	12	1.83	57	60	45	250	110	2	614
15 EINKORN MPI	49	42	52	0.80	59	75	60	220	60	2	356
16 486 RAC	137	45	184	0.24	54	120	270	90	110	4	755
17 1496-1 RAC	74	45	80	0.56	58	120	60	180	60	2	680
18 1496-2 RAC	50	37	71	0.52	58	90	45	210	50	2	390
19 1497 RAC	80	53	49	1.08	53	90	150	120	125	4	630
20 1498 RAC	36	44	20	2.17	56	90	45	210	45	2	321
21 2372 RAC	44	42	42	1.00	58	75	45	210	60	6	336
22 WP-44 ISC	61	45	60	0.75	60	120	60	190	60	2	548
23 WP-63 ISC	69	44	80	0.55	59	120	60	180	60	4	604
24 WP-65 ISC	42	40	39	1.03	56	90	60	200	45	2	560
25 Winterform MPI	47	41	51	0.80	56	120	60	220	60	2	354
Mean	68	43	76	0.90	57	98	82	186	66	3	538
SE	6.6	1.5	10.0	0.1	0.4	4.4	10.6	7.7	4.4	0.3	33.5
Bread wheat											
Centauro	216	73	77	0.95	53	90	120	50	300	5	634
Pandas	254	64	159	0.40	59	180	1,080	30	180	5	741
Commercial flour	297	67	138	0.49	58	90	1,140	40	240	6	775

[a] Mean value of four replicates.
[b] Mean value of two replicates.

TABLE IV

Chopin Alveograph and Brabender Farinograph Parameters of 23 Einkorn Lines Grown at Cologne (Germany) in 1993 Compared with Bread Wheat[a]

	Alveograph[b]				Farinograph			
Entry	*W* (J × 10^{-4})	*P* (mm)	*L* (mm)	*P/L*	Water Absorption (%)	Development Time (sec)	Stability (sec)	Degree of Softness (BU)
1 WP-1 ISC	17	33	10	3.30	56	75	60	250
2 WP-2 ISC	–[c]	–	–	–	57	90	138	160
3 WP-7 ISC	54	46	41	1.12	–	–	–	–
4 WP-31 ISC	71	41	78	0.52	53	120	150	125
5 WP-48 ISC	26	34	22	1.53	54	60	60	170
6 WP-67 ISC	56	46	41	1.12	55	90	25	110
7 WP-70 ISC	40	35	45	0.79	56	70	150	145
8 WP-72 ISC	50	34	56	0.60	52	75	330	80
9 MG-4276 IDG	58	38	63	0.60	54	120	150	170
10 MG-4278 IDG	36	30	44	0.69	53	120	150	150
11 MG-4280 IDG	51	40	48	0.83	54	120	165	140
12 IDG-4232 IDG	67	44	63	0.70	53	120	132	105
13 IDG-4242 IDG	9	19	10	1.86	52	60	45	270
14 IDG-4515 IDG	14	20	15	1.32	56	60	45	265
15 EINKORN MPI	38	34	40	0.85	55	85	105	140
16 486 RAC	100	40	129	0.31	52	135	690	30
17 1496-1 RAC	54	35	69	0.51	55	105	204	120
18 1496-2 RAC	37	29	47	0.61	53	75	255	90
19 1497 RAC	54	57	21	2.66	53	75	120	165
20 498 RAC	30	37	22	1.66	57	75	36	240
21 2372 RAC	43	34	53	0.63	55	90	66	205
22 WP-44 ISC	31	31	35	0.89	–	–	–	–
23 WP-63 ISC	44	31	68	0.46	55	90	180	135
Mean	45	36	46	1.07	54	91	155	155
SE	4.4	1.8	5.7	0.2	0.4	5.1	31.5	13.6
Commercial flour	297	67	138	0.49	58	90	1,140	40

[a] The results concerning baking test of five lines are reported in Figure 1.
[b] Mean value of four replicates.
[c] Missing data.

DISCUSSION

Our results concerning 25 genotype of *T. monococcum* demonstrate the existence of a large variability for breadmaking quality in Einkorn. Figure 1 illustrates rheological and baking data of five Einkorn lines chosen because of their different breadmaking quality. For each line, the flours originated from Cologne and Milan gave similar results, showing the genetic nature of the differences between good and poor breadmaking quality lines. Compared to the bread wheat control (cv. Pandas), Einkorn bread has a brilliant yellow color due to its high carotenoids content. Because grain yield of Einkorn has potential to be increased (Vallega 1979, Waines 1983, Castagna et al 1995), we concluded that the future commercial exploitation of Einkorn for quality food is a reasonable suggestion. There is, in fact, an increasing demand for "new" foods having extra attributes, like high carotene and protein contents. In addition, Einkorn is suspected to be less toxic than are tetraploid and hexaploid wheats to celiac disease patients (Auricchio et al 1982, Favret et al 1984, 1987).

Showing that Einkorns can have breadmaking characteristics comparable to conventional bread wheats is the most significant result of our experiment. This is new compared to the report of Zohary and Hopf (1993), where Einkorn is described as giving bread of poor rising quality, being consumed, in Roman times, primarily as porridge or plainly cooked. This negative appreciation of the Einkorn flours was also shared by D'Egidio et al (1993). However, some of the lines considered to be of poor quality by the cited authors were shown to produce bread volumes in the range of those of polyploid wheats (D'Egidio and Vallega 1994). We conclude that the widespread assumption that Einkorn is not a breadmaking wheat should be reconsidered. In fact, we obtained high bread volumes from more than one-third of the Einkorns genotypes investigated.

The consideration of Einkorn flours in breadmaking is, to some extent, supported by archaeological data. Excavations done in European alpine locations allowed the discovery of leavened bread remains dated between 3500 and 5000 years before present (Währen 1984, 1990), and in one carbonized loaf a definitive proof of the presence of Einkorn seeds has been given (Castelletti et al 1992).

The total number of Einkorn varieties characterized by rheological tests for their breadmaking ability (25 in this study and 12 in that of D'Egidio et al 1993) is too limited to reach a general conclusive statement concerning this species. Recently, however, several hundred strains of Einkorns were screened by SDS sedimentation volume or other micro-tests and high values were reported (Mettin 1964, Blanco et al 1994, Saponaro et al 1995). We have also screened (data not published) 385 accessions of cultivated Einkorns together with 714 primitive forms of *T. monococcum* ssp. *boeoticum*. At least 172 accessions (i.e., 16 % of the total) gave SDS sedimentation volumes higher than 60 ml, which in our experiment resulted the threshold value for considering a genotype potentially suitable for breadmaking. It is concluded that the SDS sedimentation values obtained for the 1099 strains of wild and cultivated Einkorns indicate that an ample reserve of breadmaking genes exists in this species.

ACKNOWLEDGMENTS

This work has been supported by Italian Ministry of Agriculture, Project: Miglioramento cerealicolo per innovazioni agroindustriali (M.I.C.I.A.). We are grateful to F. Codecà and A. M. Biancardi for skillful technical assistance in rheological and baking tests.

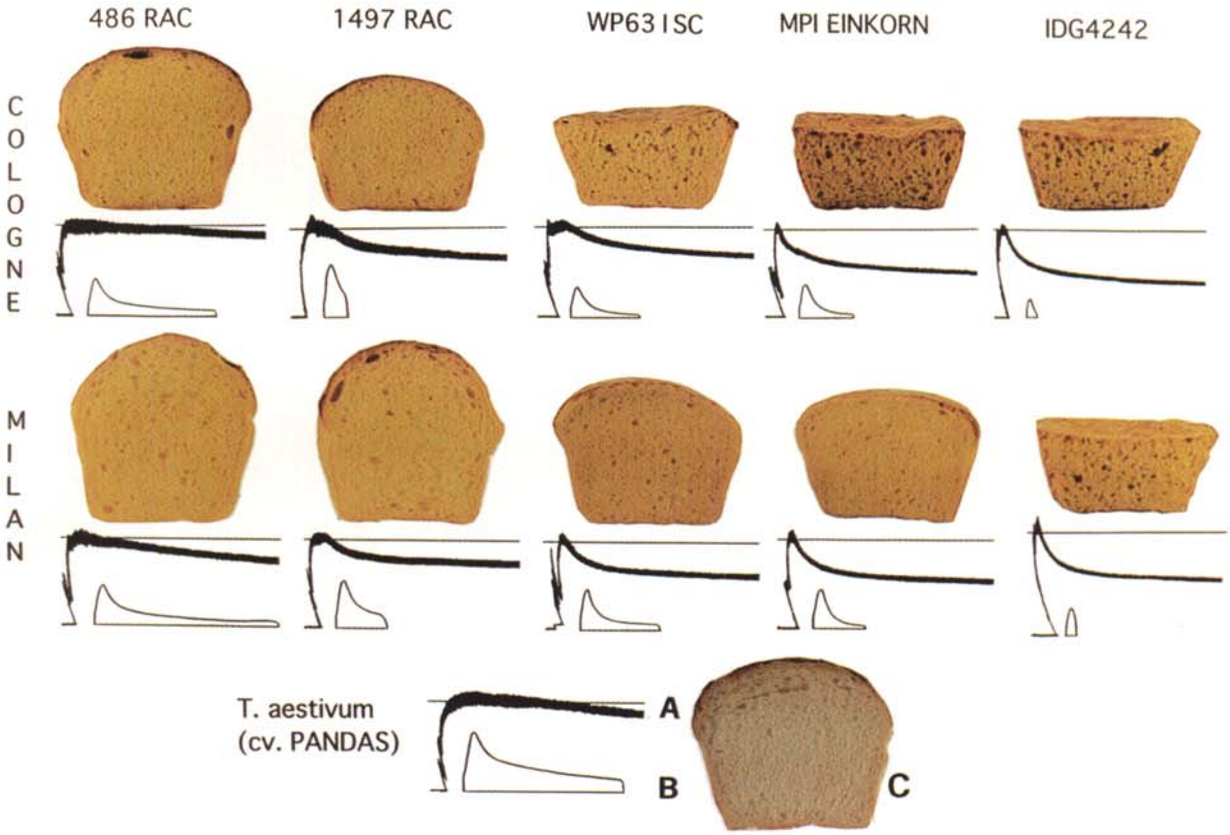

Fig. 1. Farinograms (A), alveograms (B) and breads (C) obtained from the flours of the Einkorn lines 486RAC, 149RAC, WP63ISC, MPI Einkorn, and IDG4242 grown in two locations (Cologne, Germany, and Milan, Italy). The lines are presented from left to right with decreasing breadmaking quality. The bread volumes and the crumb texture score (in brackets) of the Cologne location were 620 [6], 502 [6], 378 [2], 344 [3], and 302 cm^3 [3]. The cultivar Pandas was taken as a bread wheat control.

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[Received May 2, 1995. Accepted November 1, 1995.]