

Einkorn Characterization for Bread and Cookie Production in Relation to Protein Subunit Composition

M. Corbellini,¹ S. Empilli,¹ P. Vaccino,¹ A. Brandolini,^{1,2} B. Borghi,^{1,3} M. Heun,⁴ and F. Salamini⁵

ABSTRACT

Cereal Chem. 76(5):727–733

Twenty-four einkorns were evaluated for agronomic traits in Italy and in Germany in replicated plot trials. After dehulling and milling, the harvested kernels, flour protein content, sedimentation volume, falling number, carotenoid, and dry gluten content were determined. Faringraph profiles were obtained with a farinograph and baking and cookie quality were evaluated with standard microtests. Significant differences in yield potential were observed between the two locations, with a three-fold increase in Germany as compared with Italy. One of the einkorn lines (ID529) had farinograph stability and degree of softening indices better than those of the control bread wheat. All the samples analyzed for breadmaking aptitude showed some degree of stickiness, but it was possible to handle the dough during the different steps of breadmaking. On average, cookies

produced with einkorn flour were larger in diameter and thinner than those produced with soft wheat flour. The composition in α -, β - and γ -gliadins and in high molecular weight glutenin subunits was similar in all the lines. In contrast, the pattern exhibited in low molecular weight glutenin subunits correlated strictly with baking quality. In particular, the lines with bands arbitrarily designated *a* and *b* showed a high breadmaking potential, while the lines lacking these bands had an ample range of variability but, on average, a much lower baking potential. Our data point to a simple genetic control of the breadmaking aptitude and indicate einkorn not only as a promising source of specialty foods but also as an ideal species for genetic investigations on wheat quality.

In recent years, interest on the qualitative aspects of primitive wheats has grown, and special attention has been given to the development of new or special foods. These include bakery products, baby food, products with high dietary fiber content and carotenoids, as well as food for diabetic and celiac disease patients (Auricchio et al 1982, Favret et al 1987, Borghi et al 1996). For all these products, einkorn (*Triticum monococcum* ssp *monococcum*), a diploid wheat with A genome ($2n=2x=14$), is a promising candidate.

Einkorn was the first wheat to be domesticated some 10,000 years ago in the Near East (Nesbitt and Samuel 1996). It was widely cultivated in the Neolithic Age but during the Bronze Age it was gradually replaced by tetraploid and hexaploid wheats. Today einkorn is a relic crop, sporadically grown in marginal areas of the Mediterranean region and in West Asia (Nesbitt and Samuel 1996). In spite of the monophyletic origin (Heun et al 1997), einkorn varieties are genetically well differentiated for several agronomic traits, to the point that the breeding of lines adapted to modern farming is feasible (Waines 1983; Vallega 1992, 1996; Castagna et al 1995).

Until recently einkorn was believed unsuitable for baking products because of its poor rheological properties. In Roman times it was eaten primarily as porridge or plainly cooked (Schiemann 1948). Moreover, in the areas where einkorn still survives, the grains are used for animal feeding and the straw is employed in the construction of thatched roofs of still primitive houses (Peña-Chocarro 1996). Early experimental results speak of very soft texture of the kernel, flour characterized by a pronounced yellow color and high protein, and gluten content associated with sticky dough (Schiemann 1948, Yamashita et al 1957). Recent rheological experiments opened new perspectives for einkorn wheat in the food industry. D'Egidio et al (1993) confirmed the poor rheological properties of einkorn doughs, however, D'Egidio and Vallega (1994) were able to obtain some einkorn breads with loaf volumes and characteristics similar to those of bread wheat, in spite of dough-handling difficulties. Abdel-Aal

et al (1997) characterized a spring type einkorn and found weak mixograph curves and low loaf volumes with no bromate response. More promising results were reported by our group (Borghi et al 1996): out of 25 einkorn lines evaluated for agronomic performance and breadmaking quality, nine had acceptable gluten strength, with alveograph values and farinograph stability indices similar to those of bread wheat. After baking, the nine lines produced bread with a bright yellow color and bread wheat loaf volume.

The 25 einkorns so far characterized by rheological and baking tests were a portion of the 386 strains present in our collection, which includes an additional 28 strains with a sedimentation volume >60 mL, a threshold value for considering a genotype suitable for breadmaking.

Our objectives were 1) to assess agronomic and qualitative properties of new einkorn strains cultivated in Italy and Germany, 2) to evaluate their potential value for bread and cookie production, and 3) to investigate the relationship between bread quality and endosperm protein subunit composition in einkorn.

MATERIALS AND METHODS

Einkorn Samples and Field Trials

After a two-year evaluation of 386 einkorn strains, the lines that had interesting agronomic or qualitative traits were seed-increased and included in multilocation trials. Twenty-four einkorns, including seven accessions already tested (Borghi et al 1996), were grown in Italy at Milan (MI) in 1995 and 1996, and in Germany at Cologne (COL) in 1995. The lines were evaluated for agronomic traits in randomized complete block design trials according to the standard procedures described by Castagna et al (1995).

Seeds of three replicates of each trial were blended, and a sample of ≈ 2 kg per line was mechanically dehulled (FC4S, Otake, Satake, Japan). After overnight tempering at 15% moisture, the samples were milled with an experimental mill (Bona 4RB, Bona, Italy). The control soft wheat cultivars, Centauro and Veronese, were tempered at 15% moisture for 24 hr and the control medium-hard wheat, Pandas, was tempered at 16% moisture for 36 hr according to the procedure indicated by Ferraresi et al (1997). The ratio between grain weight free of glumes and the weight of husked grain (net/gross) was computed using 10 g of manually dehulled grains.

Flour Characteristics

Protein content ($N \times 5.7$, dry matter) was determined as in Kirstein (1983). Sedimentation volume with SDS was determined according to Preston et al (1982). Specific sedimentation volume

¹ Istituto Sperimentale per la Cerealicoltura, Via Mulino 3, 26866 S. Angelo Lodigiano (LO), Italy.

² Corresponding author. E-mail: isc.sal@andromeda.it Fax: 0039 0371210372.

³ Present address: Istituto Agrario di San Michele all'Adige Via Mach 1, 38010 San Michele all'Adige (TN) Italy.

⁴ Agricultural University of Norway, Department of Biotechnological Sciences, N-1432 Ås, Norway.

⁵ Max Planck Institut, Carl-von-Linné-Weg 10, D-50829 Köln, Germany.

was calculated as the ratio between SDS sedimentation volume and protein content. Falling number was evaluated according to ISO method 3093 (1982). Carotenoid content was analyzed according to Approved Method 14-50 (AACC 1995). Dry gluten content was determined with an automatic gluten washing apparatus (Glutomatic, Perten North America, Reno, NV). Farinograph profiles (Brabender OHG, Duisburg, Germany) were determined used a 50-g mixer according to ICC method 115-D (1986).

Baking Quality

Bread loaves from 100 g of flour were produced according to Approved Method 10-10B (AACC 1995), with minor modifications (no milk or potassium bromate) to make the procedure more similar to that traditionally used in Italy, where soft and medium-hard wheat with high-protein content are used in baking (Borghi et al 1996). Bread volume was measured by rapeseed displacement, and crumb texture was scored on the Mosh scale (1–8) (Dallmann 1981). Baking tests were run in duplicate. Bread wheat cultivars Pandas and Centauro were included as controls.

Cookie Quality

Cookie quality was assessed as indicated by Approved Method 10-52 (AACC 1995). The test was performed on 17 einkorns cultivated at three sites. Cookie tests were performed in duplicate. Two soft cookie-type wheat flours were included in the experiment.

Electrophoretic Characterization

Gladians were extracted as described by Pogna et al (1990); 30 mg of flour were dissolved in 100 µL of aqueous 70% ethanol and left

for 1 hr at room temperature. After centrifugation for 5 min at 12,000 rpm, the supernatant was mixed with an equal volume of a solution containing 60% (w/v) glycerol and 0.05% (w/v) pyronin G, and separated by A-PAGE. Glutenins were extracted as described in Morel (1994). Briefly, 30 mg of flour was washed three times with 50% (v/v) propan-2-ol at 60°C for 30 min to remove the gliadin fraction. The residue was then reduced with 20 mM dithiothreitol (DTT), alkylated with 40 mM 4-vinylpyridine, and precipitated with cold acetone. The dried pellet was resuspended either in 60% (w/v) glycerol and 0.05% (w/v) pyronin G and separated by A-PAGE or in 16.5% (w/v) glycerol and 0.1M Tris-HCl, pH 6.8, 3.5% (w/v) SDS, and 0.016% (w/v) pyronin G, and fractionated by SDS-PAGE as described by Pogna et al (1989) using a 15% separating gel.

RESULTS

Agronomic Performance

Significant differences in yield potential were observed in the two locations, with a three-fold increase in samples from COL as compared with those from MI (Table I). Compared with the bread wheat cultivated in adjacent experiments, einkorn showed a yield penalty of 75% at MI and of 50% at COL. The majority of the lines had good winter hardiness in MI. Only the very early lines, ID347 and ID369, were severely damaged by cold in winter.

Plant height, measured at MI in 1996 under conditions of reduced fertility (no nitrogen fertilizer), was lower than expected. In spite of this, most of the lines were almost completely lodged at harvesting. Apparently, lodging was not associated to differences in plant height. The short line ID121 had a score of 9 for lodging and the

TABLE I
Grain Yield and Agronomic Characteristics of 24 Einkorn Lines Grown at Milan (MI) in 1995 and 1996 and at Cologne (COL) in 1995

ID Number	Collection ^a	Original Number	Country of Origin	Gross Grain Yield (t/ha)			Frost Damage (0-9)	Heading (Days from 4-1)	Plant Height (cm)	Lodging (0-9)	Net-Gross (%)
				MI	MI	COL	MI	MI	MI	MI	MI
				1995	1996	1995	1996	1996	1996	1996	1996
121	D-GAT	ATRI 11360/80	Russia	0.96	1.84	4.08	1	54	82	9	75
131	D-BRA	1471	Germany		1.56		0	56	100	7	
140	D-BRA	3524		1.26	1.61	4.42	0	53	98	4	78
188	D-BRA	13183	Italy	1.18	1.56	6.15	1	54	93	4	67
201	D-BRA	19733	USA	1.01	1.24	4.93	3	51	82	9	72
280	D-BRA	42017	Albania	0.97	1.63	4.72	0	55	92	3	77
324	D-BRA	43470	Near East	0.75	1.38	5.22	0	55	92	6	72
325	D-BRA	43471	Near East	1.32	1.59	5.36	0	55	88	9	
347	D-BRA	43493	Balkans	1.05	1.13	3.75	7	44	92	9	80
358	AR-INTA	22554	Romania	1.07	1.46	4.16	0	50	85	1	79
361	AR-INTA	22929		1.05	1.61	4.70	3	50	87	2	
369	IT-ISC	1126		0.98	0.95	2.54	7	49	85	6	77
372 ^b	IT-IDG	MG 4280		1.00	1.36	4.10	2	55	85	8	65
529	USA-NSGC	PI 277131	Europe		1.53		1	53	90	5	
559	USA-NSGC	PI 355523	Germany	1.08	1.67	6.20	0	53	90	6	75
560	USA-NSGC	PI 355526	Belgium	0.81	0.32		1	52	84	3	74
1327 ^b	IT-IDG	IDG 4242	Spain	1.30	1.54	4.53	2	55	95	4	74
1331 ^b	IT-IDG	MG 4278		0.93	1.17	3.96	4	54	95	8	76
1335	IT-IDG	IDG 10387	Italy	1.31	1.46	5.41	1	53	98	9	68
1348 ^b	CH-RAC	486 RAC		0.99	1.06	4.64	1	52	88	0	77
1351 ^b	CH-RAC	1498 RAC	Balkans		1.60		0	52	88	3	
1352 ^b	CH-RAC	2372 RAC	Balkans	1.18	0.79	5.29	2	52	90	0	71
1382 ^b	IT-ISC	WP 31 ISC	Germany		1.00		3	55	83	8	
1394	D-MPI	TMM001	Germany		1.40	5.32	3	54	88	9	
Mean				1.06	1.33	4.71	2	53	89	5	74
LSD ^c				0.47	0.54	0.91	2	2	12	5	
Bread wheat ^d				5.34	5.25	9.56	0	34	88	0	

^a D-GAT: Institut für Genetik und Kulturpflanzen Forschung, Gatersleben, Germany; D-BRA: Institut für Pflanzenbau und Pflanzenzüchtung, Braunschweig, Germany; AR-INTA: Instituto Nacional de Tecnología Agropecuaria, Argentina; IT-ISC: Istituto Sperimentale per la Cerealicoltura, Sant'Angelo Lodigiano (LO), Italy; USA-NSGC: National Small Grains Collection, Aberdeen, Idaho, USA; IT-IDG: Istituto del Germoplasma, Bari, Italy; CH-RAC: Recherches Agronomiques de Changins, Nyon, Switzerland; D-MPI: Max Planck Institut, Köln, Germany.

^b Lines considered in the experiment of Borghi et al (1996). Original number of these lines is indicated in the third column.

^c Least significant difference ($P < 0.05$).

^d Mean value of five bread wheat cultivars: Eridano, Soissons, Centauro, Pandas and Veronese.

semi-tall line ID1352 had a score of 0. Net grain yield was 74% of gross grain yield, on average, with a wide variation among lines (65–80%).

Flour Characteristics

Flour yields were low because of the experimental procedure and, across all trials, had a range of 53–60%, with no evidence of genotypic effects (Table II). This result was expected because all the einkorn samples had a very soft texture. The hardness index (SKCS 4100, Perten) ranged from -14.8 ± 13.4 to 4.0 ± 12.9 (data not reported), remarkably lower than 42, which is considered the threshold for soft wheats (Ferraresi et al 1997).

Carotenoid content was, to some extent, influenced by the environment. For example, MI 1995 was 2.4 ppm higher than MI 1996. The genotypic differences were significant, line ID 347 had values <10 ppm at all the three sites and line ID 361 had values of 16.8–20.9 ppm. Compared with bread wheat, einkorn carotenoid content was up to 10 times higher, conferring a typical bright yellow color to all einkorn baked products.

Protein content ranged from 17.7% at COL 1995, the site characterized by the highest grain yield, to 20.2% at MI 1995, where 25% of the grain weight of line ID560 was protein. Out of the 62 einkorn samples examined, 17 had a protein content >20%.

SDS sedimentation volume revealed large fluctuations, with values covering almost the whole scale of variability (7–97 mL). When considering only the lines evaluated at all locations, the SDS sedimentation volume behaved as if it were under strict genetic control; lines ID325, ID1327, and ID1352 always had values <18 mL, while lines ID140, ID358, ID361, ID1331, and ID1348 all had SDS values >50 mL. It was impossible to extract gluten after dough washing from the lines of the first group, while the lines of the second group yielded 10.8–14.3% dry gluten.

Falling number was ≈ 300 sec on average, with only three samples <250 sec. These values indicated that the einkorn samples analyzed were not sprouted.

Rheological Tests

Farinograph water absorption was associated positively with protein content ($r = 0.57$, $P < 0.01$) and negatively to protein quality, as evaluated with SDS sedimentation test ($r = -0.35$, $P < 0.01$). In the Italian location for both years, the highest values (>60%) were observed for lines ID560, ID369, and ID347. ID347 also showed the highest value in COL. Both einkorn lines were characterized by high-protein content and medium-to-low quality (Table III).

Development time was in the range observed for hexaploid wheat and varied from <90 sec in lines ID325, ID372, ID1327, and ID1352, to 240 sec in line ID131, evaluated only for MI 1996.

Stability and degree of softening were, as in bread wheat, strictly correlated ($r = -0.87$, $P < 0.01$). For these two traits, the most promising lines were observed in the MI 1996 trial; line ID529 had a stability index of 450 sec and a degree of softening of 50 BU, which was better than that of the bread wheat cultivar Pandas, a standard for high bread wheat quality.

Baking and Cookie Quality Tests

The nine einkorn lines listed in Table IV had farinograph indices indicative of potential value in breadmaking and, hence, were tested in a baking test. All samples showed a certain stickiness; however, it was possible to handle the dough during the different steps of breadmaking. From the development time recorded with the farinograph, basic mixing times were derived and empirically adjusted during mixing by the feel of the dough. Optimum mixing times <100 sec were similar to the times suggested by the farinograph, but they were ≈ 30 sec shorter in the range of 100–180 sec. Lines ID131

TABLE II
Flour Yield, Carotenoids, Protein Content, SDS Sedimentation (SDSS) Volume, Dry Gluten, and Falling Number (FN) of 24 Einkorn Lines Grown at Milan (MI) in 1995 and 1996 and at Cologne in 1995

ID Number	Flour Yield (%)			Carotenoids (ppm)			Protein Content (%)			SDSS Vol. (mL)			Dry Gluten (%)			FN (sec)		
	MI 1995	MI 1996	COL 1995	MI 1995	MI 1996	COL 1995	MI 1995	MI 1996	COL 1995	MI 1995	MI 1996	COL 1995	MI 1995	MI 1996	COL 1995	MI 1995	MI 1996	COL 1995
121	56	53	57	17.6	12.8	12.6	20.1	17.6	19.8	49	62	11	nf ^a	12.5	nf	266	273	280
131		59			15.3			17.9			96			11.7			283	
140	58	54	57	17.8	15.7	15.0	18.1	17.6	16.9	93	97	79	12.6	12.7	12.3	308	393	316
188	57	56	57	18.9	13.9	18.3	19.0	18.4	15.0	50	65	18	12.6	14.5	10.3	308	296	290
201	57	56	58	16.0	12.9	14.0	20.4	19.3	19.5	55	64	28	11.4	13.3	nf	320	317	266
280	59	57	57	12.1	13.3	11.3	19.0	19.5	18.1	87	93	46	13.0	12.6	12.1	301	319	304
324	58	53	60	16.5	12.8	12.9	21.2	17.9	15.1	44	46	10	13.4	13.0	nf	253	231	277
325	56	53	53	16.0	7.8	12.1	18.9	18.8	17.0	10	10	7	nf	nf	nf	326	296	382
347	59	55	56	8.6	8.6	7.8	22.7	21.3	20.4	19	39	12	nf	nf	nf	300	186	332
358	58	53	57	18.6	17.0	14.5	19.0	17.1	17.4	95	96	70	12.5	12.3	10.8	302	290	371
361	55	53	56	20.3	16.8	20.9	19.5	18.8	16.3	94	87	54	14.1	12.0	12.7	277	322	272
369	60	54	53	14.9	12.0	13.7	18.2	20.7	19.2	42	26	10	nf	nf	nf	294	220	258
372	56	54	58	17.6	13.3	13.9	19.8	19.0	20.0	58	64	8	13.4	13.3	nf	261	279	261
529		58			14.3			19.8			98			14.0			337	
559	55	54	56	10.0	8.4	7.5	18.3	16.7	15.4	35	40	11	11.9	9.3	nf	346	263	270
560	57	56		14.8	12.0		25.2	21.6		33	40		17.8	15.2		331	285	
1327	60	54	57	15.9	10.9	11.1	20.5	19.0	18.5	11	11	7	nf	nf	nf	281	279	351
1331	56	54	58	18.0	16.4	14.3	21.3	19.1	19.1	88	53	59	14.1	13.3	12.6	300	270	
1335	56	57	57	12.1	9.9	9.3	19.1	19.8	16.5	56	54	35	13.7	14.1	12.2	299	304	261
1348	58	54	56	18.7	15.8	14.5	20.4	20.2	17.8	91	93	69	12.8	14.3	12.6	331	299	282
1351		56			16.8			18.8			97			13.8			304	
1352	59	60	56	19.4	17.2	16.2	23.7	21.4	19.0	18	15	8	nf	nf	nf	274	306	305
1382		55			12.5			20.3			92			17.1			304	
1394		54	57		14.0	14.5		19.0	16.2		10	8		nf			314	324
Mean	58	55	57	16.0	13.6	13.4	20.2	19.1	17.7	54	60	29	13.4	13.3	12.0	298	290	300
SE	0.3	0.3	0.4	0.8	0.6	0.7	0.4	0.3	0.4	6.8	6.4	5.8	0.5	0.4	0.3	6.3	8.3	8.7
Pandas ^b	50			2.1			13.0			90			10.3			226		
Centaurio ^b	52			2.9			11.6			80			9.3			230		
Veronese ^b	59			2.7			9.8			64			10.1			233		

^a Not formed.

^b Bread wheat representing wheat classes of superior and ordinary breadmaking quality and cookie making quality, respectively. Pandas is a medium hard cultivar, Centaurio and Veronese are soft cultivars.

and ID529, characterized by development times of 240 and 225 sec, respectively, had much shorter optimum mixing times (150 and 165 sec, respectively).

The baking test data reflect the nine most promising einkorn lines, all characterized by high bread volumes and crumb scores, comparable to the performances of the best hexaploid wheats. Over the three locations, lines ID140 and ID280 gave the most promising results; line ID529, tested only at MI 1996, had the highest bread volume (918 cm³).

Cookies produced with einkorn flour were, on average, larger in diameter and thinner than those produced with soft wheat flour (Table V). Mean width ranged from 9.01 cm at MI 1995 to 9.46 cm

at COL, compared with 8.92 cm for the soft wheat Veronese and 8.66 cm for a commercial flour. As expected, cookie height was negatively correlated with cookie width ($r = -0.74$, $P < 0.01$). Line ID559 had the largest diameter at all locations with values $\approx 10\%$ larger than the soft wheat Veronese. Line ID372, the einkorn with the smallest cookie diameter, was better than the commercial flour. Although lines with very low SDS sedimentation volumes gave the poorest results, no relevant relationship was observed. Einkorn flour protein content was high compared with that of the typical cookie flour obtained from hexaploid wheat (Table II). Among einkorn flours, a negative correlation between protein content and cookie diameter ($r = -0.66$, $P < 0.01$) was observed.

TABLE III
Farinograph Values of 24 Einkorn Lines Grown at Milan (MI) in 1995 and 1996 and at Cologne (COL) in 1995

ID Number	MI 1995				MI 1996				COL 1995			
	Water Absorption (%)	Developing Time (sec)	Stability (sec)	Degree of Softening (BU)	Water Absorption (%)	Developing Time (sec)	Stability (sec)	Degree of Softening (BU)	Water Absorption (%)	Developing Time (sec)	Stability (sec)	Degree of Softening (BU)
121	54.0	96	60	195	56.2	108	78	210	57.2	72	36	260
131					54.9	240	390	70				
140	53.4	108	216	80	54.0	180	300	70	52.6	138	180	100
188	54.0	168	108	150	55.9	165	108	140	53.4	60	108	150
201	58.0	120	48	200	56.3	120	138	160	58.6	90	30	240
280	54.0	168	198	80	54.3	135	210	70	53.6	96	186	110
324	57.4	108	48	240	56.1	75	60	200	54.0	66	24	290
325	57.6	72	30	285	56.3	60	36	250	57.0	51	24	270
347	60.0	66	36	255	60.9	90	42	250	59.4	72	30	250
358	54.0	198	270	50	54.1	150	240	100	53.2	84	72	75
361	54.0	162	228	110	56.3	102	192	160	53.8	78	102	160
369	61.0	114	42	215	60.1	78	48	230	55.4	72	48	235
372	59.8	66	36	270	56.2	86	144	170	56.4	66	24	260
529					54.4	225	450	50				
559	54.0	120	102	215	55.2	120	90	200	56.4	54	24	275
560	62.8	144	60	165	61.4	120	60	180				
1327	54.2	72	30	300	53.7	54	24	260	53.8	36	42	275
1331	54.2	120	216	120	55.3	168	150	160	57.6	66	24	180
1335	52.8	108	192	120	53.6	120	210	110	52.8	120	156	120
1348	53.8	180	186	100	55.4	180	390	70	53.4	108	180	115
1351					54.5	180	300	60				
1352	57.8	78	42	210	59.1	60	30	260	56.4	42	42	230
1382					55.1	150	270	110				
1394					55.1	45	30	275	55.0	60	30	295
Mean	56.1	119	113	177	56.0	125	166	159	55.3	75	72	205
SE	0.7	9.4	19.3	17.4	0.4	9.2	21.9	12.8	0.5	5.7	13.3	16.2
Pandas ^a	60.4	168	330	75								
Centauro ^a	53.6	84	222	40								
Veronese ^a	53.0	90	120	130								

^a Bread wheat representing wheat classes of superior and ordinary breadmaking quality and cookie making quality, respectively. Pandas is a medium hard cultivar, Centauro and Veronese are soft cultivars.

TABLE IV
Baking Tests of 9 Einkorn Lines Grown at Milan (MI) in 1995 and 1996 and at Cologne (COL) in 1995

ID Number	MI 1995			MI 1996			COL 1995		
	Mixing Time (sec)	Bread Volume (cm ³)	Crumb Score (1–8)	Mixing Time (sec)	Bread Volume (cm ³)	Crumb Score (1–8)	Mixing Time (sec)	Bread Volume (cm ³)	Crumb Score (1–8)
131				150	765	6			
140	120	818	5	135	750	5	90	903	5
280	150	810	7	120	833	5	75	770	5
358	180	780	5	120	718	6	80	860	5
361	120	740	4	105	840	4	75	780	6
529				165	918	6			
1331 ^a	105	690	4	105	623	6	60	840	5
1335	105	798	6	90	635	5	75	808	5
1348 ^a	150	760	5	150	710	4	75	820	5
Mean	132	771	5	127	755	5	76	826	5
SE	10.6	17.0	0.4	7.1	38.5	0.3	3.4	23.3	0.2
Pandas ^b	180	730	7	180	730	7	165	740	6
Centauro ^b	240	720	7	240	730	6			
Bread flour	240	885	7	210	875	7	240	865	7

^a Lines included also in the experiment of Borghi et al (1996).

^b Pandas is a medium hard cultivar, Centauro is a soft cultivar.

Electrophoretic Characterization

When fractionated by A-PAGE, the gliadins resolved into ≈ 13 bands (Fig. 1). The composition of α -, β - and γ -gliadins was similar in all lines. Differences were detected for ω -gliadins, with several lines lacking these proteins or showing very faint bands. Interestingly, the lines with no or low content of ω -gliadins were of better quality than the others, as evaluated by SDS sedimenta-

tion volume, farinograph stability, and degree of softening (Table VI). Figure 2 shows the SDS electrophoretic patterns of high molecular weight (HMW) and low molecular weight (LMW) glutenin subunits (GS) of the tested lines. All lines showed the same pattern in HMW-GS; differences were detected in the LMW-GS composition. The nine lines (ID131, ID140, ID280, ID358, ID361, ID529, ID1348, ID1351 and ID1382) showed two bands, arbitrarily called

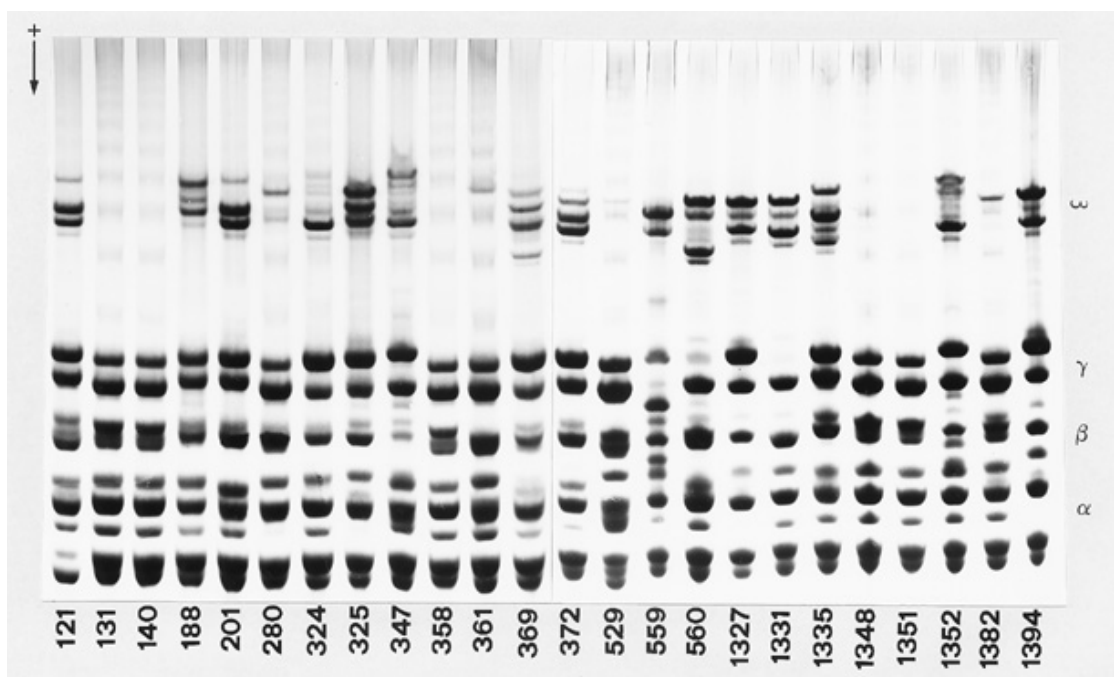


Fig. 1. Acid-PAGE patterns of gliadins from *Triticum monococcum*. Lines are ordered as in Table I. Regions of the gel correspond to α -, β -, γ - and ω -gliadins.

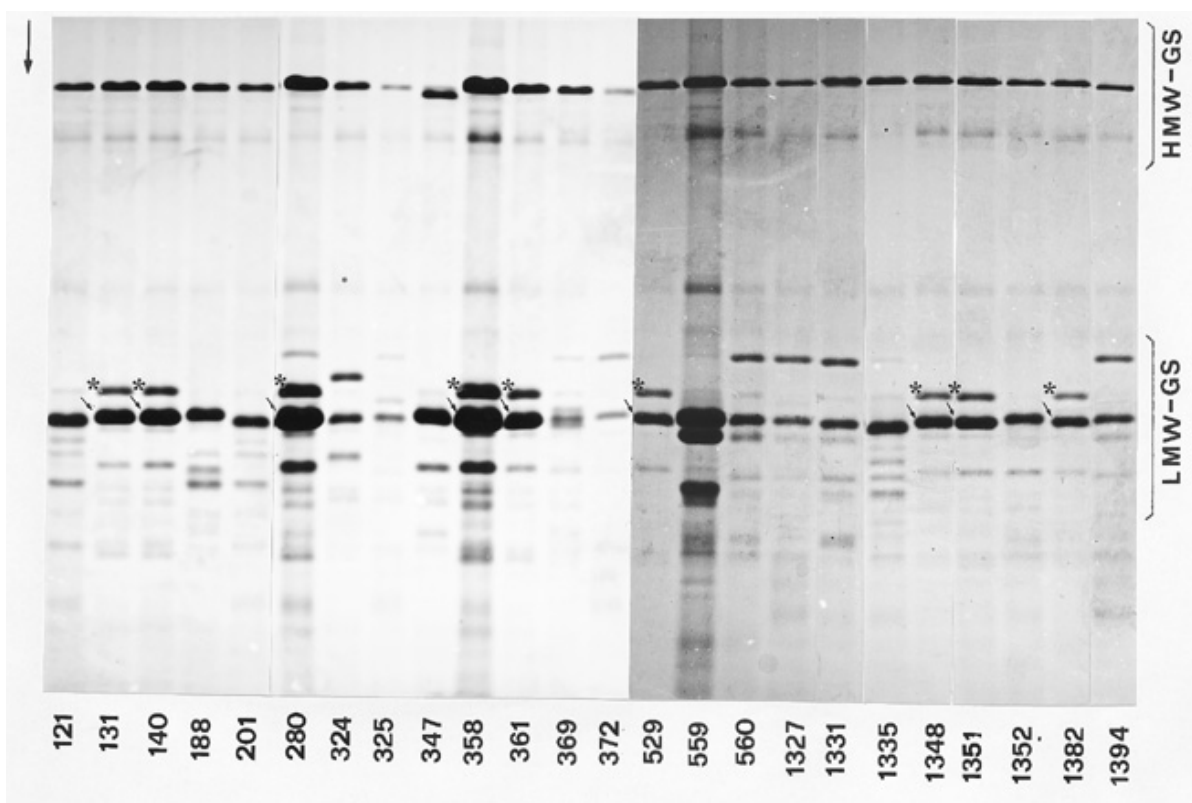


Fig. 2. SDS-PAGE (15% acrylamide) patterns of glutenin subunits from *Triticum monococcum*. Lines are ordered as in Table I. HMW-GS = high molecular weight glutenin subunits; LMW-GS = low molecular weight glutenin subunits. Bands *a* and *b* are indicated by asterisk and arrow, respectively.

TABLE V
Cookie Test of 17 Einkorn Lines Grown at Milan (MI) in 1995 and 1996 and at Cologne (COL) in 1995

ID Number	Width (cm)				Height (cm)			
	MI	MI	COL	Mean	MI	MI	COL	Mean
	1995	1996	1995		1995	1996	1995	
121	9.0	10.0	9.4	9.5	0.77	0.63	0.72	0.71
140	9.4	9.6	10.0	9.7	0.68	0.67	0.59	0.65
201	8.7	9.1	9.4	9.1	0.80	0.70	0.80	0.77
280	9.3	9.3	9.9	9.5	0.75	0.73	0.60	0.69
324	9.2	10.0	10.0	9.7	0.69	0.67	0.63	0.67
325	9.2	9.6	10.0	9.6	0.70	0.72	0.60	0.67
347	8.8	9.1	8.9	9.0	0.74	0.71	0.76	0.74
358	9.0	9.2	9.4	9.2	0.71	0.70	0.63	0.68
361	9.3	9.3	9.3	9.3	0.71	0.67	0.63	0.67
369	9.0	8.8	8.8	8.8	0.75	0.78	0.75	0.76
372	8.5	9.4	8.4	8.8	0.75	0.71	0.70	0.72
559	9.7	9.8	9.8	9.8	0.59	0.63	0.68	0.64
1327	8.9	9.9	10.0	9.6	0.70	0.66	0.60	0.65
1331	8.4	9.4	9.4	9.1	0.79	0.70	0.75	0.74
1335	9.0	9.0	9.3	9.1	0.71	0.73	0.69	0.71
1348	9.0	9.3	9.3	9.2	0.78	0.68	0.68	0.71
1352	9.1	9.0	9.5	9.2	0.74	0.73	0.67	0.71
Mean ^a	9.0	9.4	9.5	9.3	0.73	0.70	0.68	0.70
LSD ^b	0.3	0.3	0.3	0.2	0.04	0.04	0.04	0.03
Cookie wheat ^c		9.0				0.80		
Cookie flour		8.7				0.78		

^a Values are means of two replicates.

^b Least significant difference ($P \leq 0.05$).

^c Soft wheat cultivar Veronese.

TABLE VI
SDS Sedimentation Volume and Farinograph Characteristics of Two Groups of Lines Differing in Electrophoretic Pattern of Low Molecular Weight Glutenins (LMW-GS)

LMW-GS Composition	No. of Lines	SDS Sedimentation Volume		Farinograph			
		Mean \pm SE	Range	Stability (sec)		Degree of Softening (BU)	
				Mean \pm SE	Range	Mean \pm SE	Range
Bands <i>a,b</i> present	9	94 \pm 5.6	87–97	305 \pm 23.1	192–450	84 \pm 14.9	50–160
Bands <i>a,b</i> absent	15	40 \pm 4.3	10–65	83 \pm 17.9	24–210	203 \pm 11.6	110–275

a and *b* (indicated by asterisk and arrow, respectively) missing in all the other lines. All the lines with these bands showed good breadmaking potential (Table VI). The lines lacking them had an ample range of variability for the qualitative traits, but on average they were significantly worse.

DISCUSSION AND CONCLUSIONS

Einkorn is an interesting genetic resource among diploid wheats (Waines 1983, Vallega 1978), and its potential value for human consumption has been investigated in recent years (D'Egidio et al 1993, D'Egidio and Vallega 1994, Borghi et al 1996, Abdel-Aal et al 1997). This study contributes to the characterization of einkorn flour, including its adaptability to cookie production. Our data support the possibility of producing cookies with characteristics similar to those of hexaploid wheat flours. Additional positive attributes of einkorn flour are high protein content and bright yellow color due to a carotenoid content up to 10 times higher than in ordinary wheat.

The multipurpose aptitude of some einkorn lines was evidenced. Comparing the results of the breadmaking test reported in Table IV with those of the cookie test reported in Table V, some lines with good breadmaking aptitude also appear suitable for cookie production: lines ID140, ID280 and ID361 were among the best for both uses. This ambivalent aptitude is a peculiarity of einkorn flours and may give this crop an advantage over tetraploid and hexaploid wheats where end-use properties are strictly genotype-dependent (Pomeranz 1971).

The nine lines identified as suitable for breadmaking originated from different collections (Table I). It is hard to say whether this characteristic was perceived by farmers and users of the Neolithic Age and was intentionally selected. The differences in protein subunit composition may have been unintentionally accumulated in cultivated lines during the thousand years of cropping in Europe. We demonstrated that cultivated European einkorn originated monophyletically from a wild population of the Karacadag region in the Fertile Crescent (Heun et al 1997). A protein composition comparison of wild and cultivated einkorns is in progress and will eventually contribute to the understanding of the origin of high-quality einkorn strains.

The dramatic differences in SDS sedimentation volume and in rheological properties observed are associated with the presence or absence of a very limited number of storage protein subunits. These results strengthen the importance of LMW-GS in breadmaking quality. In the last few years, this class of proteins has been receiving greater attention because it became clear that quality in durum and bread wheat cannot be explained by HMW-GS glutenins alone, and that additive and interaction effects of HMW-GS and LMW-GS play a decisive role (Gupta et al 1994). Interestingly, ω -gliadins may also have a key role in structure and properties of *T. monococcum* gluten. A future article will give more details about the genetic control of the storage protein subunits in the lines examined in this study. The data in this article, however, point to a simple genetic control of breadmaking aptitude. Furthermore, our results indicate that einkorn is not only a promising source of new or special foods but may also be an ideal species for genetic investigation on wheat quality.

ACKNOWLEDGMENTS

This work has been supported by the Italian Ministry of Agriculture, Project: Miglioramento cerealicolo per innovazioni agroindustriali (M.I.C.I.A.).

LITERATURE CITED

- American Association of Cereal Chemists. 1995. Approved Methods of the AACC, 9th ed. Method 10-10B approved November 1995; Method 10-52 approved September 1985, revised November 1988, November 1989, October 1991, and September 1992, reviewed October 1994; Method 14-50 approved April 1961, revised October 1982 and October 1984. The Association: St. Paul, MN.
- Abdel-Aal, E. S. M., Hucl, P., Sosulski, F. W., and Bhirud, P. R. 1997. Kernel, milling and baking properties of Spring-type spelt and einkorn wheats. *J. Cereal Sci.* 26:363-370.
- Auricchio, S., De Ritis, G., De Vincenzi, M., Occorsio P., and Silano, V. 1982. Effects of gliadin-derived peptides from bread and durum wheats on small intestine cultures from rat fetus and coeliac children. *Pediatr. Res.* 16:1004-1010.
- Borghini, B., Castagna, R., Corbellini, M., Heun, M., and Salamini, F. 1996. Breadmaking quality of einkorn wheat (*Triticum monococcum* ssp. *monococcum*). *Cereal Chem.* 73:208-214.
- Castagna, R., Borghi, B., Di Fonzo, N., Heun, M., and Salamini, F. 1995. Yield and related traits of einkorn (*T. monococcum* ssp. *monococcum*) in different environments. *Eur. J. Agron.* 4:371-378.
- Dallmann, M. H. 1981. Porosity tables. Pages 4-9 in: Fortschritt der Getreideforschung. (in German) Verlag Moritz Schäfer: Detmold, Germany.
- D'Egidio, M. G., Nardi, S., and Vallega, V. 1993. Grain, flour, and dough characteristics of selected strains of diploid wheat, *Triticum monococcum* L. *Cereal Chem.* 70:298-303.
- D'Egidio, M. G., and Vallega, V. 1994. Bread baking and dough mixing quality of diploid wheat *Triticum monococcum* L. *Ital. Food Bev. Technol.* 4:6-9.
- Favret, E. A., Cervetto, J. L., Solari, R. M., Bolondi, A., Manghers, L. E., Boffi, A., and Ortiz, J. P. 1987. Comparative effect of diploid, tetraploid and hexaploid wheat on the small intestine of coeliac patients. (in Spanish) *Latin-Am. Soc. Pediatr. Gastroenterol. Nutr.*: Sao Paulo, Brazil.
- Ferraresi, A., Mazza, L., Monti, M., Corbellini, M., and Borghi B. 1997. Genetical and environmental effects on kernel hardness in Italian bread wheat (*Triticum aestivum* L.) varieties. (in Italian) *Riv. Agron.* 31:934-944.
- Gupta, R. B., Paul, J. G., Cornish, G. B., Palmer, G. A., Bekes, F., and Rathjen, A. J. 1994. Allelic variation at glutenin subunit and gliadin loci, *Glu-1*, *Glu-3*, and *Gli-1* of common wheats. I. Its additive and interaction effects on dough properties. *J. Cereal Sci.* 19:9-17.
- Heun, M., Schaffer Pregl, R., Klawan, D., Castagna, R., Accerbi, M., Borghi, B., and Salamini, F. 1997. Site of einkorn wheat domestication identified by DNA fingerprinting. *Science* 278:1312-1314.
- ICC. 1986. Standard Methods of the International Association for Cereal Chemistry. Method N. 115-D. The Association: Vienna, Austria.
- ISO. 1982. Catalogue International Association for Standardization. 2nd ed. International Standard 3093. ISO: Geneva, Switzerland.
- Kirstein, W. J. 1983. Rapid, automatic, high capacity Dumas determination of nitrogen. *Micro Chem. J.* 28:529-547.
- Morel, M.-H. 1994. Acid-polyacrylamide gel electrophoresis of wheat glutenins: A new tool for the separation of high and low molecular weight subunits. *Cereal Chem.* 71:238-242.
- Nesbitt, M., and Samuel, D. 1996. From staple crop to extinction? The archaeological and history of hulled wheats. Pages 41-100 in: Proc. Int. Workshop on Hulled Wheats. Promoting the Conservation and Use of Underutilized and Neglected Crops. S. Padulosi, K. Hammer, and J. Heller, eds. Int. Plant Genetic Res. Inst.: Rome, Italy.
- Pogna, N. E., Mellini, F., Beretta, A., and Dal Belin Peruffo, A. 1989. The high-molecular-weight glutenin subunits of common wheat cultivars grown in Italy. *J. Genet. Breed.* 43:17-24.
- Pogna, N. E., Autran, J.-C., Mellini, F., Lafiandra, D., and Feillet, P. 1990. Chromosome 1B-encoded gliadins and glutenin subunits in durum wheats: Genetics and relationships to gluten strength. *J. Cereal Sci.* 11:15-34.
- Pomeranz, Y. 1971. Wheat Chemistry and Technology. Am. Assoc. Cereal Chem.: St. Paul, MN.
- Peña-Chocarro, L. 1996. In situ conservation of hulled wheat species: The case of Spain. Pages 129-146 in: Proc. Int. Workshop on Hulled Wheats. Promoting the Conservation and Use of Underutilized and Neglected Crops. S. Padulosi, K. Hammer, and J. Heller, eds. Int. Plant Genetic Res. Inst.: Rome.
- Preston, K. R., March, P. R., and Tipples, K. H. 1982. An assessment of the SDS sedimentation test for the prediction of Canadian bread wheat quality. *Can. J. Plant Sci.* 62:545-553.
- Schiemann, E. 1948. Wheat, rye, barley: Systematics, history and utilization. (in German) Fischer-Verlag: Jena, Germany.
- Vallega, V. 1978. Search of useful genetic characters in diploid *Triticum* spp. Pages 156-162 in: Proc. Int. Wheat Genet. Symp., 5th. S. Ramana-ujam, ed. Indian Soc. Genet. Breed.: New Delhi.
- Vallega, V. 1992. Agronomical performance and breeding value of selected strains of diploid wheat *Triticum monococcum*. *Euphytica* 61:13-23.
- Vallega, V. 1996. The quality of *Triticum monococcum* L., in perspective. Pages 212-220 in: Proc. Int. Workshop on Hulled Wheats. Promoting the Conservation and Use of Underutilized and Neglected Crops. S. Padulosi, K. Hammer, and J. Heller, eds. Int. Plant Genetic Res. Inst.: Rome.
- Waines, J. G. 1983. Genetic resources in diploid wheats: The case for diploid commercial wheats. Pages 115-122 in: Proc. Int. Wheat Genet. Symp. 6th. S. Sakamoto, ed. Maruzen: Kyoto, Japan.
- Yamashita, K., Tanaka, M., and Koyama, M. 1957. Studies on the flour quality of *Triticum* and *Aegilops*. *Seiken Zihou*. 11:20-26.

[Received February 11, 1999. Accepted June 22, 1999.]