Grain, Flour, and Dough Characteristics of Selected Strains of Diploid Wheat, *Triticum monococcum* L.[1]

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ABSTRACT

The grain, flour, and dough quality of 12 germ plasm accessions of domesticated diploid wheat, *Triticum monococcum* L. ("einkorn"), were investigated and compared with those of modern cultivars of *T. durum* and common wheat. Entries were assayed for kernel weight, test weight, yellow berry incidence, flour yield, whole meal ash and protein content, flour particle size, sodium dodecyl sulphate sedimentation volume, and alveograph parameters as well as for protein, gluten, ash, and carotene content of flours. Flour yields of einkorn wheats were analogous to those of common wheat cultivars and far greater than those of durum wheats. Gluten from *T. monococcum* was weak, scarcely extensible, and rather sticky; it had a lower water-retention capacity than that of common and durum wheats. Reduced grain dimensions, high ash content, small flour particle size, and extremely high carotene content were additional distinctive features of the diploid wheats examined. The remarkably wide range of values observed for most of these attributes indicated that *T. monococcum* strains better suited for producing the commonest wheat-based aliments could probably be identified in more extensive surveys or be obtained by breeding. Developing free-threshing commercial cultivars of diploid wheat offers opportunities in foodstuff diversification, coeliac disease prevention, animal feed, the production of protein-rich foods, and in the exploitation of novel endosperm mutants.

Developing commercial cultivars of domesticated diploid wheat, *Triticum monococcum* L. ("einkorn"), appears to be a most attractive venture (Vallega 1979, 1992; Waines 1983), of interest to technologists, breeders, and medical researchers. In fact, the diploid nature of this primitive wheat renders it ideal for the identification and direct exploitation of numerous endosperm mutants unavailable in the polyploid wheat taxa (*T. durum* Desf. and *T. aestivum* L.). Thus, it is extremely flexible in relation to the wide array of products demanded by modern industries. Einkorn, moreover, is superior or usefully distinct from durum and common wheats with respect to herbicide resistance (Multani et al 1989), tillering ability (Vallega 1979), resistance to diseases (The 1975, Vallega 1978, Rubies Autonell and Vallega 1991), lysine content in protein (Sharma et al 1981), and protein yield per hectare (Vallega 1979, 1992). Additionally, investigations by Auricchio et al (1982) and Favret et al (1984, 1987) suggest that flours of *T. monococcum* might be nontoxic in coeliac disease. In theory, even the exploitation of F1 hybrid vigour would seem more promising in diploid wheat than in the polyploid wheats (Vallega 1991). On the other hand, extensive field trials have shown that the grain-yielding ability of domesticated strains of *T. monococcum* preserved in germ plasm collections is relatively high (Forlani 1954; Vallega 1979, 1992) and grossly equivalent to that of the polyploid wheat land races cultivated before the advent of modern breeding methods. Perhaps more importantly, free-threshing strains (*T. monococcum* ssp. sinskajae Filat. et Kurk.) have been identified (Filatenko and Kurkiev 1975).

Diploid wheat was widely cultivated in Europe and elsewhere until the beginning of this century (Harlan 1981). However, its economical importance and that of other non-free-threshing wheats has greatly diminished with time. Presently, einkorn survives as a crop only in marginal farms of Yugoslavia, Turkey, and Italy (Feldman 1976, Hammer and Perrino 1984), where it is used for feeding livestock and for human consumption (Schiemann 1956, Yamashita and Tanaka 1960). As a result of this abandonment, the technological properties of *T. monococcum* have been the subject of very few fragmentary investigations. Early this century, Le Clerc et al (1918) reported high values for ash, acidity, and gluten in flours of accession CI 2433. Decades later, Schiemann (1948) described einkorn flours as "very fine, gluten rich and with a strong yellowish tinge." Yamashita et al (1957) reported the obtainment of sticky doughs and acceptable loaf volumes from an unidentified *T. monococcum* strain. Very fine flours, comparable to those produced by the softest common wheat cultivars, were reported for three einkorns assayed by Williams (1986). Recently, Blanco et al (1991) found a wide range of sodium dodecyl sulphate sedimentation (SDSS) volumes in accessions of diverse origins.

Our aim in this study was to compare the main kernel, flour, and dough attributes of 12 agronomically valid *T. monococcum* accessions (Vallega 1992) with those of modern cultivars of durum and common wheat. Data for each entry is presented in detail to enable breeders to perform a reasoned choice of parents. The predictive value of these assays varies in relation to the foodstuffs to be produced and to the manufacturing technologies used.

MATERIALS AND METHODS

Grain Samples

The set of wheats examined comprised a free-threshing diploid wheat strain (*T. monococcum* ssp. sinskajae Filat. et Kurk., accession WIR 48993), 11 tenacious-glumed einkorns (*T. monococcum* ssp. monococcum), durum wheat cultivars Creso (good spaghetti-cooking quality) and Latino, as well as soft common wheat cultivars Mec (excellent breadmaking quality) and Centauro. Entries were grown in a rain-fed field experiment near Rome during 1989-90 in 10-m^2 plots distributed in a completely randomized block design with three replications. As expected, grain yields of *T. monococcum* accessions (827–2,528 kg/ha) were lower than those of the polyploid wheat controls (2,473–4,432 kg/ha). After combine harvesting, tenacious-glumed *T. monococcum* strains were dehulled with an experimental abrasive rice-pearling machine (Naldini, Bologna, Italy) and then subjected to ventilation, sieving, and hand-sorting to separate naked grains from chaff and residual invested kernels. With this procedure, only about 50% of the kernels in the original hulled samples were recovered; the pearling apparatus was adjusted to cause only very slight abrasions along the lateral margins of grains, so it tended to dehull only the relatively larger kernels. Therefore, mean kernel weight and mean protein content of the *T. monococcum* grains used for quality assays were 5.2 mg higher and 1.1% lower, respectively, than those of hand-threshed samples used for agronomical studies (Vallega 1992). Equal portions of naked grains from three replications were mixed in 1-kg samples used for kernel weight, test weight, yellow berry incidence, ash and protein content determinations, as well as milling experiments and flour quality assays. Mean kernel weight was determined on 20 g of wheat with broken grains removed. Yellow berry percentage, defined as the proportion of visible, not wholly-vitreous kernels, was assessed on 300 grains. Test weight (kg/hl) was measured using a 250-ml chondrometer.

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Milling

Grain (800 g per entry) was cleaned and tempered to 16.5% moisture for 18 hr. Standard milling was performed with a Bühler type MLU 202 laboratory mill (Bühler, Uzwill, Switzerland) with three breaking and three reducing passages to produce bran, shorts, and two streams of break and reduction flours. Use of this mill, designed for processing soft rather than hard wheats, served to highlight the profound milling yield differences between *T. monococcum* and *T. durum* (mean flour yield = 70.8 and 44.0%, respectively). However, at the same time, use of this mill impeded the obtainment of durum wheat flour samples that were directly comparable to those of the other two wheats. Data on the rheological properties and flour composition of durum wheats should therefore be interpreted with caution. Flour ash and flour carotene content as well as flour, shorts, and bran yields of tenacious-glumed *T. monococcum* processed with the pearling apparatus were analogous to those recorded for WIR 48993, a strain subjected only to the customary threshing operations. Whole meal ash and protein content determinations, as well as SDSS assays, were performed on grain samples (50 g) ground with a 1.0-mm sieve Cyclotec mill (Tecator, Höganäs, Sweden).

Carotene, Ash, Protein, Gluten, and Flour Particle Size

Pigment content of flours (expressed as parts per million of carotene) was determined according to AOAC standard method 14.045 (AOAC 1975). Ash content (% dry matter) of grains and flours was determined on 5-g samples according to the ISO standard method ISO-2171-B (ISO 1980). Protein content of grains and flours was determined by the Kjeldhal method (% N × 5.7 d.m.). Wet gluten of flours was determined according to ICC standard method 106/2 (ICC 1986). For dry gluten determinations, gluten balls were desiccated with a Glutork 2020 (Falling Number, Huddinge, Sweden) at 150°C for 4 min and then left to cool for 3 min. Wet and dry gluten contents were expressed as percent dry matter. Flour particle size was estimated on 50-g flour samples using a column of round sieves shaken mechanically for 5 min. Four sieves, 20 cm wide, with mesh apertures of 193, 129, 106, and 44 μm were used. For ease of presentation, the weights of flour fractions withheld (particles >129 μm) or passing through the two upper sieves were separately pooled. Carotene, ash, protein, gluten, and flour particle size determinations were performed separately on break and reduction flours, and weighted data from these fractions were used for estimating straight-run flour characteristics. Break and reduction flour data is presented separately only for flour carotene content and flour particle size.

Alveograph and SDSS Assays

Alveograph tests were performed on straight-run flours using the Chopin method, according to the standard method ICC 121. Alveograms were evaluated in terms of overpressure (P), average length of the curve (L), P/L ratio, swelling index (G), and deformation energy (W). Alveograph parameters are currently used for estimating a wide array of rheological characteristics, including bread-loaf volume, cookie-baking quality, spaghetti-making quality, flour-water absorbing capacity, and dough stability (Rasper et al 1986, Landi 1988, Addo et al 1990). SDSS assays were performed as in Axford et al (1978), with a solution of 3% SDS. SDSS volume is well correlated with bread-loaf volume and, in general, with gluten strength (Dexter et al 1980, De Ambrogio and Jenabzadeh 1987). All assays, except those concerning flour yield and alveograph parameters, were performed in duplicate. Means and standard errors for each character were computed separately for each of the three wheat species compared.

RESULTS AND DISCUSSION

Seed Characteristics

Kernel weight, test weight, and yellow berry data are presented in Table I. As expected, the small, typically flat and oblong kernels of *T. monococcum* weighed considerably less (mean = 27.4 mg) than those of common and durum wheats. Mean test weight (77.8 kg/hl) and mean percent yellow berry incidence (2.3%) of einkorns were also lower than those of the polyploid wheats.

TABLE I
Grain Characteristics and Milling Yields of Einkorn, Durum, and Common Wheats Grown near Rome, Italy, in 1990

	Grain Characteristics[a]					Milling Yields				
Entries	Mean Kernel Weight (mg)	Test Weight (kg/hl)	Yellow Berry (%)	Ash[b] (%)	Protein[b] (%)	Break Flour (%)	Reduction Flour (%)	Shorts (%)	Bran (%)	Straight-Run Flour (%)
Einkorn wheats										
CI 13961[c]	34.3	79.5	0	2.05	18.3	35.8	35.8	18.3	10.1	71.6
CI 13963	37.4	79.3	0	2.21	18.7	33.8	36.3	18.5	11.5	70.1
PI 277133	24.7	76.6	4	2.16	16.2	36.5	34.3	17.2	12.0	70.8
WIR 48993	28.5	76.4	2	2.52	15.1	37.2	36.0	16.6	10.2	73.2
PI 290508	23.6	77.3	1	2.23	16.6	36.9	33.3	17.1	12.7	70.2
VV 281	22.3	76.4	3	2.22	15.1	32.6	32.6	19.6	15.2	65.2
VV 319	30.6	78.6	3	2.28	13.5	32.2	38.4	15.4	14.0	70.6
CI 2433	29.2	78.6	4	2.14	13.8	31.4	39.6	17.2	11.8	71.0
WIR 8365	23.0	77.7	3	2.05	13.3	34.6	39.4	17.4	8.6	74.0
PI 221413	23.5	77.7	1	2.10	12.5	30.8	38.7	19.0	11.5	69.5
PI 277130	26.9	77.5	3	2.12	12.6	37.6	33.8	17.9	10.7	71.4
PI 306545	25.5	78.6	3	2.05	12.9	33.1	38.5	18.8	9.6	71.6
Mean[d] ($n = 12$)	27.4 ± 1.37	77.8 ± 0.31	2.3 ± 0.41	2.18 ± 0.038	14.9 ± 0.62	34.4 ± 0.69	36.4 ± 0.72	17.8 ± 0.34	11.5 ± 0.54	70.8 ± 0.63
Durum wheats										
Creso	43.8	77.5	4	2.01	13.6	13.3	31.3	43.2	12.2	44.6
Latino	50.5	80.6	30	1.94	12.6	14.2	29.1	45.7	11.0	43.3
Mean ($n = 2$)	47.1 ± 2.37	79.1 ± 1.10	17.0 ± 9.19	1.98 ± 0.025	13.1 ± 0.35	13.8 ± 0.32	30.2 ± 0.78	44.5 ± 0.88	11.6 ± 0.42	44.0 ± 0.46
Common wheats										
Mec	34.0	81.7	53	1.88	13.8	34.0	33.4	11.1	21.5	67.4
Centauro	35.0	77.0	18	1.80	12.8	35.8	36.9	8.3	19.0	72.7
Mean ($n = 2$)	34.5 ± 0.35	79.4 ± 1.66	35.5 ± 12.37	1.84 ± 0.028	13.3 ± 0.35	34.9 ± 0.64	35.2 ± 1.24	9.7 ± 0.99	20.3 ± 0.88	70.1 ± 1.87

[a] All determinations were performed in duplicate.
[b] Dry matter percentage.
[c] Prefixes WIR, CI or PI, and VV refer, respectively, to accessions from the N.I. Vavillov All-Union Institute of Plant Industries (U.S.S.R.), the U.S.D.A. Small Grains Collection (U.S.A.), and the Cereal Research Institute (Italy).
[d] Mean ± SEM.

Flour Yield

The mean straight-run flour yield (Table I) of *T. monococcum* (70.8%) was analogous to that of common wheat and remarkably higher than that of durum wheat (44.0%). Mean break flour (34.4%) and mean reduction flour yields (36.4%) of einkorns were also practically identical to those of common wheats, yet bran production of *T. monococcum* was considerably lower (11.5 vs. 20.3%).

Diploid wheats with small kernels (22–25 mg) furnished flour yields analogous to those of large-seeded (34–37 mg) accessions. The unexpectedly high flour and shorts yields obtained from einkorns, despite their small and oblong kernels, suggest that the pericarp of *T. monococcum* seeds is rather loosely attached to the endosperm, and that diploid wheat grains have a friable texture. Einkorns, moreover, completely lack the deep crease that characterizes polyploid wheat kernels, and this feature, too, undoubtedly enhanced their flour yields.

Flour Particle Size

Particle size determinations (Table II) showed a greater preponderance of fine particles ($<$129 μm) in *T. monococcum* (mean = 56.9%) than in common wheats (52.0%) and durum wheats (31.5%), thus confirming earlier observations by Schiemann (1956) and Williams (1986) regarding the soft texture of einkorn grains. Especially fine particles were produced by VV 281 (fine particles = 63.0%) and CI 13961 (59.9%).

Pigment Content

Carotene content in straight-run flours of *T. monococcum* (mean = 14.1 ppm) was about three times greater than that of the polyploid controls and as high as 17.0 ppm and 17.9 ppm in flours of accessions PI 221413 and PI 277130, respectively. In contrast to that observed for common and durum wheats, carotene of *T. monococcum* was slightly but consistently more abundant in break flours than in reduction flours, thus suggesting a different positioning of yellow pigments in these kernels. Semolina of commercial cultivars of durum wheat generally contains only about 2.5–8.4 ppm of carotene (Canadian Grain Commission 1980, Fortini et al 1980); common wheat flours seldom surpass 4.1 ppm (Geddes 1944). It should be noted that a strong yellowish tinge is favoured in semolina of durum wheats as well as in common wheat flours consumed in some Near Eastern countries (Aykroyd and Doughty 1970). High carotene content is important also in poultry and swine feed.

Ash Content

Ash content in straight-run flours of *T. monococcum* (mean = 0.74%) was notably higher than that of common wheat (mean = 0.48%) and analogous to that reported for other primitive tenacious-glumed wheat species (Le Clerc et al 1918). Mean whole meal ash content (Table I) of einkorns (2.18%) was also higher than that of common and durum wheats. The typically low ash content of present-day polyploid cultivars is largely the result of deliberate selection for low mineral content (Rasmusson et al 1971) and rounder kernels. Attaining this objective in *T. monococcum* seems feasible, especially considering the broad range for flour ash content (0.62–0.91%) found in the small sample of accessions investigated in this study.

Protein and Gluten

Protein percentage means (Tables I and II) for whole meals (14.9%) and straight-run flours (14.0%) of *T. monococcum* were only slightly higher than those of the polyploid controls. However, accessions CI 13961 and CI 13963 surpassed protein content of durum and common wheats by as much as 5–6%. Dry gluten content of straight-run flours (Table II) was also somewhat higher in einkorns (mean = 12.4%) than in flours of the polyploid controls. Ratios of dry gluten and protein content in straight-run flours were, on the average, quite similar for diploid, tetraploid, and hexaploid wheats, but the range of values observed in einkorns (63.1–114.3%) was much wider than expected. Indeed, repeated analyses on break and reduction flours of CI 13963, as well as on break flours of CI 13961 (data not shown), furnished dry gluten values that consistently exceeded those recorded for protein. Undoubtedly, the capacity exhibited by these accessions to retain appreciable amounts of nonproteagenous gluten materials deserves to be investigated further. Noteworthy also, is the rather low water-retention capacity manifested by gluten of *T. monococcum*. In fact, ratios of dry and wet gluten content (Table II) were distinctly higher (mean = 34.2%) than in polyploid wheats (mean = 30.5%).

TABLE II
Flour Characteristics of Einkorn, Durum, and Common Wheats Grown near Rome, Italy, in 1990[a]

Entries	Straight-Run Flour[b] Ash[c] (%)	Protein[c] (%)	Dry Gluten[c] (%)	Dry Gluten/ Protein	Dry Gluten/ Wet Gluten	Carotene (ppm)	Particle Size (% < 129 μm)	Break Flour Carotene (ppm)	Particle Size (% < 129 μm)	Reduction Flour Carotene (ppm)	Particle Size (% < 129 μm)
Einkorn wheats[d]											
CI 13961	0.70	18.3	22.0	97	38.4	14.5	59.9	15.4	62.1	13.6	57.8
CI 13963	0.67	17.2	19.7	120	35.3	15.3	54.5	15.7	60.6	14.9	48.8
PI 277133	0.81	15.1	13.4	70	32.6	12.6	58.1	13.1	53.8	12.1	62.7
WIR 48993	0.91	14.9	14.1	96	34.3	12.1	55.5	12.1	47.9	12.1	63.3
PI 290508	0.73	14.9	11.9	80	32.6	14.4	59.4	15.7	55.8	13.0	63.3
VV 281	0.68	14.0	9.2	73	35.5	12.7	63.0	13.1	62.1	12.4	63.9
VV 319	0.74	13.1	10.4	76	32.4	11.3	56.6	11.3	51.1	11.4	61.2
CI 2433	0.70	12.8	9.3	61	35.9	13.3	53.7	13.5	49.1	13.1	57.3
WIR 8365	0.77	12.5	7.9	68	35.6	13.0	54.9	13.0	43.6	13.1	64.8
PI 221413	0.62	11.8	10.1	84	32.0	17.9	56.7	19.0	47.5	17.0	64.1
PI 277130	0.62	11.6	10.9	96	31.5	17.0	53.6	18.5	49.9	15.4	57.7
PI 306545	0.82	11.3	10.4	88	33.7	15.6	56.8	16.4	52.6	14.9	60.5
Mean[e] ($n = 12$)	0.74 ± 0.023	14.0 ± 0.64	12.4 ± 1.20	84 ± 4.7	34.2 ± 0.59	14.1 ± 0.58	56.9 ± 0.81	14.7 ± 0.71	53.0 ± 1.75	13.6 ± 0.48	60.5 ± 1.31
Durum wheats											
Creso	0.99	12.8	11.8	95	29.5	4.3	29.6	4.3	33.5	4.3	27.9
Latino	0.93	12.8	11.1	82	32.4	3.8	33.3	3.3	35.7	4.1	32.1
Mean ($n = 2$)	0.96 ± 0.021	12.8 ± 0.00	11.5 ± 0.25	89 ± 4.6	30.9 ± 1.03	4.1 ± 0.18	31.5 ± 1.31	3.8 ± 0.35	34.6 ± 0.78	4.2 ± 0.07	30.0 ± 1.48
Common wheats											
Mec	0.48	11.8	11.1	93	31.8	4.8	51.0	4.3	51.4	5.3	50.7
Centauro	0.47	11.6	9.9	91	27.9	4.5	53.0	4.6	48.3	4.5	57.6
Mean ($n = 2$)	0.48 ± 0.004	11.7 ± 0.07	10.5 ± 0.42	92 ± 0.7	29.8 ± 1.38	4.7 ± 0.11	52.0 ± 0.71	4.4 ± 0.11	49.9 ± 1.10	4.9 ± 0.28	54.2 ± 2.44

[a] All determinations were performed in duplicate.
[b] Determinations performed separately on break and reduction flours; weighted means from these fractions were used to calculate straight-run flour characteristics.
[c] Dry matter percentage.
[d] Prefixes WIR, CI or PI, and VV refer, respectively, to accessions from the N.I. Vavillov All-Union Institute of Plant Industries (U.S.S.R.), the U.S.D.A. Small Grains Collection (U.S.A.), and the Cereal Research Institute (Italy).
[e] Mean ± SEM.

TABLE III

Alveogram and Sodium Dodecyl Sulphate Sedimentation (SDSS) Data for Einkorn, Durum, and Common Wheats Grown near Rome, Italy, in 1990[a]

	Alveograph Parameters[b]					SDSS[c]
Entries	***W*** **($\times 10^{-4}$J)**	***P*** **(mm)**	***L*** **(mm)**	***P/L***	***G*** **(ml)**	**Volume (ml)**
Einkorn wheats[d]						
CI 13961	...[e]	...	...	...	...	16
CI 13963	25	32	17	1.9	9.0	20
PI 277133	65	45	40	1.1	14.0	42
WIR 48993	18	24	17	1.4	9.0	15
PI 290508	...	...	...	...	...	25
VV 281	...	...	...	...	...	25
VV 319	28	30	14	2.2	8.0	20
CI 2433	...	...	...	...	...	15
WIR 8365	30	34	25	1.4	11.0	25
PI 221413	...	...	...	...	...	24
PI 277130	31	26	45	0.6	14.5	29
PI 306545	24	28	21	1.3	10.0	26
Mean[f] ($n = 7$ or 12)	32 ± 5.8	31 ± 2.6	26 ± 4.6	1.4 ± 0.20	10.8 ± 1.0	23 ± 2.2
Durum wheats						
Creso	195	117	45	2.6	15.0	38
Latino	112	85	37	2.3	13.5	23
Mean ($n = 2$)	154 ± 29.3	101 ± 11.3	41 ± 2.8	2.5 ± 0.11	14.3 ± 0.8	31 ± 5.3
Common wheats						
Mec	153	57	83	0.7	20.0	63
Centauro	217	58	116	0.5	24.0	60
Mean ($n = 2$)	185 ± 22.6	58 ± 0.4	100 ± 11.7	0.6 ± 0.07	22.0 ± 1.4	62 ± 1.1

[a] Alveograph and SDSS assays performed on straight-run flours and whole meals, respectively.
[b] *W* = deformation energy; *P* = overpressure; *L* = average length of the curve, *G* = swelling index.
[c] SDSS assays performed in duplicate.
[d] Prefixes WIR, CI or PI, and VV refer, respectively, to accessions from the N.I. Vavillov All-Union Institute of Plant Industries (U.S.S.R.), the U.S.D.A. Small Grains Collection (U.S.A.), and the Cereal Research Institute (Italy).
[e] Doughs of five diploid wheats could not be processed with the alveograph or produced small inconsistent curves, impossible to measure by the standard procedure.
[f] Mean ± SEM.

Alveograph and SDSS Assays

Gluten balls and doughs of all the diploid wheats examined were sticky and, in some cases, scarcely cohesive. Because of this, dough sheets of five *T. monococcum* samples either could not be processed with the alveograph or produced small inconsistent curves, impossible to measure by the standard procedure. Gluten strength, as estimated by *W* (Table III), of the other seven accessions was very poor (mean $W = 32$) compared to that of the polyploid controls (*W* range = 112–217). *W* values such as those obtained for PI 277133 ($W = 65$) are typical of North American soft white wheats (Rasper et al 1986) and occur rather frequently in low-quality polyploid cultivars widely grown in other parts of the world (Fig. 1). Gluten strength rankings between species, as estimated by the SDSS, were analogous to those furnished by the alveograph. However, although sedimentation volumes of *T. monococcum* (mean = 23 cm^3) were substantially lower than those of common wheats, they approached those of durum wheats, particularly accessions PI 277133 (42 cm^3) and PI 277130 (29 cm^3). The latter accession appears most interesting as a parent in breeding programs, in that it presented relatively high *W* and SDSS values in spite of its low protein content.

Dough extensibility of *T. monococcum* (mean $L = 26$) was substantially inferior to that of common wheats and comparable to that of durum wheats for accessions PI 277130 ($L = 45$) and PI 277133 ($L = 40$). A similar tendency was observed for dough springiness and shortness. *G* values, in fact, were highest for common wheats (mean $G = 22.0$) and lowest for durum wheats (mean $G = 14.3$) and *T. monococcum* (mean $G = 10.8$). Noteworthy high *G* values were recorded, again, for accessions PI 277130 ($G = 14.5$) and PI 277133 ($G = 14.0$). Dough tenacity of *T. monococcum* (mean $P = 31$) was also far lower than that of durum and common wheats. However, relatively high values, comparable to those of the common wheat controls, were observed for PI 277133 ($P = 45$) and WIR 8365 ($P = 34$). Einkorns generally exhibited *P/L* ratios between those of durum and common wheats. Interestingly, accessions VV 319 ($P/L = 2.2$) and CI 13963 (*P/*

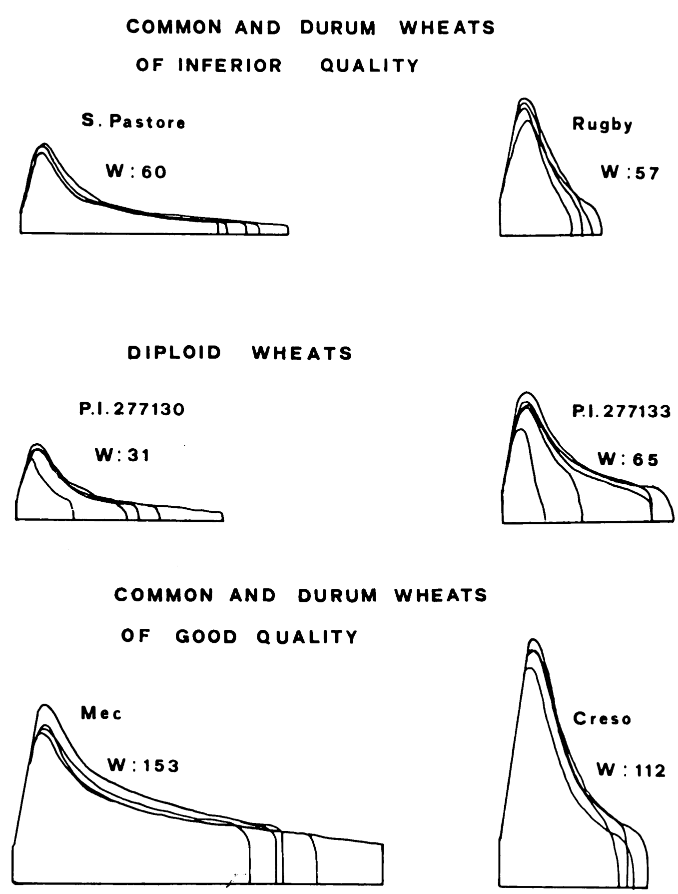

Fig. 1. Alveographic profiles of selected diploid, durum, and common wheats. Cultivars S. Pastore and Rugby were grown under different environmental conditions.

$L = 1.9$) presented P/L values of common wheat cultivars, whereas other *T. monococcum*, especially PI 277130 ($P/L = 0.6$), exhibited ratios more often found in durum wheats.

On the whole, the rheological properties of the 12 *T. monococcum* accessions investigated were poor. However, the range of values obtained in SDSS and alveograph assays indicated that examining a larger collection of diploid wheats would probably lead to the identification of strains that produce a stronger gluten and are, therefore, better suited for manufacturing classical wheat-based comestibles as diverse as leavened bread, spaghetti, chapatis, bulgur, and couscous. Einkorns with high SDSS volumes (up to 61 cm^3) have already been identified by Blanco et al (1990). Moreover, it seems reasonable to assume that diploid genotypes of improved gluten quality could also be obtained from crosses between some of the accessions examined in this study (especially PI 277133, PI 277130, and WIR 8365).

CONCLUSIONS

Generally speaking, the quality level of the 12 *T. monococcum* accessions examined corresponded to that expected from wheats successfully cultivated for millenia, yet never subjected to modern breeding procedures. Flour yields of einkorns were analogous to those of common wheat cultivars and far greater than those of durum wheats processed with the same experimental mill. The rheological properties of the einkorns, on the contrary, were poor and unbalanced in characteristics required for producing the commonest wheat-based foodstuffs. Gluten of *T. monococcum* was comparable, in strength, to that of soft wheats used for manufacturing cookies, but it was less extensible and rather sticky, with a low water-retention capacity. Reduced grain dimensions and high ash content, as well as small flour particle size and extremely high carotene content, were also distinctive features of the einkorns examined. On the other hand, these diploid wheats displayed a remarkably wide range of values for most of the quality attributes investigated; thus, the possibility of identifying *T. monococcum* accessions with significantly different characteristics cannot be discarded.

Evidently, the ever-narrowing quality specifications of modern industries should not be overestimated when evaluating the potential of a primitive crop. Characters such as ash content, gluten quality, grain size, and grain form can now be modified, almost at will, using well-established breeding procedures. Also, certain defects can be corrected, at least in part, with appropriate processing techniques. Moreover, some of the distinctive quality attributes of *T. monococcum* may prove valuable. Changes in consumption patterns have, in fact, greatly augmented the appeal of novel wheat-based comestibles. The demand for more protein-rich foods destined to malnourished populations has increased, as has the demand for high-carotene, high-protein animal feeds. In perspective, however, the appeal and economical prospects of *T. monococcum* do not reside as much in its capacity to mimic attributes already present in the polyploid wheats as in its genetic potential to code for characteristics found or sought in diploid cereals such as maize and barley. These characteristics include high lysine, high amylose, increased digestibility, and nontoxicity in coeliac disease. As a matter of fact, the current availability of free-threshing strains and populations of diploid wheat (Kurkiev and Filatenko 1975, Vallega 1979) makes the search for novel endosperm mutants much easier than it has been in the past.

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