Euphytica (2006) 150: 195–205
DOI: 10.1007/s10681-006-9107-6

Agronomic and qualitative traits of *T. turgidum* ssp. *dicoccum* genotypes cultivated in Italy

P. De Vita[1,2], C. Riefolo[1], P. Codianni[1], L. Cattivelli[1] & C. Fares[1,*]
[1]*C.R.A. Istituto Sperimentale per la Cerealicoltura, S.S. 16 km 675 – 71100 Foggia, Italy;* [2]*Enea Trisaia, S.S. 106 Jonica km 419,5 – 75026 Rotondella (MT), Italy (*author for correspondence: e-mail: fares@iscfoggia.it)*

Received 1 September 2005; accepted 24 January 2006

Key words: HHW-GS, gluten index, grain yield, pasta cooking quality, protein content, *T. turgidum* ssp. *dicoccum*

Summary

The increasing popularity of organic agriculture and health food products has led to a renewed interest in hulled wheat species such as emmer (*Triticum turgidum* ssp. *dicoccum* Schubler). Knowledge on agronomic and quality traits is required for effective and efficient use of germplasm collections in breeding programs. The objective of this study was to estimate agronomic and grain quality traits of emmer wheat cultivated in Italy. A total of 20 emmer accessions consisting of landraces, breeding lines or cultivars selected from landraces and modern cultivars were examined under low input conditions. The study was conducted for three successive years (2002–2004) at one location of Southern Italy (Foggia). The entries were characterized for agronomic and qualitative traits [grain yield (t ha^{-1}), thousand grain weight (g), test weight (kg hl^{-1}), grain protein content (%), HMWG composition, dry gluten content (%), gluten index and yellow index, alveograph indices and Total Organic Matter (TOM) on cooked pasta]. The results showed a large genetic variability for most of the traits measured and, even if most of the accessions showed inferior bread- and pasta-making performance, modern cultivars exhibited improved quality traits with some potential to perform healthy and tasty food.

Abbreviations: Heading date (HD); Plant height (PH); Grain yield (GY); Grain protein yield (GPY); Thousand kernel weight (TKW); Test weight (TW); Grain protein content (PC); Dry gluten and Gluten index (GC and GI);Yellow index (YI); Intermediate molecular weight glutenin group (IMWG); Low molecular weight glutenin subunits (LNW-GS); High molecular weight glutenin (HMW-GS); Total organic matter (TOM); Cultivar (cv); High Temperature (HT)

Introduction

Emmer (*T. turgidum* ssp. *dicoccum* Schubler) is one of the earliest domesticated wheat derived from wild emmer (*T. turgidum* ssp. *dicoccoides*). Described as "farro" in Italy, emmer has been cultivated for many centuries in several region of Central Italy (D'Antuono, 1994; Porfiri et al., 2001). Trends in organic agriculture and consumption of health food products have led to a renewed interest in hulled wheats. Suitability to low-input agriculture, adaptation to marginal lands, good competition with weeds and potential for development of healthy food, make emmer an attractive crop. (D'Antuono et al., 1993, 1994; Laghetti et al., 1998). Some of the ancient wheats have a unique composition in secondary components such as carotenoids and starch which may play a role as functional food ingredients. Emmer is particularly appreciated for its content of resistant starch, fibre and antioxidant compounds (D'Antuono et al., 1998; Galterio et al., 2003). However, the poor qualitative gluten composition has restrained the use of emmer to a limited number of food products, such as biscuits and traditional cakes. The low gluten properties are due to reduced synthesis of the glutenin fractions which greatly affect the rheological quality of semolina (Galterio et al., 1998). The lack of high molecular weight glutenin (HMW-GS) 7 + 8 subunits and the presence of HMW-GS 6 + 8 and 13 + 16 subunits explain the poor technological behaviour of meal obtained from emmer genotypes (Galterio et al., 2001). An efficient way to improve the rheological properties of wild tetraploid wheat might be the introgression of good quality traits from durum (*T. turgidum* ssp. *durum*). A breeding program based on crosses between emmer and durum wheat was developed to obtain new emmer genotypes with improved agronomic and qualitative traits, preserving the functionality properties of the landraces (Fares et al., 2000; Galterio et al., 2001).

The recent expansion of hulled wheat cultivation generated an intense exchange of seeds of native emmer populations and new cultivars. As a result of this process three types of emmer are presently grown in Italy: (i) emmer landraces; (ii) varieties selected from landraces; and (iii) modern cultivars obtained by crossing cultivated emmer (*Triticum turgidum* ssp. *dicoccum*) and durum (*T. turgidum* ssp. *durum*). The description of the agronomic characteristics is an important prerequisite for an effective and efficient use of germplasm collections in breeding programs. In spite of the increasing interest in emmer only limited agro-morphological characterization data are available. The objective of this study was to estimate the agronomic performances and the grain quality traits of 20 emmer accessions cultivated in Italy to find suitable genotypes as potential resources for food production.

Materials and methods

Genetic materials, experimental design and agronomical management

A total of 20 emmer accessions cultivated in Italy were included in this study: 8 Italian landraces, 10 advanced breeding lines or varieties selected from landraces (seeds were obtained from the CNR-IGV Plant Genetics Institute, Bari, Italy), and 2 modern cultivars selected after a breeding program at the C.R.A. Istituto Sperimentale per la Cerealicoltura di Foggia (Table 1). All genotypes were grown in the experimental fields of the C.R.A. Istituto Sperimentale per la Cerealicoltura di Foggia in Southern Italy for three successive growing-seasons (2001/2002, 2002/2003, 2003/2004).

The emmer accessions were sown every year at the beginning of November in moist conditions and no irrigation was applied thereafter adopting low input practices. Seedling density was 200 seeds m^{-2} (Troccoli et al., 2005) and the previous crop was fallow. 50 N unit per hectare of fertilizers were split in two applications: 1/3 at sowing, as diammonium phosphate (100 kg ha^{-1}) and 2/3 at tillering (growth stage 21; Zadoks et al., 1974) as ammonium nitrate (120 kg ha ha^{-1}). The soil type was clay loam with a pH of 7.8. The crop cycle was from November to the end of June. The size of plot was 10.2 m^2 (eight rows, each 7.0 m long and 0.17 m apart), arranged in a randomized complete block design with three replicates. Plants were harvested after physiological maturity during early July. Daily maximum and minimum temperatures and rainfall were recorded at the meteorological station beside the experimental fields (Table 2).

Parameters recorded

The entries were characterized for agro-morphological and qualitative traits. The following parameters were recorded for each plot:

1. Heading date (HD, days after 1th April): was recorded when about half of the culms showed emerging spikes (growth stage 55, Zadoks et al., 1974).
2. Plant height (PH, cm): was measured in all plots, during the milk-waxy maturation, when the maximum height level was achieved.
3. Grain yield (GY, t ha^{-1}): the weight of hulled grain mechanically harvested from a plot trial.
4. Grain protein yield (GPY, t ha^{-1}): determined as grain protein content × grain yield/100.
5. Thousand kernel weight (TKW, g): was calculated as the mean weight of three sets of 100 grains per plot.
6. Test weight (TW, kg hl^{-1}): defined as the weight of a given volume of seeds was measured on a 250 g sample by means of a Shopper chondrometer equipped with a 1/4 litre container. Each measure was made in duplicate.
7. Grain protein content (PC, % N × 5.70): determined in duplicate by means of approved method UNI 10274 and expressed on dry weight basis.
8. Ash content (%) determined in duplicate by means of the approved method UNI 2171 and expressed on dry matter basis.
9. Emmer semolina samples were obtained after moistening over-night dehulled grain samples to 16.5% humidity and milling was performed using a laboratory mill (MLU 202, Buhler, Uzwill,

Table 1. Genotypes of *T. turgidum* spp. *dicoccum* used in this study

Name	Origin
Abruzzo	Italian landrace
Garfagnana	Italian landrace
Umbria	Italian landrace
Leonessa	Italian landrace
Italia Centrale	Italian landrace
Molise	Italian landrace
Potenza	Italian landrace
PLV 5	Advanced breeding line obtained by selection from Moroccan landrace
PLV 6	Advanced breeding line obtained by selection from landrace (unknown)
PLV 7	Advanced breeding line obtained by selection from landrace (unknown)
PLV 8	Advanced breeding line obtained by selection from landrace (unknown)
PLV 9	Advanced breeding line obtained by selection from Iranian landrace
PLV 10	Advanced breeding line obtained by selection from Ethiopian landrace
PLV 11	Advanced breeding line obtained by selection from landrace (unknown)
PLV 12	Advanced breeding line obtained by selection from English landrace
Lucanica	Variety obtained by selection from Serbian landrace
Farvento	Variety obtained by selection from Spanish landrace
Molise Colli	Variety obtained by selection from Italian landrace
Mosè	Cultivar obtained by cross (*T. turgidum* spp. *durum* cv. Simeto × *T. turgidum* spp. *dicoccum*. landrace Molise)
Padre Pio	Cultivar obtained by cross (*T. turgidum* spp. *durum* cv. Simeto × *T. turgidum* spp. *dicoccum*. landrace Molise)

Table 2. Monthly rainfall and mean maximum and minimum temperatures for three growing seasons compared to long-term data for Foggia (Italy)

	2001–2002			2002–2003			2003–2004			Long term data 1955–1994		
	Tmax (°C)	Tmin (°C)	Rainfall (mm)	Tmax (°C)	Tmin (°C)	Rainfall (mm)	Tmax (°C)	Tmin (°C)	Rainfall (mm)	Tmax (°C)	Tmin (°C)	Rainfall (mm)
November	17.7	8.7	56.0	22.2	11.0	17.7	20.5	11.1	5.4	16.7	6.9	61.4
December	12.0	4.3	55.4	14.9	8.5	130.8	14.5	5.8	164.6	12.8	3.9	59.9
January	13.1	2.3	47.4	15.0	7.4	171.6	13.8	5.7	45.7	11.3	2.5	48.0
February	17.8	7.5	10.6	11.3	3.4	24.8	16.3	4.6	15.4	12.5	2.7	42.9
March	19.4	8.3	22.2	17.7	5.5	37.2	17.4	6.0	23.7	15.4	4.1	46.4
April	21.0	9.2	110.4	20.5	7.5	37.4	20.6	10.3	51.9	19.1	6.2	46.8
May	26.0	12.9	61.2	29.5	14.5	12.2	24.4	10.8	48.4	24.7	10.4	37.1
June	31.6	16.7	5.6	35.0	19.8	56.6	30.3	16.6	99.0	29.5	14.6	32.0
Sum			368.8			488.3			454.1			374.4

Switzerland), with three breaking and three sizing passages, equipped with a semolina purifier. The semolina extraction rate was 60–70%.

10. Dry gluten and Gluten index (GC and GI) were determined in triplicate on semolina according to approved methods UNI 10689 and 10690, respectively, using the Glutomatic 2020 system (Perten, Sweden). The score applied for each gluten index was: <30 weak gluten quality; 30-60 sufficient gluten quality; 60–80 e very good gluten quality; >80 excellent gluten quality (approved method UNI 10940). For the determination of dry gluten, wet gluten was dried with Glutorx 2020 at 150 °C for 5 min and left to cool for 3 min.
11. Rheological characteristics (W index and P/L) of emmer semolina were evaluated using the Chopin Alveograph (Chopin, Cedex France) according to standard method UNI 10453.
12. Grain hardness was measured with the single-kernel characterization system, SKCS Model 4100 (Perten Instruments Sweden), on a cleaned sample of 300 whole seeds. Results were expressed as mean values and standard deviations.
13. Yellow index (YI, b*) was used for determining semolina color with a reflectance colorimeter (Chroma Meter CR-200 Minolta, Japan) equipped with a xenon arc lamp in the L*, a*, b* system poured into the special attachment provided. Each measure was made in triplicate.

Pasta processing

The emmer semolina samples deriving from the three replicates for each genotypes were blended to obtain a mix for pasta processing. The samples analyzed were obtained from the experimental trial of the third year. Pasta was prepared by mixing emmer semolina with 30% tap water to obtain a total dough water content of 44–45%. The dough was processed into spaghetti with a laboratory press (Serma) with a capacity of 1–2 kg. Extrusion conditions applied were: temperature 50 ± 5°C, pressure 70 ± 10 atm, and vacuum was 700 mm Hg. A high temperature drying procedure was applied for 9 h at about 80 °C.

Laboratory tests on pasta

To assess pasta cooking quality, spaghetti (100 g) were cooked in 1l of boiling tap water, and the optimal cooking time was taken when the white core in the strands disappeared after squeezing them between two glass plates. Total Organic Matter (TOM), was determined by the standard method of D'Egidio et al. (1982) (Method 153, ICC 1995). TOM represents the amount of surface material released from cooked pasta into the washing water after rinsing. TOM values >2.1 g/100 g corresponded to low quality, between 2.1 and 1.4 g/100 g corresponded to good quality and <1.4 g/100 g is considered an indication of very good quality (D'Egidio & Nardi, 1996).

SDS-PAGE

Flour samples (50 mg) were extracted according to Laemmli (1970). Electrophoresis was performed in a SE 600 Ruby Hoefer vertical unit with stacking and running gel concentration 3% and 10%, respectively. The crosslinker concentration was 1.3%. The gel size was 16 × 18 × 0.15 cm. Sample loading was 20 μl for slot. Run time was 18–19 h at a constant current of 10 mA for the gel. Staining and destaining was carried out according to Lafiandra (1985). The identification of high-molecular-weight subunits of glutenins (HMW-GS) and alleles was based on the classification of Payne & Lawrence (1983), Vallega & Waines (1987) and Branlard et al. (1989).

Statistical analysis

Statistical analysis was conducted for each measured parameter by analysis of variance (ANOVA) and the means were separated by Tukey's multiple range test using Mstat-C version 2.00 software. Pearson's correlation analyses among 11 agronomic traits were also carried out. Standard errors and mean values were recorded for pasta cooking quality data.

Results

Analysis of variance

Three sources of variation were considered Year, Genotype and Genotype × Year, and all traits evaluated showed significant variations.

Agro-morphologic traits

Rainfall was 368.8, 488.3 and 454.1 mm during 2001–2002, 2002–2003 and 2003–2004 growing seasons, respectively, an amount not far from the long-term average recorded at Foggia (364.4 mm). Even though the

Table 3. Data of three growing seasons (2001–2004) and mean values of agronomic traits

	Genotype	HD days after 1th April	PH cm	GY t ha^{-1}	TW kg hl^{-1}	TKW g	GPY t ha^{-1}
Landraces	Abruzzo	43 c	111 df	2.43 cf	69.9 e	41.1 cd	0.44 dg
	Garfagnana	42 df	114 ae	2.40 cf	71.7 ce	40.4 cd	0.45 dg
	Umbria	42 df	102 hi	2.17 fg	70.8 de	29.9 f	0.40 eh
	Leonessa	42 ce	101 i	2.83 a	70.6 e	32.4 ef	0.51 ac
	Italia Centrale	42 df	112 cf	2.25 eg	71.5 ce	38.2 d	0.39 gh
	Molise	42 eg	115 ad	2.37 dg	71.1 ce	40.6 cd	0.43 dg
	Potenza 1	42 cd	109 eg	2.05 g	71.7 ce	39.9 cd	0.37 h
	mean	42	109	2.36	71.0	37.5	0.43
Genotypes selected from landraces	PLV5	40 h	113 bf	2.62 ad	71.2 ce	39.6 cd	0.47 bd
	PLV6	41 gh	108 fg	2.31 dg	71.4 ce	38.9 d	0.43 dh
	PLV7	40 h	114 ae	2.26 eg	70.7 e	40.7 cd	0.42 dh
	PLV8	40 h	113 be	2.89 a	71.1 ce	38.9 d	0.53 a
	PLV9	41 gh	109 eg	2.83 a	71.0 ce	40.0 cd	0.51 ac
	PLV10	36 i	88 j	2.88 a	72.0 ce	34.6 e	0.55 a
	PLV11	40 h	119 a	2.79 ab	72.1 ce	38.1 d	0.51 ac
	PLV12	41 fg	117 ab	2.73 ac	73.6 bc	45.6 ab	0.52 ab
	Lucanica	46 a	117 ac	2.27 eg	72.4 ce	33.2 ef	.40 fh
	Farvento	45 b	118 ab	2.06 g	73.5 bd	39.3 cd	0.40 fh
	Molise Colli	42 df	113 bf	2.46 bf	70.6 e	39.7 cd	0.46 ce
	mean	41	112	2.56	71.8	39.0	0.47
Modern cultivars	Mosè	29 k	82 k	2.80 a	75.8 ab	45.9 a	0.47 bd
	Padre Pio	31 j	106 gh	2.57 ae	77.4 a	42.5 bc	0.45 df
	mean	30	94	2.68	76.6	44.2	0.46
Years	2001–02	40.5 b	112 a	2.66 b	73.1 a	40.1 a	0.53 a
	2002–03	39.7 a	106 c	1.97 c	69.6 b	36.0 b	0.35 c
	2003–04	41.0 c	109 b	2.87 a	73.3 a	40.8 a	0.48 b
	Total Mean	40	109	2.50	72.0	39.0	0.46

Values in each column followed by different letters are significantly different ($P < 0.05$).
GY = grain yield; PH = plant height; HD = heading date; TW = test weight; TKW = thousand kernel weight; GPY = grain protein yield.

amounts of rainfall were similar during the entire study period the distribution was not uniform influencing greatly the grain yield (Table 3). Each year was characterized by exceptional meteorological events. During 2001–2002, 110.4 mm of rain was concentrated in April, whereas during 2002–2003 and 2003–2004 large portions of the total rainfall occurred at the beginning of the wheat season, leaving the rest of the growing season in drought. Drought was particularly severe during 2002–2003 when the lowest grain yield (1.97 t ha^{-1}) was recorded. In 2003–2004, there was moderate rainfall during grain filling, allowing a higher yield (2.87 t ha^{-1}). Grain yield of the tested genotypes ranged from 2.05 t ha^{-1} (landrace Potenza 1) to 2.89 t ha^{-1} (PLV8); usually genotypes selected from landraces and modern cultivars yielded more than landraces.

The climatic conditions also influenced the morphologic traits. The heading date was earlier by 1–1.3 days in 2002-2003 relative to 2001–2002 and 2003–2004 when an extended drought period occurred during stem elongation (March and April). The differences among genotypes were significant (Table 3). The modern cultivars (mean value of 30 days) headed 11–12 days earlier than the landraces and genotypes selected from landraces (mean values of 42 and 41 days, respectively).

Plant height reached maximum levels during the first year (2001–2002) when the mean value for all genotypes was 112 cm indicating more favorable soil moisture conditions during stem elongation compared with 2002–2003 and 2003–2004 (106 and 109 cm, respectively). Among the tested genotypes, Mosé was the shortest. Landraces and genotypes selected from landraces were generally tall, although there were some exceptions (e.g. PLV10, 88 cm).

Test weight in modern emmer cultivars showed higher values compared with landraces and landrace selections. Indeed, Mosé and Padre Pio were 75.8 and 77.4 kg ha^{-1} relative to a mean value of 71.0 for landraces and 71.8 kg ha^{-1} for selections from landraces. Similarly, the thousand kernel weights of the modern cv. Mosè was the highest recorded, and only the genotype PLV12 obtained by selection from a landrace showed a similar value (45.6 g).

Some researchers have suggested the use of grain protein yield instead of grain protein content as a selection criterion to increase grain yield and stabilize protein content (e.g., McNeal et al., 1982; Loffler & Busch, 1982). The mean values of GPY were higher in 2001-2002 (0.53 t ha^{-1}) than in the second and third years (0.35 and 0.48 t ha^{-1}, respectively) indicating a more efficient soil nitrogen utilization. Among the genotypes evaluated PLV8, PLV9, PLV10, PLV11, PLV12 and Leonessa showed GPY values higher than 0.50 t ha^{-1}. As far as the modern cultivars were concerned the GPY values were lower, ranging from 0.45 (Padre Pio) to 0.47 (Mosé).

Qualitative parameters

The genotypes used in this study were analyzed for chemical composition of the kernels (protein, gluten and ash content, and yellow index) (Table 4). The protein content of all emmer genotypes showed high values ranging from 16.8% (Mosè) to 19.5 (Farvento). Considering the different origins of the accessions, the modern cultivars showed a PC of about 1% less than the others. The mean values recorded within years were higher in the first and second years at 19.9% and 18.1%, respectively, compared to 16.8% recorded in the last and more productive year confirming the traditional negative correlation between PC and GY (Kramer, 1979).

A similar trend and restricted variability was observed for dry gluten content with average values ranging from 15.2 g (modern cultivars) to 16.9 g (mean value of landrace selections). The ash content and the yellow index data showed a reduction of semolina ash content and an increase in YI in the modern genotypes. Mosé and Padre Pio recorded the lowest values of ash content (1.92 and 1.99%, respectively) and the highest values of YI (18.1 and 16.5, respectively) in agreement with a previous study (Fares et al., 2000). The landraces showed an extremely low mean value (13.9) for the YI and only a small improvement was achieved in the genotypes selected from landraces (mean value 15.2).

The low gluten index values confirmed the well known poor gluten quality of emmer (Galterio et al., 1994; Cubadda & Marconi, 1995). This was generally true for many accessions evaluated in the present study, nevertheless the modern cultivars showed an acceptable values of gluten quality (49 and 56 for Mosé and Padre Pio, respectively), identifying a gluten of sufficient quality.

Technological parameters and pasta cooking quality

The evaluation of the rheological and technological properties of emmer semolina confirmed the indicative values of GI shown in Table 4. In fact, the modern cv. Padre Pio and Mosé showed the highest values for the alveograph parameter (W = 159 and 135 10^{-4} joule, respectively), much more than any other genotypes (Table 5). A deficit in technological quality was particularly severe within the breeding lines selected from landraces where the values ranged from 7 (Lucanica) to 35 (PLV12). Among the Italian landraces, Abruzzo was the only one with an almost acceptable W value (56). The values of P/L recorded for all the genotypes tested, ranging from 0.77 to 1.47 (Padre Pio) associated with the low W values confirmed the low quality of emmer semolina.

Regarding pasta cooking quality all emmer genotypes had low TOM values ranging from 0.7 to 1.4 g/100 g as a consequence of the protein coagulation occurring during high temperature (HT) drying conditions. It is known that HT drying systems produce protein coagulation before cooking, so the protein network formed prevents starch granules from escaping during cooking (Dalbon, 1983). Even if the differences among the three groups of genotypes tested were similar, the genotypes selected from landraces showed the best values of TOM (mean value 0.9 g/100 g) with a moderate variability within the group (from 0.7 to 1.2 g/100 g).

HMW-GS are known to be closely associated with grain quality (Payne, 1987; Weegels et al., 1996). Such association was also confirmed in this study (Table 5; Figure 1). At the *Glu-A1* locus, the allele *a* coding

Table 4. Mean values of qualitative traits for growing seasons 2002–2004

		PC%	GC%	YI	ASH %	GI
Landraces	Abruzzo	18.3 bg	16.2 ef	14.2 cf	2.39 a	45 ac
	Garfagnana	18.7 ae	17.1 ac	14.2 cf	2.34 ab	36 bf
	Umbria	18.8 ad	16.8 cd	13.2 f	2.18 df	42 ad
	Leonessa	18.3 bg	16.9 bc	13.6 df	2.14 f	42 ae
	Italia Centrale	17.8 eg	16.2 ef	13.8 df	2.21 cf	34 bg
	Molise	18.2 bg	16.5 ce	13.4 ef	2.24 cd	34 bg
	Potenza 1	18.1 cg	16.8 ce	14.9 bf	2.21 cf	37 bf
	mean	18.3	16.7	13.9	2.24	39
Genotypes selected from landraces	PLV5	17.9 eg	16.6 ce	15.1 be	2.18 df	22 fg
	PLV6	18.2 bg	16.8 ce	15.1 be	2.21 cf	30 cg
	PLV7	18.3 bg	17.0 ac	15.1 be	2.21 ce	23 fg
	PLV8	18.2 bg	16.8 cd	15.7 bc	2.17 df	22 fg
	PLV9	18.0 dg	16.6 ce	16.6 ab	2.23 ce	22 fg
	PLV10	19.0 ab	17.6 ab	14.1 cf	1.99 g	34 bg
	PLV11	18.1 bg	16.7 ce	15.3 bd	2.15 ef	24 eg
	PLV12	19.0 ab	17.0 ac	15.6 bc	2.24 cd	31 cg
	Lucanica	17.7 gh	16.2 df	14.9 bf	2.23 ce	44 ad
	Farvento	19.5 a	17.6 a	13.5 ef	2.28 bc	17 g
	Molise Colli	18.6 af	16.8 cd	15.6 bc	2.20 cf	27 dg
	mean	18.4	16.9	15.2	2.19	27
Modern cultivars	Mosè	16.8 h	14.8 g	18.1 a	1.92 g	49 ab
	Padre Pio	17.7 fg	15.6 f	16.5 ab	1.99 g	56 a
	mean	17.3	15.2	17.3	1.96	53
Years	2001–02	19.9 a	18.6 a	15.5 a	2.31 a	43 a
	2002–2003	18.1 b	16.6 b	15.3 a	2.12 b	34 b
	2003–2004	16.8 c	14.8 c	14.0 b	2.13 b	24 c
	Total Mean	18.3	16.6	14.9	2.19	34

Values in each column followed by different letters are significantly different ($P < .05$).
PC = protein content; GC = dry gluten content; GI = gluten index; YI = yellow index; ASH = ash content.

for subunit 1 was found in all genotypes with four exceptions. PLV10 and the modern cv. Mosè have a *null* allele. The landrace Leonessa possessed subunit 2* encoded by allele *b*, and landrace Lucanica had allele III which codes for a single major subunit. These results were in accord with a previous report (Branlard et al., 1989) in which a high frequency of subunit 1 was found in *Triticum dicoccum*. The *Glu-B1* locus exhibited the highest allelic variation with novel variants. The subunit pair 6 + 8 was frequently present in emmer although generally rare in modern durums (Branlard et al., 1989). This combination was found among landraces (Potenza 1, Italia Centrale and Garfagnana) and breeding lines selected from landraces (PLV7, PLV8 and PLV11). A novel allelic variant was identified as the *Glu-B1* locus and, after Pfluger et al. (2001), was named with the progressive roman-numerical nomenclature of Vallega and Waines (1987) and Branlard et al. (1989). This new allele, designed *Glu-B1-XVIII*, consisting of the x-type subunit showing a mobility greater than that of subunits 7 and 13, and lower than subunit 14, whereas the y-type subunit showed a mobility greater than that of subunit 18 (Figure 1). This combination was found in eight accessions: (PLV5, PLV6, PLV9, Molise Colli, Mosè, Molise, Garfagnana and Italia Centrale). Among the landraces the allelic variants were more numerous due to genetic heterogeneity. More than one combination of subunit pairs at *Glu-B1* occurred in sibling accessions. Some samples from landraces had the same HMW subunit pattern, suggesting that Italian emmer

Table 5. Technological parameters of semolina (W and P/L), pasta cooking quality (TOM) and HMW composition evaluated in 2003–2004

		TOM (g)		W (10^{-4} joule)		P/L		HMW	
		Mean	SE	Mean	SE	Mean	SE	Glu-A1	Glu-B1
Landraces	Abruzzo	1.0	0.03	56	2	0.97	0.05	1	22
	Garfagnana	1.0	0.01	23	2	1.43	0.16	1	6 + 8, 28 + 29, XVIII
	Umbria	1.1	0.03	41	3	0.82	0.17	1	22
	Leonessa	1.1	0.03	22	3	1.20	0.02	2*	28 + 29
	Italia Centrale	1.4	0.04	10	4	1.51	0.02	1	6 + 8, 28 + 29, XVIII
	Molise	1.1	0.02	21	3	1.44	0.10	1	XVIII
	Potenza 1	1.0	0.02	27	3	1.13	0.02	1	6 + 8
	mean	1.1	0.03	29	3	1.21	0.08		
Genotypes selected from landraces	PLV 5	0.7	0.03	31	3	0.77	0.02	1	XVIII
	PLV 6	0.9	0.02	30	3	0.94	0.06	1	XVIII
	PLV 7	0.7	0.01	27	3	1.34	0.27	1	6 + 8
	PLV 8	0.9	0.03	8	3	0.78	0.37	1	6 + 8
	PLV 9	0.8	0.03	15	3	1.65	0.40	1	XVIII
	PLV 10	0.8	0.01	33	3	0.91	0.01	null	14 + 15
	PLV 11	1.1	0.02	18	4	1.98	0.42	1	6 + 8
	PLV 12	0.8	0.03	35	3	1.24	0.18	1	7 + 8
	Lucanica	0.9	0.04	7	3	2.31	0.67	III	VI
	Farvento	1.2	0.01	9	4	1.76	0.21	1	22
	Molise Colli	0.9	0.01	29	3	1.01	0.02	1	XVIII
	mean	0.9	0.02	22	3	1.34	0.24		
Modern cultivars	Mosè	1.0	0.05	135	3	1.33	0.14	null	XVIII
	Padre Pio	1.0	0.02	159	3	1.47	0.20	1	7 + 8
	mean	1.0	0.04	147	3	1.40	0.2		

landraces are genetically related. On the other hand, the *Glu-B1* allele *b*, of great technological importance, coding for subunit pair 7 + 8 (Payne, 1987; Weegels et al., 1996) occurred only in Padre Pio and PLV10.

Discussion

Many studies have separately investigated agronomic or quality traits in accessions of Italian emmer (Galterio

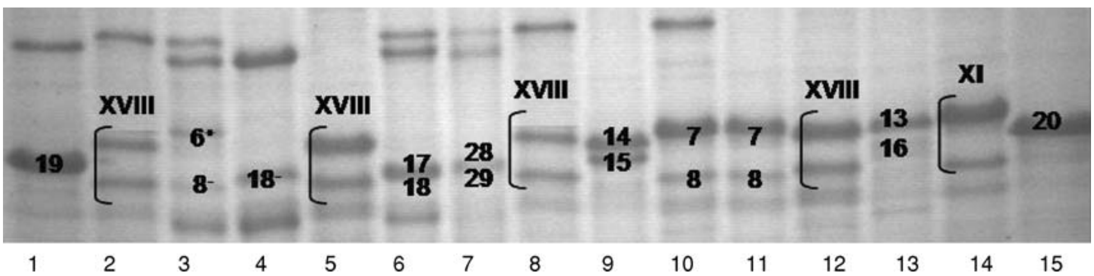

Figure 1. SDS-PAGE patterns of the HMW glutenin subunit (*Glu-B1*) for the following wheats: 1: *T. durum cv.* Lambro (19); 2: *T. dicoccum cv.* Molise Colli (XVIII); 3: *T. aestivum cv.* Sieve (6^{+}+8^{-}); 4: *T. aestivum cv.* Resistente (18−); 5: *T. dicoccum cv.* Mosè (XVIII); 6: *T. aestivum cv.* Loreto (17 + 18); 7: *T. aestivum cv.* Forlani (28 + 29); 8: *T. dicoccum cv*. Molise Colli (XVIII); 9: *T. dicoccum* Etiopia landrace (XVIII); 10: *T. dicoccum cv*. Padre Pio (7 + 8); 11: *T. durum cv*. Duilio (7 + 8); 12: *T. dicoccum cv*. Mosé (XVIII); 13: *T. durum cv*. Colosseo (13 + 16); 14: *T. durum cv*. Athena (XI); 15: *T. durum cv*. Arcangelo (20). Note the novel *Glu-B1*-encoded subunit XVIII identified in cv. Molise Colli (slots 2 & 8) and Mosè (slots 5 & 12).

et al., 1994, 1999, 2001, 2003; Laghetti et al., 1988; Cubadda & Marconi 1995; Troccoli et al., 1997; Piergiovanni et al., 1996). The present work represents the first attempt to evaluate a representative pool of emmer genotypes bred in Italy and grown under organic farming conditions. The study also provided a comparison among landraces, genotypes selected from landraces and recently bred cultivars originating from emmer landrace × durum cultivars. Over the last decade the emergence of organic agriculture and health food products has influenced market demand. Emmer cultivation was re-introduced and appropriate genetic materials were selected. The breeding activity was mainly focused to select genotypes for low-input conditions or adapted to marginal areas (Perrino et al., 1982), while there was little emphasis on technological traits. Observing the variability within selected breeding lines, our findings (Table 3) confirmed that the genotypes selected from landraces showed some improvements in grain and protein yield, but not in quality-related traits. On the contrary, the adoption of special breeding programs, as described in the present work, led to improved protein composition and rheological properties of dough. Our data support the possibility of introgressing some durum traits into emmer genotypes while preserving the morphological, functional and botanical characteristics of emmer (Szabò & Hammer, 1995).

The data of Table 3 show the results of selective pressure imposed by breeders to adjust the plant phenology (HD) of the modern cultivars (Mosé and Padre Pio) to southern Italian semi-arid conditions, where early maturity permits drought escape. The effects of selection for plant height was also evident.

Pearson's correlation coefficients for agronomic and qualitative traits (Table 6) showed a strong correlation between PH and HD ($r = 0.58^{***}$). Among the yield components, TW and TKW confirmed their roles in determination of GY, showing a positive correlation ($r = 0.49^{***}$ and 0.38^{**} respectively).

GPY has been proposed by several authors as an effective criterion for selection of genotypes adapted to organic agriculture (Loffler &. Busch, 1982; McNeal et al., 1982; Koekemoer et al., 1999). Based on GPY, genotypes more-adapted to the low input conditions were the advanced breeding lines PLV8 and PLV10 that associated high GY with elevated grain protein content. GPY was positively correlated with GY and PC ($r = 0.91^{***}$ and 0.26^{*}, respectively). Among the chemical traits, PC was strongly and positively correlated with GC ($r = 0.97^{***}$) and GI ($r = 0.34^{**}$). Although the trials were conducted in low input conditions, the high PC recorded (Table 4) confirmed the special attributes of emmer to grow in poor and marginal areas (Perrino et al., 1993; Cubadda & Marconi, 1994) and to store large amounts of proteins with poor technological properties (Galterio et al., 1994). Emmer semolina often exhibits a weak dough that is sticky and of poor viscoelastic properties (Galterio et al., 1994; 1998; Acquistucci et al., 2004) and the alveograph indices measured in our samples are in accord with those reports. In order to avoid any doubt on the correct use of alveograph procedure, samples were also tested for hardness index, a grain quality trait associated with milling performance (Miller et al., 1982). All samples showed values >76 (data not shown), with no significant differences among the genotypes evaluated, when we adopted a constant level of hydration for determining alveograph indices. Therefore, the low values of W index, can be ascribed to the low technological value of gluten proteins, a conclusion that is in agreement with the results of Galterio et al. (1994). The data presented in our study encompass a range of genotypes characterized by W index values ranging from 7×10^{-4} joule of Lucanica to 56×10^{-4} joule of Abruzzo. Often in the literature there are contrasting findings on gluten and protein quantity, and few reports on W index due to the difficulties of manipulating very sticky gluten. Nevertheless, there is general agreement on the poor gluten quality of emmer as consequence of its storage protein composition dominated by high concentrations of intermediate molecular weight glutenins (IMWG) group (78-50 KDa), a poor synthesis of low molecular weight glutenins (LMWG) subunits (45–30 KDa), and the absence of gliadin fractions γ-42 and γ-45 (Galterio et al., 1994, 1998, 2000; Fares et al., 2002). Nevertheless, recent breeding has improved some rheological properties after the introgression of good quality traits from durum. The examples of this specific breeding target are represented by Padre Pio and Mosè. The HMW-GS composition of the two modern cultivars are typical subunits of durum at the *Glu-B1* locus (7 + 8) for Padre Pio and at the *Glu-A1* locus ("null" allele) for Mosè. Furthermore, as suggested by Galterio et al. (2001), the superior gluten quality of these modern cultivars seems also related to the presence of the LMW-2 subunits associated to the ω-35 and γ-45 gliadinic fractions derived from the parent *T. durum*.

With the high protein content and by using the high temperature drying process, also emmer landraces could be processed into pasta of good organoleptic quality as suggested by the TOM values reported in

Table 6. Pearson's correlation among 11 agronomic and qualitative traits

	GY	HD	PH	TW	TKW	GPY	PC	GC	GI	YI	ASH
GY	1.00										
HD	−0.13	1.00									
PH	0.02	0.58***	1.00								
TW	0.49***	−0.28*	−0.05	1.00							
TKW	0.38**	−0.24	0.12	0.59***	1.00						
GPY	0.91***	−0.08	0.08	0.44***	0.33*	1.00					
PC	−0.15	0.11	0.17	−0.06	−0.11	0.26*	1.00				
GC	−0.17	0.11	0.17	−0.13	−0.15	0.24	0.97***	1.00			
GI	−0.15	−0.26*	−0.28*	0.20	−0.05	−0.01	0.34**	0.30*	1.00		
YI	0.01	−0.47***	−0.24	0.20	0.30*	0.10	0.17	0.21	0.32*	1.00	
ASH	−0.10	0.60***	0.63***	−0.13	0.07	0.15	0.59***	0.58***	0.11	−0.17	1.00

* Significant at $P < 0.05$; **significant at $P < 0.01$; *** significant at $P < 0.0001$; GY=grain yield; HD=heading date; PH=plant height; TW=test weight; TKW=thousand kernel weight; GPY=grain protein yield; PC=protein content; GC=dry gluten content; GI=gluten index; YI=yellow index; ASH=ash content.

Table 5. These findings are in agreement with Cubadda & Marconi (1995) who reported that the cooking quality of emmer pasta was fair, and more than acceptable, if high temperature drying conditions were applied. The modern cultivars showing relatively low semolina ash content and a good YI can ensure end-products with a brighter colour. Finally, improved rheological properties should enable the new genetic materials to be processed with soft technologies (low temperature of drying) allowing better preservation of the nutritional properties of the semolina.

Acknowledgements

This work was supported by MiPAF special grant "Risorse genetiche di organismi utili per il miglioramento di specie di interesse agrario e per un'agricoltura sostenibile". Authors acknowledge Dr. D. Sgrulletta for carrying out analyses that were useful to improve the data discussion.

References

Acquistucci, R., G. Aureli, P. Codianni, M. Colonna & G. Galterio, 2004. Chemical, technological, and nutritional characteristics of two lines of "farro" (*Triticum turgidum* ssp *dicoccum*). Nahrung-Food 48: 213–217.

Branlard, G., J.C. Autran & P. Monneveux, 1989. High molecular weight subunit in durum wheat (*T. durum*). Theor Appl Genet 78: 353–358.

Cubadda, R. & E. Marconi, 1995. Technological and nutritional aspects in emmer and spelt. In: Podulosi, S., K. Hammer & J. Heller (eds). Hulled Wheats. IPGRI, Rome, Italy. pp. 203–211.

Dalbon, G., 1983. Fattori che influiscono sulle caratteristiche di cottura delle paste alimentari e possibilità di migliorare la qualità con opportune tecnologie. Tecnica Molitoria 34: 553–563.

D'Antuono, L.F., 1994. Obsolete wheats in Italy: an overview on cultivation, use and perspectives for their conservation. In: Podulosi, S., K. Hammer & J. Heller (eds.) Conservation and Use of Underutilized Mediterranean Species. IPGRI, Rome, Italy. pp 41–48.

D'Antuono, L.F. & A. Pavoni, 1993. Technology and grain growth of *Triticum dicoccum* and *T. monococcum* from Italy. In: Damania A.B. (eds.) Biodiversity and Wheat Improvement ICARDA, Aleppo, Syria, pp 273–286.

D'Antuono, L.F., L. Guido, C. Galletti & P. Bocchini, 1998. Fiber quality of emmer (*T. dicoccum* Schubler) and einkorn wheat (*T. monococcum* L.) landraces as determined by analytical pyrolysis. J Sci Food Agric 78: 213–219.

D'Egidio, M.G. & S. Nardi, 1996. Textural measurement of cooked spaghetti. In: Kruger, J.E., R.B. Matsuo & J.W. Dick, (eds.) Pasta and Noodles Technology. AACC: St. Paul, MN. pp 133–156.

D'Egidio, M.G., E. De Stefanis, S. Fortini, G. Galterio, S. Nardi, D. Sgrulletta & A. Borrini, 1982. Standardization of cooking quality analysis in macaroni and pasta products. Cereal Foods World 27: 367–368.

Fares, C., M.G. Schiavone, V. Maddalena, P. Trono & P. Codianni, 2000. Nuove linee di farro per sfarinati e pasta di qualità. Molini d'Italia 4: 37–41.

Fares, C., P. Codianni, M.G. Schiavone, N. Di Fonzo & G. Galterio, 2002. Qualitative traits and storage protein composition in selected strains and new genotypes of hulled wheat (*T. turgidum* ssp. *dicoccum*) compared with durum wheat (*T. turgidum* ssp. *durum*). In Proc 2nd Int Workshop "Durum Wheat and Pasta Quality": Recent Achievements and NewTtrends" Rome, pp 193–196. M.G. D'egidio (eds.) Istituto Sperimentale per la Cerealicoltura Rome.

Galterio, G., M. Cappelloni, E. Desiderio & N.E. Pogna, 1994. Genetic, tecnological and nutritional characteristics of three Italian populations of "farrum" (*Triticum turgidum* subsp. *dicoccum*). J Genet & Breed 48: 391–398.

Galterio, G., P. Codianni, G. Novembre, C. Saponaro, N. Di Fonzo & N.E. Pogna, 1998. Storage-protein composition and technological characteristics of F_6 lines from the cross *Triticum turgidum* ssp. *durum* × *Triticum turgidum* ssp. *dicoccum*. In: Slinkard AE (eds.) Proc 9th Int Wheat Genet Symp,. University Extension Press, University of Saskatchewan, Saskatoon, Canada, vol. 4: 148–150.

Galterio, G., M. Colonna, G. Mariani & G. Novembre, 1999. Technological and nutritional characteristics of *Triticum turgidum* ssp. *dicoccum* and *Triticum spelta* grown in the Molise Region. Agr Med 129: 227–234.

Galterio, G., H. Hartings, S. Nardi & M. Motto, 2000. Biochemical and phylogenetic analysis of the major *T. turgidum* ssp. *dicoccum* Schrank populations cultivated in Italy. J Genet & Breed 54: 303–309.

Galterio, G., D. Cardarilli, P. Codianni & R. Acquistucci, 2001. Evaluation of chemical and technological characteristics of new lines of *Triticum turgidum* ssp. *dicoccum*. Nahrung/Food 45: 263–266.

Galterio, G., P. Codianni, A.M. Giusti, B. Pezzarossa & C. Cannella, 2003. Assessment of the agronomical and technological characteristics of *Triticum turgidum* ssp. *dicoccum* Schrank and *T. spelta* L. Nahrung/Food 47: 54–59.

Koekemoer, F.P., M.T. Labuschagne & C.S. Van Deventer, 1999. A selection strategy for combining high grain yield and high protein content in South African wheat cultivars. Cereal Res Comm 27: 107–114.

Kramer, T., 1979. Environmental and genetic variation for protein content in winter wheat. Euphytica 28: 209–218.

ICC., 1995. Standard Methods of the International Association for Cereal Science and Technology. Method 153, approved 1992. The Association: Vienna.

Laemmli, U.K., 1970. Cleavage of structural proteins during the assembly of the head of bacteriophage T4. Nature 227: 680–685.

Lafiandra, D. & D.D. Kasarda, 1985. One- and two-dimensional (two-pH) polyacrylamide gel electrophoresis in a single gel: separation of wheat proteins. Cereal Chem 62: 314–319.

Laghetti, G., A.R. Piergiovanni, N. Volpe & P. Perrino, 1988. Agronomic performance of *T. dicoccon* (Shrank) and *T. spelta* (L.) accessions under southern Italian conditions. Agr Med 129: 199–211.

Loffler, C.M. & R.H. Busch, 1982. Selection for grain protein, grain yield and nitrogen partitioning efficiency in hard red spring wheat. Crop Sci 22: 591–595.

Loss, S.P. & K.H.M. Siddique, 1994. Morphological and physiological traits associated with wheat yield increases in Mediterranean enviroments. Adv Agron 52: 229–276.

Margiotta, B., G. Colaprico, R. D'Ovidio & D. Lafiandra, 1993. Characterization of high Mr subunits of glutenin by combined chromatographic (RP-HPLC) electrophoretic separations and RFLP analyses of their encoding genes. J Cereal Sci 17: 221–236.

McNeal, F.H., C.F. McGuire & D.L. Klindworth, 1982. Agronomic and quality characteristics of spring wheat lines selected for protein content and protein yield. Euphytica 31: 377–381.

Miller, B.S., S. Afework, Y. Pomeranz, B.L. Bruinsma & G.D. Booth, 1982. Measuring the hardness of wheat. Cereal Foods World. 27: 61–64.

Payne, P.I., 1987. Genetics of wheat storage proteins and the effect of allelic variation on bread-making quality. Annu Rev Plant Physiol 38: 141–153.

Payne, P.I. & G.J. Lawrence, 1983. Catalogue of alleles for the complex gene loci Glu-A1, Glu-B1 and Glu-D1 which code for high molecular-weight subunits of glutenin in hexaploid wheat. Cereal Res Com 11: 29–35.

Perrino, P., K. Hammer & C.O. Lehmann, 1982. Collection of landraces of cultivated plants in South Italy 1981. Kulturpflanze 30: 181–190.

Pfluger, L.A., L.M. Martýn & J.B. Alvarez, 2001. Variation in the HMW and LMW glutenin subunits from Spanish accessions of emmer wheat (*Triticum turgidum* ssp. *dicoccum* Schrank). Theor Appl Genet 102: 767–772.

Piergiovanni, A.R., G. Laghetti & P. Perrino, 1996. Characteristics of meal from hulled wheats (*Triticum dicoccum* Schubler and *Triticum spelta* L.) an evaluation of selected accessions. Cereal Chem 73: 732–735.

Porfiri, O., R. Torricelli, D.D. Silver, R. Papa, G. Barcaccia & V. Negri, 2001. The Triticeae genetic resources of central Italy: collection, evaluation and conservation. Hereditas 135: 187–192.

Szabò, A.T. & K. Hammer, 1995. Note on the taxonomy of farro: *Triticum monococcum*, *T. dicoccon* and *T. spelta*. In: Podulosi, S., K. Hammer & J. Heller (eds). Hulled Wheats. IPGRI, Rome, Italy, pp 2–39.

Troccoli, A., P. Codianni, G. Ronga, A. Gallo & N. Di Fonzo, 1997. Agronomical performance among farro species and durum wheat in a drought-flat land environment of southern Italy. J Agron Crop Sci 178: 211–217.

Troccoli, A. & P. Codianni, 2005. Appropriate seeding rate for einkorn, emmer, and spelt grown under rainfed condition in southern Italy. Eur J Agron 22: 293–300.

UNI, Ente Italiano di Unificazione. Method 2171 for ash, 1993; Method 10689 for dry gluten, 1997; Method 10690 for gluten index, 1997; Method 10453 for CHOPIN alveograph, 1995.

Vallega, V. & J.G. Waines, 1987. High molecular weight glutenin subunit variation in *Triticum turgidum* var. *dicoccum*. Theor Appl Genet 74: 706–710.

Weegels, P.L., R.J. Hamer & J.D. Schofield, 1996. Functional properties of wheat glutenin. J Cereal Sci 23: 1–18.

Zadoks, J.C., T.T. Chang & C.F. Konzak, 1974. A decimal code for growth stages of cereals. Weed Res 14: 415–421.