Khorasan wheat, Kamut® and 'Pharaonenkorn': Origin, characteristics and potential

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Abstract

The consumer's interest in natural, unconventional and nutritional foods led to new niche markets for numerous specialty or alternative grains. Production of many of specialty grains, e.g. einkorn, emmer, or spelt wheat, is related to the rapidly increasing interest in organically grown products. Until recently ancient or primitive wheats were never the subject of modern plant breeding programmes; they exhibit some unique characteristics and are currently produced on a marginal scale. Khorasan or Oriental wheat (*Triticum turanicum*) is such a neglected and underutilized tetraploid wheat species, which probably survived over the centuries in the Near East and Central Asia. In the presented study agronomic and quality traits of 14 accessions of Khorasan wheat were evaluated in the Marchfeld region, north-east of Vienna.

The investigated material was inferior to modern durum wheats in most traits. No accession was found to tolerate low winter temperatures, tolerance to drought and fungal diseases was limited and/or modest, and grain yields were significantly lower. While the best performing spring sown *turanicum* accessions yielded in average about 260 g m^{-2}, the check spring durum wheats yielded about 380 g m^{-2}. Several characteristic and interesting features were observed which permit successful marketing of pure Khorasan grain or as admixture in grain blends. The grain has an impressive kernel size and thousand kernel weight, in most cases greater than 50 g and no seldom even greater than 60 g. The high thousand kernel weight might be a valuable trait to transfer into durum wheat to improve grain yield. Moreover, the grain has an amber colour and high vitreousness, and a 2-3% higher protein content. Rheological traits from farinograph, extensograph, and alveograph were generally lower than that of durum check cultivars. The same was the case for total yellow pigment content. Baking tests revealed loaf volumes not significantly different from durum wheat, however, the taste of the breads was evaluated superior to the control durum bread.

Due to the higher plant height, low lodging resistance and high susceptibility against powdery mildew Khorasan wheat may be more suitable for organic farming systems. However, further experiments are necessary to study the interactions between sowing density, sowing dates, weed suppression, thousand kernel weight and kernel plumpness in order to find production procedures for an optimal and stable grain yield.

Key-words: Ancient wheat - specialty grain - tetraploid wheat - *Triticum turanicum*

Introduction

Triticum turanicum Jakubz. is a tetraploid (BBAA, 2n=28) wheat species from Near and Central Asia and was first described by PERCIVAL (1921) as *T. orientale* Perc. The first scientific name and the origin of the described varieties, the Persian province of Khorasan, gave rise to the common names Khorasan and/or Oriental wheat. The taxonomic position of Khorasan wheat was often controversial: sometimes this wheat was treated as independent species and/or subspecies, sometimes as variety of durum wheat (*T. durum* Desf.) (FLAKSBERGER, 1929; BROUWER, 1972). KUCKUCK (1959) supposed that Khorasan wheat is a natural bastard between durum and Polish wheat (*T. polonicum* L.).

Khorasan wheat was cultivated only occasionally on a very limited area, not extending beyond the limits of Near and Central Asia (Turkey, Mesopotamia, Iran, Kazakhstan), and northern Africa (VAVILOV, 1951; GÖKGÖL, 1961). Cultivation in pure stands was restricted (GÖKGÖL, 1961), while the occurrence in mixture with durum and bread wheat (*T. aestivum* L.) was prevalent (UFER, 1956; GÖKGÖL, 1961). In wheat evolution, breeding and production Khorasan wheat played an obscure role until recent times. The crop survived probably over the centuries in subsistence farming systems (HAMMER, 2000). Recently, DOKUYUCU et al. (2004) identified only one landrace of Khorasan wheat in their collection of wheat landraces from the Kahramanmaras region of east-mediterranean Turkey, where the spread of modern cultivars led to the nearly extinction of landraces.

Kamut® is a registered trademark used in marketing products of the protected cultivated *turanicum* variety 'QK-77', which was registered by the USDA in 1990 (QUINN, 1999). Originally 'QK-77' was classified as Polish wheat. Reidentification in 1998 changed the classification into *turanicum* (USDA, ARS, National Genetic Resources Program, Germplasm Resources Information Network (GRIN), Online Database, National Germplasm Resources Laboratory, Beltsville, Maryland, USA). Kamut® products are marketed mainly through health food outlets. The development of new specialty foods based on grain blends has permitted the use of so-called 'ancient wheats' as components that convey naturalness, unconventional, and nutritional properties. Kamut attracted unexpected attention by both wheat scientists and producers to Khorasan wheat. Growing of Kamut is exclusively managed by license agreements and requires organic certification of the crop. Today production is mainly carried out in Montana, North Dakota, Alberta and

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Saskatchewan. Production was recently reported also for Australia, whereas production in Europe failed so far because of no suitable production area and/or lack of feedback by farmers (http://www.kamut.com/english/history/farming.htm).

In Austria a few farmers made positive experiments with sowing Khorasan wheat. Today Khorasan wheat is grown on a limited scale and is marketed under the name '*Pharaonenkorn*', i.e. grain of the pharaos'. In contrary, in Switzerland branched types of Rivet wheat (*T. turgidum*), the ancient *T. ramosum*, which are also known as '*Wunderweizen*' ('miracle wheat') are grown under the name '*Pharaonenweizen*' (FRETZ, 2001; PRO SPECIE RARA, 2002).

Plants of *T. turanicum* are characterised by erect young shoots with very narrow pubescent leaves. The plants tiller very little and the straw is thin. The spikes are narrow, lax or very lax with long narrow white glumes. The spikelet lemmas have long and strong, more or less deciduous, white or black awns. The stem immediately below the inflorescence is characterized in some varieties by a distinctive wave. The grains are very large - up to twice the size of bread wheat kernels - narrow, vitreous, and flinty with a characteristic hump (PERCIVAL, 1921; VAVILOV, 1951; STALLKNECHT et al., 1996).

The aim of this study was to test and describe genetic resources of Khorasan wheat in regard to their agronomic and qualitative potential and value under eastern Austrian growing conditions, and to probably identify Khorasan wheat germplasm superior in some traits to durum cultivars.

Materials and methods

13 *T. turanicum* accessions from the genebanks of the IPK Gatersleben and the BAB Linz were evaluated together with 'QK-77'. The seed of the latter genotype was originally bought as commercial Kamut. As check cultivars Austrian spring ('Extradur', 'Helidur', 'Topdur') and winter durum wheats ('Heradur') were used.

The crop was sown both in autumn and in spring. The field trials (2000-2004) were carried out at the BOKU Experimental Farm Groß-Enzersdorf (16° 332´E, 48° 112´N). In 2003 and 2004 the trials were carried out under organic farming conditions. Fertilisation, pest management, climatic condition and other characteristics of the trials are described in detail in GRAUSGRUBER et al. (2005).

During vegetation period date of heading, lodging, plant height at harvest, and resistances against powdery mildew (*Erysiphe graminis*), leaf rust (*Puccinia recondita*) and yellow rust (*Puccinia striiformis*) were evaluated. Thousand kernel weight and hectolitre weight were determined after harvest. In 2003 spike length, the number of spikelets per spike, spike density, the number of kernels per spikelet and the kernel weight were recorded from 10 randomly selected spikes per replicate. After harvest protein and wet gluten content were determined. In 2002 and 2003 dough rheological traits were evaluated by the farinograph, extensograph and alveograph. Yellow pigment and mineral content was determined from whole grain meal. Baking tests were carried out using semolina/flour <275 µm.

All statistical analyses were carried out with SAS 8.2 software and spreadsheet programmes. The field trials were analysed according to their field design. Mean comparisons to the standard durum cultivar(s) were carried out using the two-tailed stepdown bootstrap test (SAS Institute, 1999; WESTFALL et al., 1999). Overall genotypic means of 31 investigated traits were subjected to principal components analysis. Five principal components with an eigenvalue >1 were extracted. The eigenvectors of these 5 principal components were subjected to a cluster analysis using Ward's minimum variance method.

Results and discussion

The cold winter of 2002/2003 aside with no or little snow coverage, especially in February, led to severe damage of the autumn sown Khorasan wheats. Only a few single plants survived. Although soil temperatures were below -5°C for a long period they were never below -10°C. Since winter wheats can resist significantly lower temperatures (PORTER and GAWITH, 1999), none of the investigated accessions of Khorasan wheat can be considered to be of winter growth habit. Data for the winter crops from 2000-2002, when no severe frost damage was observed, can be found in detail in

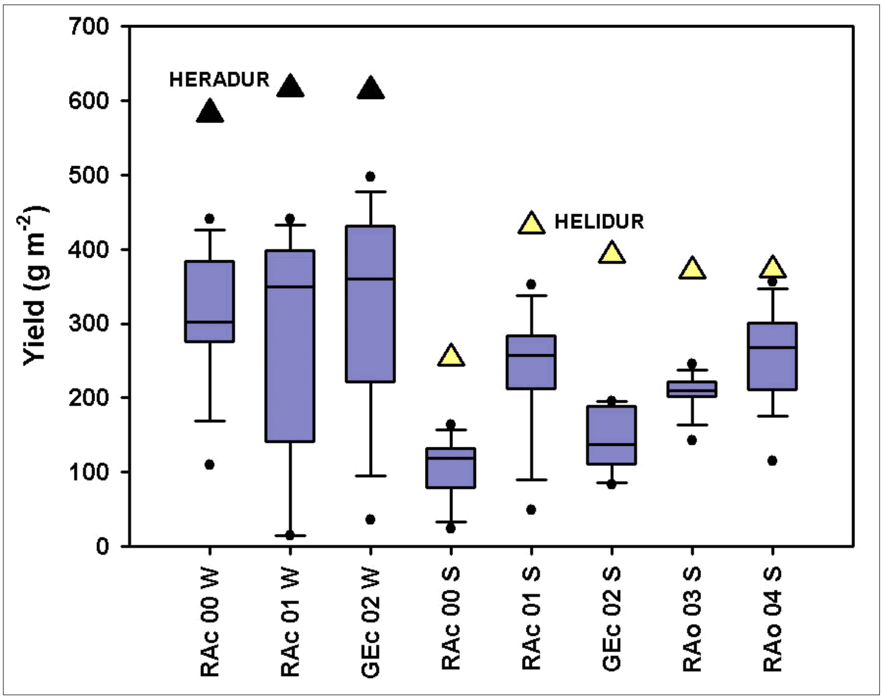

Figure 1: **Variation in yield for Khorasan wheats (boxplots) compared to standard durum wheats (triangles). Abbreviations: RA, Raasdorf; GE, Groß-Enzersdorf; c, conventional; o, organic; 00, 2000; 01, 2001; 02, 2002; 03, 2003; 04, 2004; W, winter crop; S, spring crop.**

Table 1: **Overall means of selected agronomic and qualitative traits**

Genotype	YLD[1]	TKW	PROT	GLUT	SEDI	R_{50}	E	A
Durum check	381.8*	42	15.5*	42	27	168	195	47
QK-77	264.3*	63*	17.4*	46	16*	130	122*	24†
BVAL 212017	260.7*	62*	17.8*	52*	20*	115	129*	21†
TRI 680	224.2*	52*	18.1*	45	19*	123	111*	22*
TRI 909	164.8*	43	17.8*	46	21*	117	117*	20*
TRI 3287	204.4*	56*	18.4*	46	19*	127	123*	25†
TRI 4326	218.0*	60*	18.0*	44	18*	143	115*	22†
TRI 5254	214.3*	58*	18.0*	45	19*	160	115*	25†
TRI 6075	82.7*	49	14.3*	33*	33*	140	202	47
TRI 6243	188.0*	44	17.3*	47	19*	087*	097*	14*
TRI 10343	198.4*	58*	18.4*	45	18*	193	111*	29
TRI 11532	209.7*	57*	18.7*	46	19*	190	115*	32
TRI 11533	153.8*	54*	18.7*	48†	19*	197	116*	33
TRI 17462	133.1*	44	18.1*	51*	21*	103	119*	17*

Genotype	WAF	DDT	FQN	W	P:L	G	YP	LV
Durum check	68.3	3.2	78	237	1.4	19.5	9.3	343
QK-77	65.3	2.8	48	226	2.3*	16.3*	9.3	282
BVAL 212017	66.8	3.0	60	183*	2.2*	16.1*	7.2*	-
TRI 680	68.9	2.8	53	279	3.2*	15.1*	6.8*	332
TRI 909	70.5	3.3	48	258	3.1*	15.1*	4.1*	-
TRI 3287	69.4	3.0	50	272	4.1*	13.6*	5.8*	322
TRI 4326	69.2	2.8	49	240	3.8*	13.9*	7.1*	334
TRI 5254	70.4	3.0	56	297*	3.1*	15.3*	6.8*	359
TRI 6075	59.2	3.0	55	-	-	-	4.1*	-
TRI 6243	70.6	2.8	48	231	3.1*	14.8*	4.0*	312
TRI 10343	68.9	2.8	55	414*	2.4*	17.7*	6.4*	345
TRI 11532	69.1	3.0	55	410*	2.7*	16.7*	6.8*	333
TRI 11533	70.4	3.0	61	338*	3.3*	15.1*	5.1*	327
TRI 17462	69.5	3.0	50	205	2.7*	15.5*	4.1*	324

Means with an appended * and † are significantly different from the durum check at P<0.05 and P<0.1, repectively.

The durum check is represented as artificial mean of Extradur, Helidur and Topdur, except for loaf volume, where the durum check is Heradur.

[1] YLD, yield (g m^{-2}); TKW, thousand kernel weight (g); PROT, protein content (%); SEDI, Zeleny sedimentation value (ml); R_{50}, Extensograph dough resistance at 50 mm extensibility (BU); E, Extensograph dough extensibility (mm); A, Extensograph dough energy (cm³); WAF, Farinograph water absorption (%); DDT, Farinograph dough development time (min); FQN, Farinograph quality number (mm); STA, Farinograph dough stability (min); W, Alveograph dough energy ($\times 10^{-4}$ J); P:L, Alveograph ratio dough stiffness:dough elasticity; G, Alveograph dough swelling (mL); YP, total yellow pigment content (ppm); LV, loaf volume (ml 100 g^{-1} flour)

GRAUSGRUBER et al. (2005). Variation in grain yield in the respective environment is demonstrated in *Figure 1*. Overall means for selected agronomic and qualitative traits of spring grown Khorasan wheat are demonstrated in *Table 1*.

Although Khorasan wheat originates from dry regions of the Near East and Central Asia its drought tolerance is questionable. In the presented study Khorasan wheat responded with yield losses higher than those of the Austrian durum wheats if water supply was not optimal in spring, e.g. sparse rainfall in 2000 or excessive rainfall in 2002 (GRAUSGRUBER et al., 2005). Already PERCIVAL (1921) and VAVILOV (1951) stated that Khorasan wheat has little adaptation to differences in environmental conditions and is found primarily on irrigated land, and MUNNS et al. (2000) observed no potential for salt tolerance in 5 *turanicum* accessions. A winter growth habit would be advantageous in order to benefit from a longer vegetation period, winter moisture and an earlier flowering and, hence, grain filling period. In the Iranian province of Khorasan where *T. turanicum* is still cultivated on a small acreage the crop is generally sown in autumn. However, winters in the Iranian tablelands can not be compared to conditions in Central Europe. In literature references on *turanicum* exhibiting a high winter hardiness are rare (DOKUYUCU et al., 2004).

In the present study average yield of the best performing spring sown Khorasan wheat was 264 g m^{-2} (with a minimum of 146 g m^{-2} in 2000 and a maximum of 352 g m^{-2} in 2001), which was significantly lower than yields of standard spring durum wheats. ABDEL-AAL et al. (1998a) report a yield of about 3 t ha^{-1} for Saskatchewan grown Khorasan wheat. It has to be considered that the sowing density in our trials was sub-optimal for reaching maximum yields because of the low tillering capacity of Khorasan wheat. Ancient wheats in general are inferior to modern wheats in many agronomic characters. Consequently, improvements in production are essential to stabilize grain yields. Further investigations on optimal sowing densities for maximal yield, yield components and the build-up of yield have to be carried out to identify the optimal production procedures.

While most *turanicum* accessions exhibited lower yields and hectolitre weights than durum wheats, thousand kernel weight was significantly higher. ABDEL-AAL et al. (1998a) reported values for test weight (75 kg hL^{-1}) and thousand kernel weight (67 g) similar to the values of the best performing genotypes in our study. SISSONS and HARE (2002) reported a variation in hectolitre weight of 72-79 kg hL^{-1} and thousand kernel weight of 44.0-52.9 g under Australian environmental conditions. This variati-

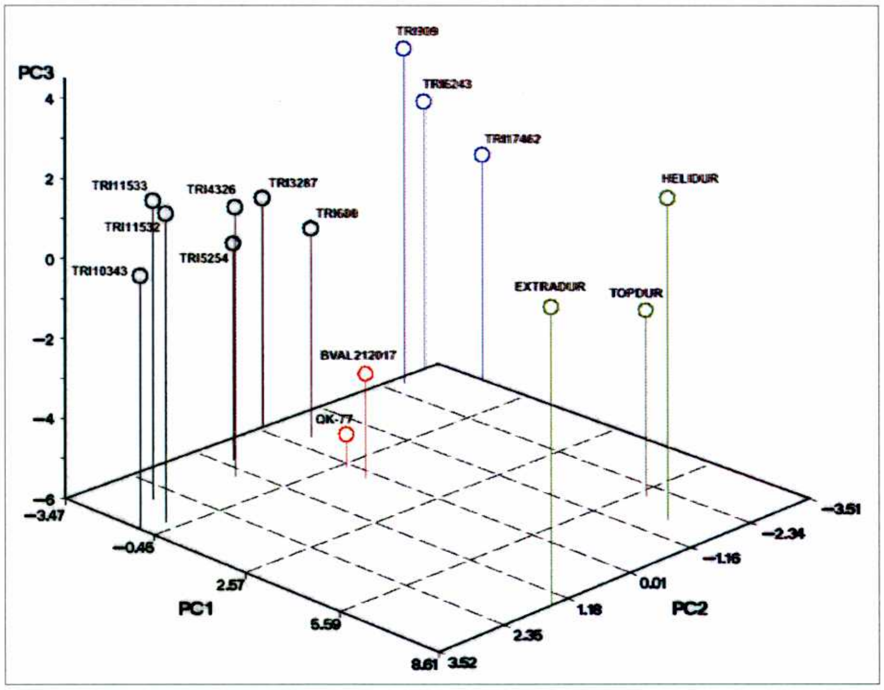

Figure 2: **Scatter plot of durum and Khorasan wheats based on their first three principal components. PC1, PC2 and PC3 explained 49.95%, 16.48% and 13.85%, respectively, of the total variation of 31 variables subjected to principal components analysis**

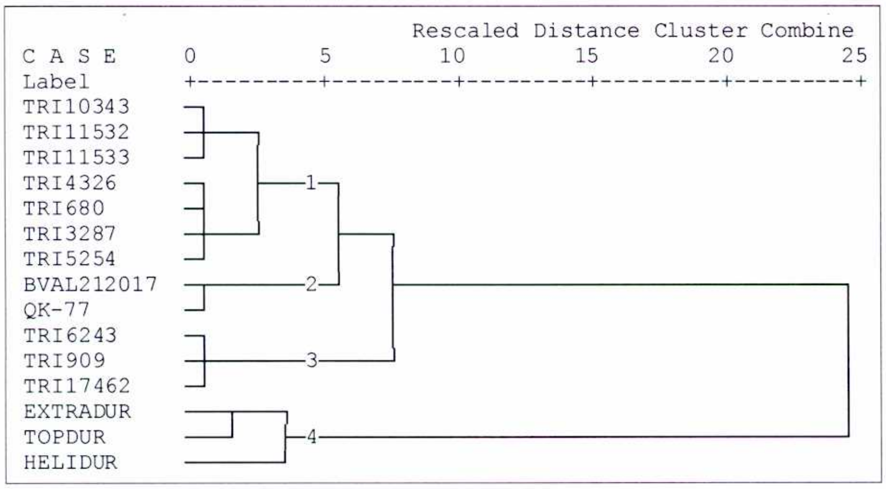

Figure 3: **Dendrogramm of the cluster analysis (Ward's method) using the genotypic eigenvectors of the first five principal components (91% of total variation) from principal components analysis of 31 agronomic and qualitative traits**

on is comparable to the variation observed in our trials (71-76 kg hL^{-1}, 41.4-64.5 g). While the thousand kernel weight is significantly higher, the hectolitre weight is lower than for durum wheats and falls below marketing limits of 78 and 80 kg hL^{-1}. The lower hectolitre weights are certainly due to the kernel shape (large, long kernels with a distinctive hump) of Khorasan wheat. SISSONS and HARE (2002) refered to Khorasan wheat having the lowest values of hectolitre weight within five tested tetraploid species. In regard to disease resistance the reports are rare. VAVILOV (1951) reported a high susceptibility to rust, while KAMINSKE (2002) observed leaf and yellow rust only on single plants. In our investigations a medium to high susceptibility to leaf and yellow rust was observed for the spring sown crop, however, disease scoring was often difficult as the leaves were to a more or less higher degree already covered with powdery mildew pustules. Then, rust pustules were in most cases only observed on the younger leaves. The present material was also highly susceptible to Fusarium head blight caused by artificial inoculation (GLADYSZ, pers. commun.). A higher susceptibility to powdery mildew was also observed by KAMINSKE (2002). FIGLIUOLO et al. (1998) tested 14 *turanicum* accessions for their resistance to eyespot (*Pseudocercosporella herpotrichoides*), however, none of the accessions was observed as resistant. LUPEI and VOLUEVICH (1997) studied alloplasmic lines of common wheat and reported that cytoplasms of Polish and Khorasan wheat increased the level of seedling resistance of two Byelorussian spring wheats against high aggressive isolates of *Septoria nodorum*.

Protein contents were generally higher in the present study than the 13.5-17.0% reported by SISSONS and BATEY (2003) for 5 Australian grown *turanicum* accessions. With the exception of farinograph water absorption SISSONS and HARE (2002) reported inferior farinograph and extensograph traits for Khorasan compared to durum wheats. The values reported by the latter authors are very similar to our results, with the exception that the absolute values for extensograph resistance of the Khorasan wheats, and farinograph water absorption of the durum wheats were higher than that of the Australian grown crops.

SISSONS and HARE (2002) also reported a higher yellow index of durum semolina measured as *b* value by means of a chromometer. This corresponds to our results, where with the exception of the Kamut wheat 'QK-77' all *turanicum* accessions exhibited significantly lower contents of total carotenoids. Inferior values for sedimentation volume, mixograph peak time, peak value and band width compared to durum wheat were reported by ABDEL-AAL et al. (1998b) for a *turanicum* accession originating from Turkey. The latter authors found similar yellow index (*b*) values for the tested Khorasan and durum wheat, however, lipoxygenase activity was found to be higher in Khorasan wheat. The authors conclude that Khorasan wheat can be used as a substitute for high-quality durum in pasta production, although a variety with low enzyme activity would be highly desirable. Since Kamut wheat grains are often used as germinated seeds in the diet it is important to note that no free nonprotein amino acids, some of which are potentially toxic for humans, were found in germinated Kamut seeds (ROZAN et al., 2000). However, since the problem of potentially toxic free non-protein amino acids appears more in fresh leguminous seeds, it can be supposed that no other wheat species is affected by that problem, and, therefore, all wheat seedlings can be regarded as safe in that respect.

Looking at the whole set of data the performance of TRI 6075 is remarkable. This genotype performed controversial in several traits. According to spike morphology this genotype was identified as *turanicum*, however, cytological studies revealed 42 chromosomes (LELLEY, pers. commun.), and molecular studies using microsatellites confirmed an *aestivum* introgression (BÖRNER, pers. commun.). Multivariate analysis grouped the investigated material into four clusters (*Figure 2* and *3*). Cluster 2 consists of 'QK-77' and BVAL 212017, which among the tested Khorasan wheats showed highest values for yield, thousand kernel weight, hectolitre weight, yellow pigment content, etc., but absolutely no winter hardness if sown in autumn (GRAUSGRUBER et al., 2005). These two genotypes differ from the rest also in regard to spike morphology: 19-21 spikelets compared to 12-14 spikelets per 10 cm spike length. According to the descriptors of the European Wheat Database spike density of the former genotypes is designated as lax, while the other genotypes have very lax spikes (*Figure 4*). In the meantime also molecular studies using microsatellites revealed that these two genotypes are more closely related to some *durum* and *polonicum* accessions than to *turanicum* accessions (BÖRNER, pers. commun.). Hence, the classification of Kamut wheat 'QK-77' and BVAL 212017 must probably be thought over. Cluster 3 included the wretched genotypes in regard to almost all traits, while the two subgroups of Cluster 1 represented the best performing *turanicum* genotypes. This group exhibits acceptable yields, high grain weight, high percentage of plump kernels, etc. especially when a continuous water supply is provided, either through winter moisture in case of autumn sowing or through an optimal distribution of rainfall in spring and during grain filling period. From climate data we can conclude that these genotypes will tolerate low temperatures down to -5°C without severe damage, however, do not exhibit 'true' frost tolerance (GRAUSGRUBER et al., 2005).

Analysis of the mineral content revealed that environment, year and/or production system affects the composition much more than the genotype (*Table 2*). Considering only the results from the 2003 organically grown crop, higher values for single Khorasan wheat accessions compared to winter durum 'Heradur' were observed for iron (TRI 5254), manganese ('QK-77', TRI 11532, TRI 11533), copper (TRI 11532, TRI 11533) and zinc

Figure 4: **Spike morphology: lax spike of Kamut wheat 'QK-77' (left; 14 spikelets) vs. very lax spike of Khorasan wheat TRI 4326 (right; 12 spikelets)**

('QK-77', TRI 6243, TRI 11532, TRI 11533). The latter genotypes showed also somewhat higher values for potassium, calcium and magnesium.

Conclusions

The variation in agronomic and quality traits observed in the *turanicum* accessions was significantly different from that observed in Austrian durum cultivars.

Table 2: **Mineral content (ppm) of *T. durum* cultivars and *T. turanicum* accessions**

Genotype	Year	Fe	Mn	Cu	Zn	K	Ca	Mg
Heradur	2001	32.6	26.6	4.4	22.1	4667	402	1003
Heradur	2002	27.6	27.6	6.5	28.3	4975	457	1236
Heradur	2003	43.0	10.6	3.8	12.5	3486	278	468
Helidur	2001	42.8	30.4	6.3	39.2	5424	543	1541
Helidur	2002	34.8	30.3	6.5	37.1	4625	468	1432
QK-77	2003	34.7	13.6	3.3	15.8	3129	331	540
TRI 680	2003	26.5	9.8	2.7	9.5	2442	240	355
TRI 3287	2003	27.6	10.0	2.6	9.4	2902	230	365
TRI 4326	2003	33.5	10.2	2.9	9.1	1861	220	362
TRI 5254	2003	55.6	10.0	3.5	9.0	1770	220	370
TRI 6243	2003	37.2	10.0	3.2	20.0	3331	292	585
TRI 10343	2003	30.0	9.9	3.0	10.1	1907	218	387
TRI 11532	2001	34.3	35.5	5.0	35.5	4943	440	1304
TRI 11532	2002	38.2	36.7	5.2	35.7	4512	347	1342
TRI 11532	2003	24.2	9.9	3.0	9.7	1565	261	372
TRI 11533	2003	26.8	10.0	3.6	10.1	2553	242	422
TRI 17462	2003	41.6	10.0	3.4	12.2	2144	295	385

In 2001 and 2002 the crop was grown conventionally, while in 2003 it was organically grown (production details see GRAUSGRUBER et al., 2005)

However, the potential of Khorasan wheat for the genetic improvement of durum is questionable, since in most traits the *turanicum* accessions exhibited lower values in performance than the durum checks. Valuable genes for an introgression into durum wheat may be primarily those encoding the high thousand kernel weight. Benefits in regard to disease resistance and better adaptation to abiotic stress are questionable, since the Khorasan wheats were all very susceptible to powdery mildew and rusts. Moreover, winter hardiness and drought tolerance is minimal and/or questionable in the investigated material. Although most rheological traits were inferior to durum wheats, baking volume and bread taste of Khorasan wheat was similar and/or higher than that of durum wheat. Baked products made from Khorasan wheat with excellent texture, flavour and taste can be an alternative food source for *aestivum* sensitive patients. In regard to coeliac disease, however, it has to be emphasized that Kamut and/or Khorasan wheat are no alternatives to gluten-free products; they are wheats, likewise einkorn, emmer, durum, spelt or bread wheat. Therefore, all these cereals have proteins toxic to coeliac patients and should be avoided (KASARDA, 2001). SIMONATO et al. (2002) showed that Kamut wheat was as allergenic for patients suffering from IgE-mediated food allergy as durum wheat. The authors recommend that allergy patients should be cautious about grains that are proposed as hypoallergenic or safe foods, however, are closely related to other allergy sources.

The low tillering capacity, the low number of spikelets per ear and kernels per spikelet - ranging from 0 to 3 with an average of 1 (spring crop) to 2 (winter crop) - and the high thousand kernel weight indicate that grain yield of Khorasan wheat is mainly determined by the thousand kernel weight. Due to the higher plant height, low lodging resistance and high susceptibility against powdery mildew Khorasan wheat may be more suitable for organic farming systems. In fact, the production of Kamut brand grain is exclusively organic. In this case, however, it has to be considered that Khorasan wheat has a low tillering capacity and, therefore, the weed pressure can be high if sowing density is too low. Further experiments are required to study the interactions between sowing density, sowing dates, weed suppression, thousand kernel weight and kernel plumpness to find production procedures for an optimal and stable yield, and clean grain (considering other cereal grains from volunteer plants, weed seeds, freedom from disease, e.g. *Fusarium* etc.). Khorasan wheat is of interest to increase diversity both on the field and on the consumers' table, albeit the adaptation of Khorasan wheat is low and by far not all spring wheat growing areas are suitable for production.

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