Food ©2009 Global Science Books

Oriental Wheat an Underutilised Tetraploid Wheat Species. A Case Study: Nutritional and Technological Traits of Kamut

Angela R. Piergiovanni[1*] • Rosanna Simeone[2] • Antonella Pasqualone[3]

[1] Istituto di Genetica Vegetale-CNR, via Amendola 165/a, 70126 Bari, Italy
[2] Dipartimento di Biologia e Chimica Agro-forestale ed Ambientale, Sezione di Genetica e miglioramento genetico, Università di Bari, via Amendola 165/a, 70126 Bari, Italy
[3] Dipartimento PROGESA, Sezione di Industrie agro-alimentari, Università di Bari, via Amendola 165/a, 70126 Bari, Italy

Corresponding author: * angelarosa.piergiovanni@igv.cnr.it

ABSTRACT

Interest in the so-called ancient wheats (einkorn, emmer, spelt and Oriental wheat) has increased dramatically over the last decades. Of particular interest, in relation to human consumption, are the nutritional traits as well as the pasta- and bread-making performances. This is attributable to the strict relationships between these features and the economic value of food derivatives entirely or partially prepared using ancient wheat species. Studies on agronomic, biochemical and technological traits of emmer and spelt have been the object of some reviews, while little attention has been devoted to Oriental wheat (*T. turgidum* L. subsp. *turanicum* (Jakubz.) A. Löve & D. Löve). This review describes the current state of knowledge regarding genetic, compositional and technological traits of Oriental wheat, a neglected and underutilised tetraploid wheat species. Comparison with ancient and modern wheat cultivars is also discussed. Literature dealing with the accession QK-77, registered as Kamut®, the only variety belonging to this species, is analysed in depth. The results of field trials carried out in Southern Italy, a geographical area traditionally devoted to durum wheat cultivation, are discussed. Moreover, the state of the art about the incorporation or the preparation of popular foods with Kamut® is presented.

Keywords: food derivatives, genetic diversity, Khorasan wheat, meal composition, protein electrophoresis, *Triticum turanicum*

CONTENTS

INTRODUCTION

At the beginning of agriculture, in the late Stone Age, some *Triticum* species have been domesticated from wild ancestors growing in the Fertile Crescent. Einkorn (*Triticum monococcum* (L.), MK, 2n = 2x = 14, AA) and emmer (*T. turgidum* L. subsp. *dicoccum* (Schrank) Thell, 2n = 4x = 28, AABB) are among the earliest cultivated wheat species and they were staple crops for some millennia. These hulled wheat species have been progressively replaced by more productive and free-threshing species such as common (*T. aestivum* subsp. *aestivum* (L.) and durum (*T. turgidum* L. subsp. *durum* (Desf.) Husnot) wheat though spelt (*T. aestivum* subsp. *spelta* (L.) Thell, 2n = 6x = 42, AABBDD), another hulled wheat species, survived for very long time in delimited European regions. Other *Triticum* species such as, Oriental wheat or Khorasan (*T. turgidum* L. subsp. *turanicum* (Jakubz.) A. Löve & D. Löve) along with Polish (*T. turgidum* L. subsp *polonicum* (L.) Thell) and Persian wheat (*T. turgidum* L. subsp *carthlicum* (Nevski in Kom.) A. Löve & D. Löve), three tetraploid (2n = 4x = 28, AABB) species of more recent origin as compared to hulled wheat species, were never staple crops. Oriental, Polish and Persian wheat have retained over the time, the role of inferior or marginal crops in world-wide agriculture and have survived still today in subsistence farming systems located in marginal areas characterised by poor nutritional habits (Abdel-Aal *et al.* 1998b).

Over the last decades, the attention towards the so-called ancient wheats: einkorn, emmer, Oriental wheat and spelt has constantly increased (Stallknecht *et al.* 1996; Abdel-Aal and Wood 2004). Farmers are rediscovering these species because they grow under organic conditions, in marginal areas and often get higher incomes with respect to modern wheat cultivars (Laghetti *et al*. 1999; Grausgruber *et al.* 2005). Consumers are tempted by specialities based on ancient wheats because these specialities are perceived as more natural, characterised by healthy properties and nutritionally equilibrated (Dean *et al.* 2007). The interest of food industry derives from the necessity to increase the diversification of commercialised products. Breeders looks at genetic diversity present in the ancient wheats germplasm as an important reservoir of economically useful genes (Sisson and Hare 2002; Grausgruber *et al.* 2004a). Finally, collection, characterisation and conservation of this germplasm can contribute to the biodiversity safeguard.

Among ancient wheats, researchers have devoted very little attention to Oriental wheat. This species was described for the first time by Percival (1921) as *T. orientale* Perc. The two samples described by Percival originated from the

Received: 27 January, 2009. Accepted: 17 May, 2009.

Invited Mini-Review

Persian province of Khorasan. For this reason this province was identified as the centre of origin of the new species and, Khorasan wheat is also used as common name. Some decades later Gökgöl (1961) indicated the western Anatolia as centre of origin because the material from this Turkish region showed a higher botanical diversity than that detectable in Khorasan. Several revisions of the taxonomic position of Oriental wheat have been proposed over the time. It has been considered an independent species (Percival 1921), a free-threshing tetraploid wheat (Brouwer 1972), a convarieties of *T. turgidum* subsp *turgidum* (MacKey 1988) or a natural hybrid between durum and Polish wheat (Kuckuck 1959). Filatenko *et al.* (2001) described the existence of two eco-geographical groups within the species. However, still today the role-played by Oriental wheat in the evolution of common and durum wheat continues to be obscure.

Vavilov (1951), Ufer (1956) and Gökgöl (1961) recorded that Oriental wheat is cultivated on very small surfaces, not extending beyond the limits of Turkey, Iraq, Iran, Kazakhstan, Afghanistan and some countries of North Africa such as Egypt and Morocco. Recently, Dokuyucu *et al.* (2004) found only one Oriental wheat landrace during a mission aimed at the collection of wheat genetic resources in the Turkish region of Kahramanmaras. Cultivation in pure stands is restricted, while the occurrence in mixtures with durum and common wheat has been reported in literature (Gökgöl 1961; Hammer 2000). Only, the cultivation of the registered variety QK-77, named Kamut® (Quinn 1999), has achieved economical relevance in parts of North-Western North America (Montana, North Dakota, Alberta and Saskatchewan). Several websites claim that Kamut® descended from grains found in an Egyptian tomb in the 1940s but, the more plausible view, is that it is a selection from a current-day Egyptian landrace.

We know little about the use, food-processing technology and the ways in which Oriental wheat has been consumed in ancient times. There are major obstacles in using textual evidences because of difficulties in translation and interpretation of the oldest sources. On the other hand, the main obstacle limiting the introduction or reintroduction of Oriental wheat in Southern Europe is the lack of information on their agronomic requirements, nutritional characteristics and technological performances (Nesbitt and Samuel 1996). To shed light on this species, the present review summarises the information available in the scientific literature dealing with Oriental wheat, as well as with its cultivation in Europe.

THE ORIENTAL WHEAT GERMPLASM

Genetic resources of *Triticum* L. are important for the development of new wheat cultivars, because it is easy to transfer genes from the primary gene-pool to common or durum wheat. Assessment of genetic diversity is an essential component in germplasm characterisation, conservation and utilisation in order to establish effective breeding programs. This key work is fundamental to identify the accessions carrying useful genes to improve wheat yield, quality, resistance to pest and diseases, etc. Oriental wheat germplasm collections held at gene-banks are very small compared to those of other *Triticum* species. The genetic variation existent within these collections is still in large part unknown. A very recent screening of gliadin and albumin fractions of the Oriental wheat collection held at Agricultural Research Service, National Small Grain Collection (ARS-USDA) (Aberdeen, USA), starts to sheld light on this topic (Piergiovanni 2009). This study has evidenced that the polymorphism of both these protein fractions existing in the collection is inferior to that observed for other collections of ancient wheats germplasm (Romanova *et al.* 2001; Piergiovanni and Volpe 2003; Alvarez *et al.* 2006). Moreover, the observation that accessions collected in the same country showed the identical combinations of gliadin and albumin electrophoretic profiles strongly suggests that duplicates could be present in the ARS-USDA collection. Overall, the study confirms that a higher degree of protein polymorphism is found in the accessions from Iran and Turkey (Piergiovanni 2009). This is consistent with the fact that these countries are indicated as the centres of origin of Oriental wheat (Percival 1921; Gökgöl 1961). Based on these results it is predictable that Oriental wheat would be a limited source of genes for breeders as compared to einkorn, emmer or spelt germplasm. This assumption, however, need to be confirmed by investigations based on others approaches such as the DNA molecular markers and glutenin polymorphism. Still today, only a very low number of Oriental wheat accessions have been studied by using molecular markers. SSRs (Simple Sequence Repeat) markers are known to show a much higher level of polymorphism in wheat than any other molecular marker. Li *et al.* (2006) estimated the genetic diversity in samples from Southwest China belonging to 6 subspecies of *T. turgidum* by using these markers. Unfortunately, only 2 Oriental wheat accessions were included in this study. However, the UPGMA cluster analysis of data revealed that these two accessions are different from each other and included in different clusters. Microsatellite markers have been used by Khlestkina *et al.* (2006) to study Kamut® wheat along with accessions belonging to other 13 tetraploid wheat species. The authors observed that in about 10% of tested material the grouping according to the markers was inconsistent with the formal taxonomic classification. Several accessions originally classified as *T. turanicum* had to be re-classified. Generally, the oriental wheat accessions were grouped into one big cluster (with two subgroups), while the Kamut® samples were grouped into the neighbouring cluster together with durum and polish accessions from regions around the Fertile Crescent.

AGRONOMIC PERFORMANCE IN SOUTHERN EUROPEAN ENVIRONMENTS

The attention devoted by European farmers towards Oriental wheat as well as other ancient wheats is mainly related to the expectation that they better perform in disadvantageous pedo-climatic conditions as compared to modern cultivars. However, this assessment is far to be scientifically demonstrated. Presently, only fragmentary information is available on the agronomic requirements and response of Oriental wheat to different environmental conditions (soil fertility, drought, waterlodging, salinity, etc.). The first trials carried out in France and Northern Italy from 1994 to 1999 failed because of adverse climatic conditions and lack of feedback by farmers (see http://www.kamut.com). More recently, encouraging results have been obtained during trials carried out in Austria, Switzerland and Italy. Grausgruber *et al*. (2004b, 2005) compared the agronomic traits of thirteen Oriental wheat accessions held at the gene-bank of Institute für Pflanzengenetik und Kulturpflanzenforschung (IPK) gene-bank (Gatersleben, Germany) with the cultivar Kamut® and four durum wheat cultivars. The trials were carried out over a period of 4 years in the Marchfeld region (North-East Austria). All the Oriental wheat samples were inferior to modern durum wheats in most agronomic traits such as yield (average values: 309.5 g m^{-2} and 499.9 g m^{-2} for Oriental wheat and controls, respectively), susceptibility to powdery mildew, leaf rust and yellow rust, tendency for lodging, low adaptation to differences in environmental conditions. Although Oriental wheat originates from dry regions of the Near East and Central Asia its drought tolerance was found questionable. Grausgruber *et al*. (2005) observed that yield, grain weight and percentage of plump kernels benefit of a continuous water supply. This can be either through winter moisture in case of autumn sowing or through an optimal distribution of rainfall in spring and during grain filling period. Two studies, carried out in marginal areas of Central and Southern Italy, compared the agronomic performances of Oriental wheat with emmer accessions and durum wheat varieties (Piergiovanni *et al.* 2005; Stagnari *et al.* 2008). Grain yield of Oriental wheat was found inferior to that of controls in both trials (280 g m^{-2} and 310-360 g m^{-2}, respectively). Moreover, Stagnari *et al.* (2008), in agreement with Grausgruber *et al.* (2005), reported that Oriental wheat genotypes were taller than durum varieties, had a low adaptation to changeable environmental conditions, showed a high susceptibility to diseases and tendency for lodging. Other studies available in the literature evidenced the lack of Oriental wheat accessions resistant to eyespot (*Pseudocercosporella herpotrichoides*) and Fusarium (Figliuolo *et al.* 1998; Oliver *et al.* 2008). Although, the field trials carried out are insufficient to identify the optimal agri-technique as well as the genotypes more suited for the European environments, the acquired data suggested that organic farming systems are more suitable for Oriental wheat production. Moreover, in Southern European environments, the variety Kamut® appears to be more adapted for spring sowing though, in the Iranian province of Khorasan, it is traditionally sown in autumn.

GRAIN QUALITY

One distinctive trait of Oriental wheat is the visual aspect of individual kernels clearly differing from that of other tetraploid wheat species. The exceptionally high kernel weight (1000-seeds weight: 43-64 g) is explained by the very large kernel size-up to twice the size of durum wheat kernels. The narrow and flinty kernel shape, which allows a not dense agglomeration within the chondrometer, is the reason for a not very high hectoliter weight ranging from 72 to 80 kg hL^{-1}.

Research has demonstrated that emmer and spelt kernels are characterised by protein content generally higher than those of modern durum and common wheat cultivars (Abdel-Aal *et al.* 1998b; Piergiovanni 1999; Oliveira 2001; Sissons and Hare 2002). This has been attributed to the lower yield associated to ancient wheat species as compared to modern cultivars (Vallega 1992). A general tendency to accumulate high protein levels has been observed also for Oriental wheat kernels by some authors who tested several genotypes in different environments. As shown in **Table 1**, Oriental wheat overcomes the protein content of durum cultivar checks in European (Grausgruber *et al.* 2004b, 2005; Stagnari *et al.* 2008), Australian (Sissons and Hare 2002; Sissons and Batey 2003) and Canadian (Gauthier *et al.* 2006) environments. However, spelt and emmer genotypes performed better than Kamut® in trials carried out in Italy (Piergiovanni *et al.* 2005; Brandolini *et al.* 2008). Protein content is one of the most important parameters when high-temperature drying technology is used to improve the pasta cooking quality. Semolina protein content above 12% is considered one of the parameters required obtaining good pasta quality. Experimental evidence suggests that, similarly to emmer, also Oriental wheat could satisfy this requirement (**Table 1**). However, in addition to the quantity also the composition of the wheat endosperm proteins affects pasta quality (Troccoli *et al.* 2000). Consequently, identification of accessions characterised by good pasta-making quality within germplasm collections would require not only the protein content measurement but also the determination of electrophoretic profiles of gluten proteins (Kovacs *et al.* 1995; Porceddu *et al.* 1998; Sissons *et al.* 2002).

It is known that ancient and modern wheat showed different ash content. Several studies have evidenced that the ash content of whole grain is dependent on wheat species and that, within a species, the genotype-environment interactions play an important role in determining this parameter (Peterson *et al.* 1986; Troccoli *et al.* 2000). Favourable growing conditions result in higher ash values due to increased uptake of minerals from soil. The typically low ash content of present-day cultivars is mainly the result of a deliberate selection to increase quality for the milling industry. For these reasons, the ash amount can be considered an indicator of the primitiveness of a wheat species. The screening of the ARS-USDA Oriental wheat accessions evidenced, as expected higher ash contents than in modern cultivars (mean value 2.09 % dw) but a low variation of this parameter within the collection (Piergiovanni *et al.* 2008).

The reduction of protein content after grain debranning has been also investigated due to the more frequent use of refined than whole meal by food industries (**Table 1**). On the average, protein loss was inferior for ancient wheats compared to durum and common wheat cultivars (about 1% vs. more than 2%). In accordance with studies on other ancient wheat species (Abdel-Aal *et al.* 1998a, 1998b; Piergiovanni 1999; Oliveira 2001; Sissons and Batey 2003) also for Oriental wheat a pronounced protein accumulation leads to high gluten concentrations. Stagnari *et al.* (2008) recorded gluten contents ranging from 10.7 to 12.7% dw for 14 Oriental wheat lines grown in Central and Southern Italy, while 15.5% dw was reported for Kamut® by Piergiovanni *et al.* (2005). The latter value was assessed in whole Kamut® meal, and lowered to 12.2% dw in the corresponding refined flour. Gluten is the major contributor to pasta quality in traditional drying processes. Therefore all parameters related to this grain component need to be carefully investigated. A higher value of the ratio dry gluten/protein content for whole Kamut® meal (94.5) as compared to emmer (79.0) and durum (87.5) controls has been reported by Piergiovanni *et al.* (2005).

Nowadays, cereals are recognised sources of health-enhancing bioactive components such as minerals, fiber, phenolics, tocopherols and carotenoids. The development of new specialty foods based on ancient wheat blends requires the careful evaluation of these minor grain components to substantiate differences or similarities between ancient and modern wheats. As concerns, the aptitude to store macro and micro minerals in grains, the comparison between Oriental wheat accessions and modern wheat cultivars grown in the same environment is still at beginning stages. Data available in the literature suggest that the environment, the annual climatic conditions and the agri-technique could affect mineral content of Oriental wheat grains much more than the genotype contribution to variation (Robberecht *et al.* 1999; Grausgruber *et al.* 2004b; Piergiovanni *et al.* 2005). In fact, the comparison of content of some minerals in Kamut® kernels grown in different years and environments shown relevant differences (**Table 2**) attributable to the background of the grains (country of cultivation, element content of the soil and agro-technique). Some surveys

Table 1 Protein content reported in the literature for various wheat species cultivated in the same environments. All the values are expressed as % dw.

Oriental wheat	Kamut	Emmer	Spelt	Durum wheat	Common wheat	Localisation of field trials	Reference
14.3 - 18.7	17.4 [a]			15.5		Austria	Grausgruber *et al.* 2004
14.7 - 17.0		14.8 - 18.1		13.7 -17.6		Central Italy	Stagnari *et al.* 2008
	16.9	14.0 - 16.0	17.1 - 18.7	14.0 - 18.3	13.7 -15.6	North Italy	Brandolini *et al.* 2008
	16.4 [a]	17.7 [a]	18.4 [a]	14.3 [a]	16.6 [a]	South Italy	Piergiovanni *et al.* 2005
	15.1 [b]	16.6 [b]	17.3 [b]	12.6 [b]	14.0 [b]	South Italy	Piergiovanni *et al.* 2005
14.8				10.5		Canada	Gauthier *et al.* 2006
13.9 - 16.7				12.2 - 13.7		Australia	Sissons and Hare 2002
13.7 - 17.0						Australia	Sissons and Batey 2003
	18.4 [a]					USA	Report of Midallion Laboratory, Minneapolis

a - whole meal; b - refined meal.

Table 2 Comparison of mineral content (ppm dry matter) of Kamut and some durum wheat cultivars as reported in the literature.

Cultivar name	Species	Fe	K	Ca	Mg	Cu	Zn	Mn	Na	P	Se	Si
Kamut (1)	Oriental wheat	34.7	3129	331	540	3.3	15.8	13.6	--	--	--	--
Heradur (1)	Durum wheat	43.0	3486	278	468	3.8	12.5	10.6	--	--	--	--
Kamut (2)	Oriental wheat	28.8	4908	166	1118	--	--	--	59.8	4450	0.07	--
Norba (2)	Durum wheat	36.4	4718	220	833	--	--	--	98.8	3821	0.02	--
Farvento (2)	Emmer	38.3	4291	226	1142	--	--	--	98.2	4217	0.05	--
Kamut (3)	Oriental wheat	45.7	4453	284	1345	5.7	39.3	--	28.7	--	--	14.9
Spelt (3)	Spelt	43.4	4338	280	1328	5.3	33.6	--	8.0	--	--	28.2

References: (1) Grausgruber *et al.* 2004b; (2) Piergiovanni *et al.* 2005; Robberecht *et al.* 1999

showed that selenium is declining in the food chain (Frost 1987; Combs 2001). The importance of this trace element is related to its presence, as selenocysteine, in glutatione peroxidase (GPX), as well as to its protective function against several kinds of cancers (Diplock and Chaudhry 1988; Ip 1998; Rayman 2005). Because wheat is one of the most important dietary sources of this element increasing the Se content of wheat grains represents an important goal. In this frame very interesting, if confirmed by further studies, could be the aptitude of Kamut® to store in its kernel selenium amounts significantly higher than those detected in the kernels of other tetraploid species (**Table 2**).

On the other hand, it is well established that several biological processes are influenced by the contemporaneous action of more than one ion. For example, high levels of phytates, which account for the main fraction of phosphorous, are detrimental because they reduce the calcium absorption across the small intestine (Raboy 2001; Bohn *et al.* 2008). This is an important nutritional limit of wheat because it is not only seriously deficient in calcium (26-55 mg/100 g), but also characterised by a Ca/P ratio near 1:10, far to the 1:1 value required by human bone formation. As shown in **Table 2**, the Ca/P ratio of Kamut® kernels (0.037) is inferior to that of durum and common wheat tested cultivars (0.058 and 0.054, respectively). The ratio Mg/Ca is also relevant from a nutritional point of view due to the strong linkage between these elements in several biological processes such as the contractile activity of cardiac muscle, the parathyroid hormone levels, etc. (Shils 1988). As shown in **Table 2**, the literature reported opposite results. While in Grausgruber *et al.* (2004b) the Mg/Ca ratio of Kamut® was found comparable to that of Heradur (1.63 and 1.68, respectively) and in Robberecht *et al.* (1999) it was found identical to that of spelt (4.74), a significant difference was observed in Piergiovanni *et al.* (2005) between Kamut® and Norba (Mg/Ca 6.73 and 3.78, respectively). Of course, the screening of the mineral contents on a large sample set of Oriental wheat accessions is required to draw conclusive assessments about the aptitude of this species to store minerals in grains.

Carotenoids in wheat include xanthophylls, mainly lutein, xanthophyll esters and carotenes (Abdel-Aal *et al.* 2007). The consumption of foods with high levels of carotenoids, especially lutein and zeaxanthin, has been related to a reduced incidence of age-related pathologies. Sissons and Hare (2002) found higher yellow indices for Oriental wheat respect to other tetraploid species measuring the b^* value by means of a colorimeter. The quantisation of yellow pigments extracted, using solvents, from Oriental wheat accessions (4.0-7.1 ppm) or in Kamut® meal (6.0 ppm) has confirmed that this species has yellow index higher than that of other tetraploid wheat species (Grausgruber *et al.* 2004b; Piergiovanni *et al.* 2005) but inferior to that of einkorn (D'Egidio *et al.* 1993; Abdel-Aal *et al.* 2002; Brandolini *et al.* 2008). These results support the hypothesis that Oriental wheat germplasm accessions could be a potential source for breeding programmes of accessions having high pigment contents. A strong yellowish tinge of semolina is not only highly appreciated by the pasta industry (Troccoli *et al.* 2000) but also important in poultry and swine feed (D'Egidio *et al.* 1993). Although Oriental wheat could be an interesting substitute for high-quality durum in pasta production due to its high protein and pigment contents, accessions with low lipoxygenase activity would be highly desirable for commercial purposes. In fact, rancid odour may even appear because of the action of lipase and lipoxygenases producing a fast degradation of lutein pigments in pasta processing.

The construction of dietary guidelines for calcium oxalate stone patients starts with the restriction of food rich in oxalate. Because cereal foods contribute to the daily oxalate intake to a considerable extent, ancient wheats could help to control its intake. The soluble and total oxalate contents of various cereal grains have been recently studied (Siener *et al.* 2006). The soluble fraction of Kamut® kernels (28.4 mg/100 g) was found inferior to that of spelt, common and durum wheat kernels (31.2, 45.7 and 40.0 mg/100 g, respectively). Moreover, also the total oxalate content of Kamut® (46.5 mg/100 g) was found less than those of common and durum wheat samples (59.3 and 76.6 mg/100 g, respectively).

In the past claims have been made that ancient wheats do not contain the allergens that damage intestinal membranes in celiac and gluten-sensitive patients. However, several molecular and structural studies demonstrated that this hypothesis is not right and that gluten from cereals can trigger coeliac disease (Dutau 2004; Shan *et al.* 2005; Wieser and Koehler 2008). Recent *in vitro* and *in vivo* tests demonstrated that also Oriental wheat grains are toxic for celiac patients (Guandalini and Gupta 2002; Simonato *et al.* 2002). This is not surprising because of the close phylogenetic relationship of Kamut® and the other cereals.

A CASE STUDY: POPULAR FOODS BASED ON KAMUT®

Consumers are becoming increasingly aware of the benefits of including a variety of cereal grains as a major portion of their diet (Kantor *et al.* 2001). Nowadays, ancient wheats are mainly consumed as whole grains in soups or as wholemeal to prepare several end products at home level. In the last decades, the interest of the food industry is raised towards the production of innovative food items able to preserve consumers at some extents from the risk of nutrition-related diseases. A huge interest is focused on functional foods that are regarded as able to affect beneficially one or more target functions in the body. A promising strategy for the food industry to satisfy this requirement could be the reformulation of popular foods to enhance their nutritional properties without significantly modifying their acceptability and physico-chemical characteristics. For these reasons, the incorporation as well as the preparation of common food with Kamut® meal has been the object of recent studies involving nutritionists, food technologists and food industries.

Pasta is generally made from refined durum wheat semolina. However, emerging markets exist for pasta made from whole meal or alternative wheats such as emmer and Oriental wheat. In whole wheat pasta processing, bran and germ tend to break the gluten matrix and, after drying, pasta is more rigid, less extensible and tends to break easily. Gauthier *et al.* (2006) reported that Kamut® and durum wheat kernels have similar hardness (10.5 and 10.3% PSI, particle size index, respectively), but the Kamut® contains more proteins and ash than durum. The same study evidenced that the use of coarse Kamut® semolina (210-500 μm particle size) and the removal of fine bran-rich semolina, containing high levels of damaged starch, is preferable to produce high-quality bran-rich pasta. Pasta obtained using this kind of Kamut® semolina is characterised by higher firmness and water absorption but lower cooking loss respect to pasta made from whole durum wheat.

Tortillas are traditionally made from finely ground maize or wheat flour and are characterised by a flexible texture and easy handling of the product. They are very common food in Central and South America but are becoming an important snack or bread substitute all over the world. Two recent studies (Scazzina *et al.* 2008; Serventi *et al.* 2009) have investigated the development of nutritionally enhanced tortillas by incorporating ingredients with well-documented nutritional functionality, such as carrots and whole flour of both soy and Kamut® into the standard formulation, Sensory acceptability, textural attributes, colour, total antioxidant capacity and *in vivo* glycemic index (GI) of different formulations were investigated. A very interesting product was obtained with the simultaneous combination of carrot juice, whole soy flour and whole meal Kamut® in the following amounts: 18.9, 17.0 and 41.0%, respectively. A multidisciplinary evaluation evidenced that tortillas made from this formulation were the most acceptable ones by panellists. Moreover, they were characterised by a high nutritional value for what regards the lowest GI (40 vs. 70 of the standard formulation) and relatively high antioxidant capacity (4.0 vs. 3.5 mmol/kg relative to the standard formulation). This study demonstrated the possibility to create food products characterised not only by high acceptance, but also by beneficial health effects.

Bread made from durum wheat is appreciated in many Mediterranean areas for its sensory features, long resistance to staling and good nutritional value (Quaglia 1988; Raffo *et al*. 2003; Pasqualone *et al*. 2004, 2007). In Southern Italy, there is a consolidated bread-making tradition based on durum wheat, so that there exists a certain interest by producers towards testing other tetraploid ancient wheat. Due to this consolidated tradition Pasqualone *et al*. (2005, 2006) examined the technological performances and the bread-making aptitude of Kamut® grown in Southern Italy, by considering both whole and refined flour. Over two years of trials, yellow index of the refined flour showed a mean value of 20.68, while in whole meal it accounted for 19.16. Mean gluten index was 48 in refined flour, vs. 41 in whole meal. Besides, the alveographic W did not reach 100×10^{-4} J in any of the trials as a consequence of weak dough (Goesaert *et al*. 2005). Kamut® bread was characterised by a low specific volume, slightly exceeding 3 ml/g (Simeone *et al.* 2004). Moreover, Kamut® bread was characterised by a yellowish crumb reflecting the high pigment content of starting flour, as observed also by Graugruber *et al.* (2004b). These features resemble those typical of durum wheat breads (Raffo *et al.* 2003; Pasqualone *et al*. 2004, 2007). Bread-making trials carried out with spelt cultivar Forenza grown in the same environment gave a less compact product with higher loaf volumes than Kamut®.

Although these preliminary studies showed that Kamut® could be used to reformulate very popular foods such as pasta, bread and tortillas, before setting up a whole production system, economic evaluations should be added to the nutritional and technological considerations. In fact, it should be taken in account disadvantages related to the high prices of these niche raw materials as well as the shelf life of the innovative end products.

FUTURE PERSPECTIVES

Overall compositional traits relative to Kamut® grown in Southern European environments were found to be not too dissimilar from those of durum wheat cultivars. This is very interesting because Oriental wheat has been described in the past as a species characterised by little adaptation (Vavilov 1951). Further investigations involving Oriental wheat germplasm have to be carried out to identify the accessions characterised by the best adaptation to European environmental conditions.

On the other hand, it should be taken into account that the ever-narrowing quality specifications of modern food industries should not be overestimated when evaluating the potential of a primitive crop species such as Oriental wheat. The economic perspectives of these species do not reside as much in their capacity to mimic attributes already present in modern wheat cultivars but in the possibility to be used in the preparation of novel wheat-based foods. In this frame the superior protein, pigment contents and GI observed for Kamut® as well as for other Oriental wheat accessions, should play an important role in the choice of the most appropriate end products. Furthermore, detailed studies of Oriental wheat germplasm could allow the identification of accessions in which high levels of phytochemicals, antioxidants and dietary fiber components are combined with good yield and processing quality. This means that commercially competitive lines of novel food specialities with high levels of bioactive components are a realistic goal for plant breeders.

REFERENCES

Abdel-Aal ESM, Wood P (2004) Introduction to speciality grains. In: Abdel-Aal ESM, Wood P (Eds) *Speciality Grains for Food and Feed*, American Association of Cereal Chemists, St. Paul, USA, pp 1-6

Abdel-Aal ESM, Hucl P, Sosulski FW (1998a) Food uses for ancient wheats. *Cereal Foods World* **43**, 763-766

Abdel-Aal ESM, Sosulski FW, Hucl P (1998b) Origins, characteristics and potentials of ancient wheats. *Cereal Foods World* **43**, 708-715

Abdel-Aal ESM, Young JC, Rabalski I, Hucl P, Fregeau-Reid J (2007) Identification and quantification of seed carotenoids in selected wheat species. *Journal of Agricultural Food Chemistry* **55**, 787-794

Abdel-Aal ESM, Young JC, Wood P, Rabalski I, Hucl P, Falk D, Fregeau-Reid J (2002) Einkorn: a potential candidate for developing high letein wheat. *Cereal Chemistry* **79**, 455-457

Alvarez JB, Moral A, Martin LM (2006) Polymorphism and genetic diversity for the seed storage proteins in Spanish cultivated einkorn wheat (*Triticum monococcum* L. ssp. *monococcum*). *Genetic Resources and Crop Evolution* **53**, 1061-1067

Bohn L, Meyer AS, Rasmussen SK (2008) Phytate: Impact on environment and human nutrition. A challenge for molecular breeding. *Journal of Zhejiang University Science B* **9**, 165-191

Brandolini A, Hidalgo A, Moscaritolo S (2008) Chemical composition and pasting properties of einkorn (*Triticum monococcum* L. subsp. *Monococcum*) whole meal flour. *Journal of Cereal Science* **47**, 599-609

Brouwer W (1972) *Handbuch des speziellen Pflanzenbaues, Band 1, Weizen, Roggen, Gerste, Hafer, Mais*, Paul Parey Verlag , Berlin, Germany, 622 pp

Combs GF (2001) Selenium in global food system. *British Journal of Nutrition* **85**, 517-547

Dean M, Shepherd R, Arvola A, Vassallo M, Winkelmann M, Claupein E, Lähteenmäki L, Raats MM, Saba A (2007) Consumer perceptions of healthy cereal products and production methods. *Journal of Cereal Science* **46**, 188-196

D'Egidio MG, Nardi S, Vallega V (1993) Grain, flour and dough characteristics of selected strains of diploid wheat, *Triticum monococcum* L. *Cereal Chemistry* **70**, 298-303

Diplock AT, Chaudhry FA (1988) The relationship of selenium biochemistry to selenium-responsive disease in man. In: Prasad AS (Ed) *Essential and Toxic Trace Elements in Human Health and Diseases*, Alan R. Liss., New York, pp 211-226

Dokuyucu T, Akkaya A, Akura M, Kara R, Budak H (2004) Collection, identification and conservation of wheat landraces in Kahramanmaras province in east Mediterranean region of Turkey. *Cereal Research Communication* **32**, 167-174

Dutau G (2004) Le risque allergique des produits diététiques et médicinaux. *Revue Francaise d'Allergologie et d'Immunologie Clinique* **44**, 634-645

Figliuolo G, Jones SS, Murray TD, Spagnoletti Zeuli PL (1998) Characterisation of tetraploid wheat germplasm for resistance to *Pseudocercosporella herpotrichoides,* cause of eyespot disease. *Genetic Resources and Crop Evolution* **45**, 47-56

Filatenko AA, Grau M, Knupfer H, Hammer K (2001) Wheat classification John Percival's contribution and the approach of the Russian school. In: Caligari PDS, Brandham PE (Eds) *Wheat Taxonomy: The Legacy of John Percival*, The Linnean Special Issue 3, The Linnean Society, London, pp 165-184

Frost DV (1987) Why the level of selenium in the food chain appears to be decreasing In: Combs GF, Levander OA, Spallholz J (Eds) *Selenium in Biology and Medicine Part A,* AVI Van Nostrand, New York, pp 534-547

Gauthier J, Gèlinas P, Beauchemin R (2006) Effect of stone-milled semolina granulation on the quality of bran-rich pasta made from Khorasan (Kamut®) and durum wheat. *International Journal of Food Science and Technology* **41**, 596-599

Goesaert H, Brijs K, Veraverbeke WS, Courtin CM, Gebruers K, Delcour JA (2005) Wheat flour constituents: how they impact bread quality, and how to impact their functionality. *Trends in Food Science and Technology* **16**, 12-30

Gökgöl M (1961) Die iranischen Weizen. *Zeitschrift für Planzenzüchtung* **45**, 316-333

Grausgruber H, Oberforster M, Ghambashidze G, Ruckenbauer P (2005) Yield and agronomic traits of khorasan wheat (*T. turanicum* Jakubz.). *Field Crop Research* **91**, 319-327

Grausgruber H, Sailer C, Ghambashidze G, Bolyos L, Ruckenbauer P (2004a) Genetic variation in agronomic and qualitative traits of ancient wheats. In: Vollmann J, Grausgruber H, Ruckenbauer P (Eds) *Genetic Variation for Plant Breeding*, *Proceedings of the 17th EUCARPIA General Congress,* 8-11 September, Tulln, Austria, pp 19-22

Grausgruber H, Sailer C, Ruckenbauer P (2004b) Khorasan wheat, Kamut and 'Pharaonenkorn': Origin, characteristics and potential. Vereinigung der Pflanzenzüchter und Saatgutkaufleute Österreichs, *55. Arbeitstagung der Vereinigung der Pflanzenzüchter und Saatgutkaufleute Österreichs*, 23-25 November 2004, Raumberg-Gumpenstein, Irdning, Austria, pp 75-80

Guandalini S, Gupta P (2002) Celiac disease a diagnostic challenge with many facets. *Clinical and Applied Immunology Review* **2**, 293-305

Hammer K (2000) Biodiversity of the genus *Triticum*. In: Wiethaler C, Oppermann R, Wyss E (Eds) *Organic Plant Breeding and Biodiversity of Cultural Plants*, NABU/FiBL, Bonn, Germany, pp 72-81

Kantor LS, Variyam JN, Allshouse JE, Putnam JJ, Lin BH (2001) Choose a variety of grain daily, especially whole grains: a challenge for consumers. *Journal of Nutrition* **131**, 473s-486s

Khlestkina E, Röder MS, Grausgruber H, Börner A (2006) A DNA fingerprinting-based taxonomic allocation of Kamut wheat. *Plant Genetic Resources* **4**, 172-180

Kovacs MIP, Howes NK, Leisle D, Zawistowski J (1995) Effect of two different low molecular weight glutenin subunits on durum wheat pasta quality parameters. *Cereal Chemistry* **72**, 85-87

Kuckuck H (1959) Neuere Arbeiten zur Entstechung der hexaploiden Kulturweizen. *Zeitschrift für Planzenzüchtung* **41**, 205-226

Ip C (1998) Lessons from basic research in selenium and cancer prevention. *The Journal of Nutrition* **128**, 1845-1854

Laghetti G, Piergiovanni AR, Volpe N, Perrino P (1999) Agronomic performance of *Triticum dicoccon* Schrank and *T. spelta* L. accessions under southern Italian conditions. *Agricoltura Mediterranea* **129**, 199-211

Li W, Zhang DF, Wei YM, Yan ZH, Zheng YL (2006) Genetic diversity of *Triticum turgidum* L. based on microsatellite markers. *Russian Journal of Genetics* **42**, 311-316

MacKey J (1988) A plant breeder's perspective on taxonomy of cultivated plants. *Biologisches Zentralblatt* **107**, 369-379

Nesbitt M, Samuel D (1996) From staple crop to extinction? The archaeology and history of the hulled wheats. In: Padulosi S, Hammer K, Heller J (Eds) *Hulled Wheats*, *Proceedings of the 1st International Workshop on Hulled Wheats*, 22 July 1995, Castelvecchio Pascoli, Italy, pp 41-100

Oliveira JA (2001) North Spanish emmer and spelt wheat landraces:agronomic and grain quality characteristic evaluation. *Plant Genetic Resources Newsletter* **125**, 16-20

Oliver RE, Cai X, Friesen TL, Halley S, Stack RW, Xu SS (2008) Evaluation of Fusarium head blight resistance in tetraploid wheat (*Triticum turgidum* L.). *Crop Science* **48**, 213-222

Pasqualone A, Caponio F, Simeone R (2004) Quality of re-milled semolinas used for bread-making in Southern Italy. *European Food Research and Technology* **219**, 630-634

Pasqualone A, Piergiovanni AR, Laghetti G, Simeone R (2005) Quality evaluation of alternative wheat cereals in bread production. *Proceedings of a Conference on Health and Biodiversity*, 23-25 August, Galway, Ireland, p 38

Pasqualone A, Piergiovanni AR, Laghetti G, Volpe N, Simeone R (2006) Panificazione da frumenti alternativi: valutazione di pane ottenuto da grano Kamut e da spelta. *Tecnica Molitoria* **57**, 1075-1080

Pasqualone A, Summo C, Bilancia MT, Caponio F (2007) Variation of the sensory profile of durum wheat Altamura PDO (Protected Designation of Origin) bread during staling. *Journal of Food Science* **72**, 191-196

Percival J (1921) *The Wheat Plant. A Monograph*, Duckworth & Co., London, UK, 463 pp

Peterson CJ, Johnson VA, Mattern PJ (1986) Influence of cultivar and environment on mineral and protein concentrations of wheat flour, bran and grain. *Cereal Chemistry* **63**, 183-186

Piergiovanni AR (1999) Grain quality variation in hulled wheats (*Triticum monococcum* L. *T. dicoccum* Schrank and *T. spelt* L.). A review. *Current Topics in Cereal Chemistry* **2**, 29-35

Piergiovanni AR (2009) Estimating gliadin and albumin variation at intra and inter-accession level in the USDA Oriental wheat (*T. turgidum* L. subsp. *turanicum* (Jakubz.) A. Löve & D. Löve) collection using capillary zone electrophoresis. *Cereal Chemistry* **86**, 37-43

Piergiovanni AR, Amenduni MC, Scarpa I, Losavio FP (2008) Caratterizzazione biochimica e nutrizionale della collezione di grano orientale (*Triticum turanicum* Jakubz) conservata presso l'USDA. *Proceedings of the VIII National Congress on Biodiversity*, 21-23 April, Lecce, Italy, p 64

Piergiovanni AR, Pasqualone A, Simeone R, Signorile MA, Volpe N, Laghetti G (2005) Analisi agro-tecnologica di una filiera di qualità: il caso del grano Kamut® in Italia meridionale. *Proceedings of the 6th AISTEC Congress*, Valenzano, Italy, 16-18 June, pp 1-7

Piergiovanni AR, Volpe N (2003) Capillary electrophoresis of gliadins a tool in the discrimination and characterisation of hulled wheats (*T. dicoccon* Schrank and *T. spelta* L.) lines. *Cereal Chemistry* **80**, 269-273

Porceddu E, Turchetta T, Masci S, D'Ovidio R, Lafiandra D, Kasarda DD, Impiglia A, Nachit MM (1998) Variation in endosperm protein composition and technological quality properties in durum wheat. *Euphytica* **100**, 197-205

Quaglia G (1988) Other durum wheat products. In: Fabriani G, Lintas C (Eds) *Durum Wheat Chemistry and Technology*, St. Paul, MN, American Association of Cereal Chemistry, pp 263-274

Quinn RM (1999) Kamut®: ancient grain, new cereal. In: Janick J (Ed) *Perspectives on New Crops and New Uses*, ASHS Press, Alexandria, VA, pp 182-183

Raboy V (2001) Seeds for a better future: 'Low phytate' grains help to overcome malnutrition and reduce pollution. *Trends in Plant Science* **6**, 458-462

Raffo A, Pasqualone A, Sinesio F, Paoletti F, Quaglia G, Simeone R (2003) Influence of durum wheat cultivar on the sensory profile and staling rate of Altamura bread. *European Food Research and Technology* **218**, 49-55

Rayman MP (2005) Selenium in cancer prevention: a review of the evidence and mechanism of action. *Proceedings of the Nutrition Society* **64**, 527-542

Robberecht H, Hendrix P, Van Cauwenbergh R, Van Dyck K, Deelstra H (1999) Mineral and trace element content of various vegetarian foodstuffs available in Belgium. *Zeitschrift für Lebensmitteluntersuchung und Forschung A* **208**, 156-161

Romanova YuA, Gubareva NK, Konarev AV, Mitrofanova OP, Lyapunova OA, Anfilova NA (2001) Analysis of gliadin polymorphism in a *Triticum spelta* collection. *Russian Journal of Genetics* **37**, 1054-1060

Scazzina F, Del Rio D, Serventi L, Carini E, Vittadini E (2008) Development of nutritionally enhanced tortillas. *Food Biophysics* **3**, 235-240

Serventi L, Carini E, Curti E, Vittadini E (2009) Effects of formulation on phycochemical properties and water status of nutritionally enhanced tortillas. *Journal of the Science of Food and Agriculture* **89**, 73-79

Shan Lu, Quiao SW, Arentz-Hansen H, Molberg O, Gray GM, Sollid LM, Khosla C (2005) Identification and analysis of multivalent proteolytically resistant peptides from gluten: implications for celiac spruce. *Journal of Proteome Research* **4**, 1732-1741

Shils ME (1988) Magnesium. In: Shls ME, Young VR (Eds) *Modern Nutrition in Health and Disease*, Lea and Febiger, Philadelphia, PA, pp 159-192

Siener R, Honow R, Voss S, Seidler A, Hesse A (2006) Oxalate contents of cereal and cereal products. *Journal of Agricultural and Food Science* **54**, 3008-3011

Simeone R, Pasqualone A, Signorile MA, Laghetti G, Volpe N, Piergiovanni AR (2004) Evaluation of the bread-making attitude of oriental wheat (*Triticum turanicum* Jakubz.). *Proceedings of the XLVIII SIGA Congress*, 15-18 September, Lecce, Italy, pp 157-158

Simonato B, Pasini G, Giannattasio M, Curioni A (2002) Allergenic potential of Kamut wheat allergy. *Allergy* **57**, 653-654

Sissons MJ, Batey IL (2003) Protein and starch properties of some tetraploid wheats. *Cereal Chemistry* **80**, 468-475

Sissons MJ, Hare RA (2002) Tetraploid wheat – A resource for genetic improvement of durum wheat quality. *Cereal Chemistry* **79**, 78-84

Sissons MJ, Soh HN, Turner MA (2002) Role of the gluten and its components in influencing durum wheat dough properties and spaghetti cooking quality. *Journal of the Science of Food and Agriculture* **79**, 1874-1885

Stagnari F, Codianni P, Pisante M (2008) Agronomic and kernel quality of ancient wheats grown in central and southern Italy. *Cereal Research Communications* **36**, 313-326

Stallknecht GF, Gilbertson KM, Ranney JE (1996) Alternative wheat cereals as food grains: einkorn, emmer, spelt, kamut, and triticale. In: Janick J (Ed) *Progress in New Crops*, ASHS Press, Alexandria, VA, pp 156-170

Troccoli A, Borrelli GM, De Vita P, Fares C, Di Fonzo N (2000) Durum wheat quality: a multidisciplinary concept. *Journal of Cereal Science* **32**, 99-113

Ufer M (1956) Studien an afghanischen Weizen. *Zeitschrift für Planzenzüchtung* **36**, 133-152

Vallega V (1992) Agronomic performance and breeding value of selected strains of diploid wheat *Triticum monococcum. Euphytica* **61**, 13-23

Vavilov NI (1951) The origin, variation, immunity and breeding of cultivated plants (translated from the Russian by Chester K.S.) *Chronica Botanica* **13**, 1-366

Wieser H, Koehler P (2008) The biochemical basis of celiac disease. *Cereal Chemistry* **85**, 1-13