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Description and Characterization of Hellenic Wheat Germplasm for Agronomical and Seed Quality Parameters Using Phenotypical, Biochemical and Molecular Approaches

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Abstract—Hellenic wheat germplasm developed at the Cereal Institute of Thessaloniki, during the last fifty years, is depicted in the present study, using agronomical, biochemical and molecular criteria. The bread wheat germplasm is characterized by high yield potential, adaptation to the Mediterranean conditions, and advanced qualitative traits. The biochemical analysis revealed that three cultivars ("Acheron", "Elissavet" and "Orpheus") carry the 1BL.1RS wheat-rye translocation, which was further confirmed by molecular analysis. The cultivars "Acheron" and "Elissavet", despite the presence of the translocation, have good bread making quality due to the presence of favorable genes controlling quality. Most of the Hellenic durum germplasm have high end product quality. The biochemical evaluation at the *Gli-B1* locus revealed the presence of alleles related with the γ-*45* component, indicative of high technological traits. On the other side, it was found that two older durum wheat cultivars and a population tested, had the allele *in** at the same locus, which is related with the γ-*42* component, indicative of inferior pasta quality. Most of the Hellenic germplasm, either durum or bread wheat, carries very good agronomical and qualitative traits and could be used to broaden wheat biodiversity in the S–E Mediterranean region.

Keywords: Triticum spp., yield, quality, morphological, technological traits

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INTRODUCTION

The rise of wheat breeding in Hellas begun in 1923, when Ioannis Papadakis (1903–1996), one of the most brilliant European breeders, established the first experiments to evaluate various domestic and foreign wheat cultivars. In 1927 the "Plant Breeding Institute" was founded in Thessaloniki aiming to promote research on plant breeding and more precisely in wheat [1]. At the same period, a network of substations was developed in the main wheat-producing regions of the country (Larissa, Halkidiki, Serres, Ptolemaida, Crete etc.), to broaden the adaptation of the resulting germplasm. The main vision of Prof. Papadakis was the self-fulfilment of the country's needs in wheat. To accomplish this target, Papadakis introduced foreign cultivars from countries with similar soil and climatic conditions and at the same time bred new wheat cultivars after crossing domestic to foreign germplasm [2]. Despite the difficulties of the interwar period, Papadakis' breeding program was successful and new high yielding cultivars, were released. In the same period, Papadakis developed the ecological maps of Hellas, promoting the cultivation of certain cultivars depending on the soil and climate of each region. In order to succeed in his vision, Papadakis developed unique approaches (pocket method/experiments in pots) for breeding new wheat germplasm [2–5].

The main goal of the described efforts was the rapid increase in wheat production and the country wheat self-sufficiency which was achieved in Hellas in 1957 [6]. It must be mentioned that this wheat self-sufficiency was recorded despite the reduction of the wheat harvested areas. A consequence of the previous goal was the increase of the wheat harvested area cultivated with Hellenic varieties from 21% in 1931 to 31% in 1939 and 60% in 1952 [7]. The most important release of Papadakis's effort was cultivar G-38290, more widely known as the "Number", which was produced in 1934. Although G-38290 entered the seed production in 1942, its multiplication was very slow until 1950 mainly due to the prevailing political conflicts in Hellas. However, this cultivar became popular to the Hellena farmers and it was cultivated for nearly 20 years covering 70% of wheat harvested area [8].

Modern Hellenic wheat cultivars are a result of an intensive breeding program which started late in the 1950s. Based on Papadakis's excellent approach, modern breeders developed high yielding cultivars, which combined unique traits of Hellenic (local) and Mexican (CIMMYT-International Maize and Wheat Improvement Centre) germplasm [9]. Most of these cultivars are spring wheats sown in October to exploit the prevailing moderate winter conditions of southern Balkan Peninsula.

In the following sections a detailed description of the Hellenic bread and durum wheat germplasm will be attempted using morphological, agronomical, technological biochemical and molecular criteria. The Hellenic wheat germplasm is widely adapted, carries a considerable number of valuable genes conferring resistance to abiotic and biotic stress conditions and could be used by breeders in crossing programs for the production of new cultivars extending wheat biodiversity in the South-West region of Europe.

BREAD WHEAT

Yield Potential

Modern Hellenic bread wheat (*Triticum aestivum* L.) cultivars (Table 1) are adequately resistant to low temperatures (winter and spring) and to drought conditions [10–13]. It must be noted that drought conditions during the spring season (the grain filling period) is the main factor affecting negatively wheat production in the Mediterranean zone. Most of the Hellenic cultivars, which are presented in Table 1, were originally registered in the National Catalogue of cultivated plant varieties and are characterized by moderate to very good tillering efficiency and are quite resistant to lodging [10–13]. The involvement of CIMMYT's germplasm in Hellenic breeding program resulted in selection of cultivars of broader adaptation. For this reason, the Hellenic cultivars could also be used in other countries with cropping conditions similar to those prevailing in Hellas [14]. This is getting more important if considering the excellent bread making quality of some of the aforementioned cultivars (e.g. "Apollonia", "Acheron", "Orpheus", "Elissavet") (Table 2).

Technological Traits

The main technological traits of the modern bread wheat cultivars illustrate the progress that has been achieved during the lasts two decades in Hellenic breeding programs (Table 2). Based on old local varieties, Hellene breeders succeeded in producing new germplasm combining the Hellenic gene pool with CIMMYT's elite wheat germplasm. According to the Cereal Chemistry and Technology Department (CCTD) of the Cereal Institute of Thessaloniki (today Plant Breeding and Genetic Resources Institute), bread wheat varieties are classified according to their bread making quality in three categories: High (A), Intermediate (B) and Low (C). This classification was based on the following formula, developed at the CCTD of Cereal Institute [15]:

$$CIv = (30P + 20S + 10V)/3,$$

where P is the protein content, S is sedimentation value and V is the valorimetric number. When $CIv < 300$ the quality is low, when $300 < CIv < 500$ the quality is intermediate and when $CIv > 500$ the quality is high.

It becomes evident from the data presented in Table 2, that most of the Hellenic cultivars could be attributed to the Intermediate or High category with respect to their bread making quality. The combination with the broad adaptation for the majority of these cultivars offers a good alternative for cultivation in other parts of South-eastern Europe with similar to the Hellenic weather conditions.

In an attempt to explain field performance and qualitative determination of the Hellenic germplasm, Xynias et al. [32] examined a quite large group of Hellenic bread wheat cultivars and selections with the use of biochemical markers (seed storage proteins). The majority of this germplasm (25 cultivars, Table 3) was produced at the Cereal Institute of Thessaloniki (Hellas), two cultivars ("Chios" and "Mykonos") were produced at the Laboratory of Genetics and Plant Breeding of the Aristotle University of Thessaloniki [33], and one was originated from Russia ["Kavkaz/Cgn", ("KVZ/Cgn")]. Three of the Hellenic cultivars ("Acheron", "Elissavet" and "Orpheus") were found to carry the *Gli-B1l* allele which marks for the wheat-rye 1BL.1RS translocation. The 1BL.1RS translocation is of special interest because cultivars possessing it are resistant to either biotic or abiotic stress conditions and more precisely to drought and low temperature [34, 35], most probably due to the better development of the root system [36]. However, it has a negative consequence because this translocation is responsible for quality deterioration [37]. Rabinovich [38] reported that the 1BL.1RS translocation has been transferred to many current commercial varieties from the Russian ones ("Aurora", "KVZ/Cgn" and "Skorospelka 35"). Among the three aforementioned Russian varieties the cultivar "KVZ/Cgn" has been repeatedly involved in the breeding program of the Cereal Institute in Thessaloniki because of its efficient combining ability. Thus, it is quite reasonable that the 1BL.1RS translocation was transferred to the cultivars "Acheron", "Elissavet" and "Orpheus" from "KVZ/Cgn". "Acheron" and two other cultivars ("Yecora E" and "Melia") have especially good combinations with high molecular weight (HMW) glutenin subunits, carrying

Table 1. Physiological and agronomical traits of the Hellenic bread wheat cultivars [9–13]

Cultivar	Physiological traits Resistance		Agronomical traits				
	cold (winter)	cold (spring)	drought	tillering	lodging	yield, kg/1000 m^2	adaptation
Aeges	res	ad	mod	Mod	res	550 ± 60	broad
Alfios	ad	ad	ad	Mod	ad	500 ± 40	broad
Axios	ad	ad	ad	Mod	res	590 ± 45	broad
Apollonia	res	res	good	very good	res	550 ± 50	broad
Arahthos	ad	ad	ad	Mod	res	600 ± 40	broad
Acheloos	res	res	ad	very good	ad	650 ± 40	narrow[a]
Acheron*	v.res.	v.res.	ad	Good	v.res.	580 ± 60	narrow[b]
Vergina	res	res	mod	Good	res	550 ± 60	broad
Yecora E	mod	mod	ad	Mod	res	550 ± 60	narrow[a]
Generozo E	res	res	mod	mod (–)	res	500 ± 50	narrow[b]
Gorgona	ad	ad	good	Mod	res	580 ± 40	narrow[a]
Deo	res	res	mod	Good	res	550 ± 60	broad
Doerane	res	res	good (+)	good (+)	res	600 ± 60	broad
Dodoni	res	res	ad	good (+)	res	580 ± 50	narrow[a]
Evros	res	res	ad	mod (–)	res	550 ± 60	broad
Elissavet*	res	res	res	very good	res	550 ± 60	broad
Evrotas	ad	ad	ad	mod (+)	res	550 ± 60	broad
Thiamis	ad	ad	ad	Mod	res	580 ± 45	broad
Louros	ad	ad	good	mod (+)	res	570 ± 20	broad
Lydia	ad	ad	ad	Mod	res	520 ± 40	broad
Melia	ad	ad	ad	Mod	res	560 ± 40	broad
Nestos	v.res.	v.res.	res	mod (+)	v.res.	600 ± 50	narrow[b]
Xenia	ad	ad	mod	mod (+)	ad	560 ± 35	broad
Orpheus*	v.res.	v.res.	v.res.	Good	v.res.	600 ± 50	broad
Penios	res	res	ad	Mod	res	650 ± 40	broad
S. Cerros E	mod	mod	ad	Mod	ad	560 ± 50	narrow[c]
Strimonas	ad	ad	ad	Mod	res	620 ± 40	broad
Oropos	res	res	res	Mod	res	500 ± 50	broad

ad: adequate; mod: moderate, res: resistant, v.res: very resistant;
(a) fertile environments; (b) cold and fertile environments; (c) warm and fertile environments; * presence of the 1BL.1RS translocation.

alleles *Glu-A1a*, *Glu-B1i* and *Glu-D1d* which according to Payne et al. [39] result in excellent bread-making quality.

One more interesting point in the study of Xynias et al. [32] is the presence of the 1BL.1RS wheat-rye translocation that was detected in the cultivar "Chios". More precisely, the electrophoretic analysis of this cultivar revealed that it was consisting of a mixture of different genotypes (with respect to the alleles at the *Gli-B1* and *Glu-B1* locus, Table 3) one of which possessed the *Gli-B1l* allele which marks the wheat-rye 1BL.1RS translocation. This was rather odd and for this reason Peros et al. [40] examined seven of the aforementioned Hellenic cultivars ("Orpheus", "Acheron", "KVZ/Cgn", "Elissavet", "Vergina", "Acheloos" and "Chios") using specific primers against Sec 1 and *Gli-B1* genes which are present on 1RS and 1BS chromosome arms of rye and wheat respectively. From the results of the above study it was verified that the cultivars "Orpheus", "Acheron", "KVZ/Cgn", "Elissavet" do carry the 1BL.1RS translocation. However, the presence of the translocation was not detected in cultivar "Chios". This could be attributed to the fact that different seed samples were analysed. The other two cultivars ("Vergina" and

Table 2. Technological traits of the Hellenic bread wheat cultivars [10–12, 16–31]

Cultivar	Test weight, kg/h L	1000 kernel weight, g	Sedimentation value (Ml)	Protein, %	Valorimetric value	CIv	Bread making quality
Aeges	78.0	36 ± 8	21 ± 1	13 ± 0.5	41 ± 1	406.7	B
Alfios	76.0	37 ± 2	35 ± 10	12.5 ± 0.5	53 ± 13	530.0	A
Axios	77.5	35 ± 5	28 ± 6	13 ± 0.5	50 ± 10	483.3	B (+)
Apollonia	74 ± 3	35 ± 5	42 ± 2	15 ± 2	58 ± 2	623.3	AA
Arahthos	75.7	40 ± 5	35 ± 5	13.5 ± 05	50 ± 5	535.0	A
Acheloos	78.5	36 ± 2	35 ± 5	14.3 ± v0.5	45 ± 10	526.3	A
Acheron*	77.2	35 ± 5	35 ± 5	15.5 ± 0.5	50 ± 1	555.0	A
Vergina	70.5	36 ± 5	19 ± 2	12.5 ± 0.5	38 ± 2	378.0	B (–)
Yecora E	77.9	45 ± 5	33 ± 3	14 ± 1	50 ± 5	526.7	A
Generozo E	76.0	38 ± 5	25 ± 5	13.5 ± 1.5	38 ± 5	428.3	B
Gorgona	77.4	36 ± 2	28 ± 2	13 ± 1	42 ± 3	456.7	B
Deo	75.4	36 ± 2	19 ± 2	12.5 ± 0.5	38 ± 2	378.3	B (–)
Doerane	77.2	35 ± 5	35 ± 5	14 ± 0.5	46 ± 4	526.7	A
Dodoni	70.5	35 ± 2	23 ± 2	13 ± 0.5	47 ± 2	440.0	B
Evros	76.8	34 ± 2	30 ± 6	12.5 ± 0.7	43 ± 9	468.3	B (+)
Elissavet*	78.3	35 ± 3	38 ± 4	15 ± 2	52 ± 3	576.7	A
Evrotas	74.5	35 ± 2	32 ± 8	12.5 ± 0.5	47 ± 10	495.0	B (+)
Thiamis	76.8	34 ± 3	30 ± 6	14 ± 0.5	50 ± 10	506.7	A
Louros	71.7	42 ± 3	30 ± 5	13 ± 0.5	40 ± 5	463.6	B(+)
Lydia	78.2	34 ± 2	28 ± 2	13 ± 0.6	50 ± 2	450.0	B
Melia	78.2	34 ± 2	26 ± 2	12.5 ± 0.5	53 ± 2	475	B (+)
Nestos	78.5	38 ± 2	36 ± 2	15 ± 0.5	48 ± 2	395	B (–)
Xenia	78.0	33 ± 2	26 ± 2	12.5 ± 0.6	43 ± 2	441.7	B
Orpheus*	>80.0	33 ± 2	36 ± 2	15 ± 1	50 ± 5	556.7	A
Penios	78.0	40 ± 5	28 ± 4	13 ± 0.5	45 ± 5	466.7	B (+)
S. Cerros E	78.0	38 ± 5	25 ± 5	12.5 ± 1	40 ± 5	418.4	B
Strimonas	78.0	40 ± 5	30 ± 5	13 ± 0.5	50 ± 5	496.7	B (+)
Oropos	86 ± 4	35 ± 5	32 ± 4	14 ± 1	50 ± 5	520	A

* Presence of the 1BL.1RS translocation.

"Acheloos") do not carry the translocation, confirming the previous report of Xynias et al. [32].

Even though the presence of the 1BL.1RS translocation is probably influenced by the genetic background of wheat [41], this translocation might be very useful. All four cultivars that were found carrying the 1BL.1RS translocation could be used in crosses to produce germplasm resistant to stresses (especially drought which is the most severe problem in the southern part of Europe). If the necessary precautions are taken during transferring this translocation to current cultivars (i.e. one of the parents must carry alleles *Glu-A1a*, *Glu-B1i* and *Glu-D1d*), then it would appear possible to develop high yielding varieties, resistant to lodging and biotic factors and exhibiting good qualitative traits [42]. The cultivars "Acheron" and "Elissavet" are good examples of such an approach. Successful results have been reported also in Serbia by Misic et al. [34].

The dendrogram constructed according to the presence of alleles encoding seed storage proteins revealed that the Hellenic bread wheat germplasm can be divided into three major groups (Fig. 1). The first one (I) includes only the related cultivars "Dodoni" and "Eurydice", and also three lines developed after intervarietal selection into cultivar "Nestos" (1). The second group (II) divided into two subgroups, one (2) includes the cultivars "Mykonos", "Elissavet" and "Lydia" and the other (3) which is more complicated, containing the related cultivars "Penios", "S. Cerros E", "Gorgona", "Louros" as they have some common origin and also a minor group with "Strymonas", "Acheloos" and "Oropos". Despite the presence of the 1BL.1RS wheat-rye chromosome translocation

Table 3. Gliadin (*Gli*) and high molecular weight glutenin subunit (*Glu*) diversity in Hellenic bread wheat cultivars and selections [32]

Cultivar	*Gli-A1*	*Gli-B1*	*Gli-D1*	*Gli-A3*	*Glu-A1*	*Glu-B1*	*Glu-D1*
Deo	*a*	*g*	*f*	*a*	*a*	*e*	*a*
Nestos	*g*	*g*	*b*	*c*	*a*	*d*	*e*
Nestos 1	*g*	*g*	*b*	*c*	*a*	*d*	*e*
Nestos 2	*g*	*g*	*b*	*c*	*a*	*d*	*e*
Orpheus	*a*	*l*	*f*	*a*	*c*	*c*	*d*
Eurydice	*g*	*g*	*b*	*c*	*a*	*d*	*e*
Penios	*a*	*c*	*b*	*a*	*b*	*i*	*a*
S. Cerros E	*a*	*c*	*b*	*a*	*b*	*i*	*a*
KVZ/Cgn	*b*	*l*	*f*	*a*	*c*	*c*	*d*
Acheloos	*g**	*c*	*b*	*a*	*b*	*b*	*a*
Vergina	*o*	*e*	*b*	*b*	*b*	*k*	*a*
Chios	*g**	*d + l*	*f*	*a*	*c*	*c + i*	*a*
Mykonos	*g**	*d*	*f*	*c*	*b*	*e*	*a*
Melia	*a*	*b*	*b*	*c*	*a*	*b*	*d*
Gorgona	*a*	*c*	*b*	*a*	*b*	*i*	*a*
Acheron	*a*	*l*	*f*	*c*	*a*	*i*	*d*
Generoso E	*a*	*g*	*f*	*a*	*a*	*a*	*a*
Louros	*a*	*c*	*b*	*a*	*b*	*i*	*a*
Dodoni	*g*	*g*	*b*	*c*	*a*	*d*	*e*
Strymonas	*g**	*c*	*b*	*a*	*b*	*i*	*a*
Lydia	*o*	*b*	*f*	*d?*	*b*	*b*	*a*
Yecora E	*o*	*d*	*f*	*d?*	*a*	*i*	*d*
Oropos	*m*	*c*	*b*	*b*	*b*	*i*	*a*
Xenia	*g**	*d*	*b*	*a*	*a*	*i*	*d*
Elissavet	*o*	*l*	*j*	*c*	*b*	*c*	*a*

the cultivar "Elissavet" is closer to "Lydia" and "Myconos" if someone compares it with the cultivar "KVZ/Cgn", one of the donors of the translocation. According to the third major group (III), the cultivar "Acheron" (which is the second Hellenic variety possessing the translocation) was found very close to "Yecora E" (a cultivar with excellent bread making quality) in subgroup (4) and this could be an evidence of its good bread making quality. The cultivar "Orpheus", the third Hellenic variety carrying the translocation, which is produced after intervarietal selection in the cultivar "Nestos", is also close to "KVZ/Cgn" as it was confirmed in subgroup 5.

In a more recent study, Karelov et al. [43] investigated the genetic relationship between eight Hellenic bread wheat cultivars ("Acheron", "Chios", "Elissavet", "Louros", "Lydia", "Strymonas", "Xenia" and "Yecora E") and the Russian cultivar "KVZ/Cgn" with molecular markers. It was revealed that the cultivar "Elissavet" carries genes conferring resistance to tan spot (insensitivity to toxins A and B), rusts, powdery mildew, and barley yellow dwarf virus (*Lr34*/*Yr18*/*Pm38*/*Sr57*/*Bdv1*) in combination with the genes on the wheat-rye 1BL.1RS translocation. Also, the cultivar "Strymonas" has three genes for resistance to necrotrophic diseases. The cultivar "Yecora E" carries the genes conferring resistance to tan spot and rusts (*Lr34*/*Yr18*/*Pm38*/*Sr57*/*Bdv1*) but lacks the translocation. It should be noted that the important gene *Lr34*/*Yr18*/*Pm38*/*Sr57*/*Bdv1* is rare among European wheat cultivars [44]. The third cultivar "Acheron", which carries the 1BL.1RS wheat-rye chromosome translocation, also has genes for resistance to tan spot (due to insensitivity to toxin B) and *Fusarium* head blight but lacks the resistance allele of the *Lr34* gene. Furthermore, it is concluded from all the results that cultivar "Elissavet" constitutes a remarkable combination of favourable genes and is proposed to be used more extensively as a parental line in Mediterranean breeding programs for the development of novel wheat germplasm.

DURUM WHEAT

Durum wheat (*Triticum durum* Desf.) is an important crop used primarily for making pasta products,

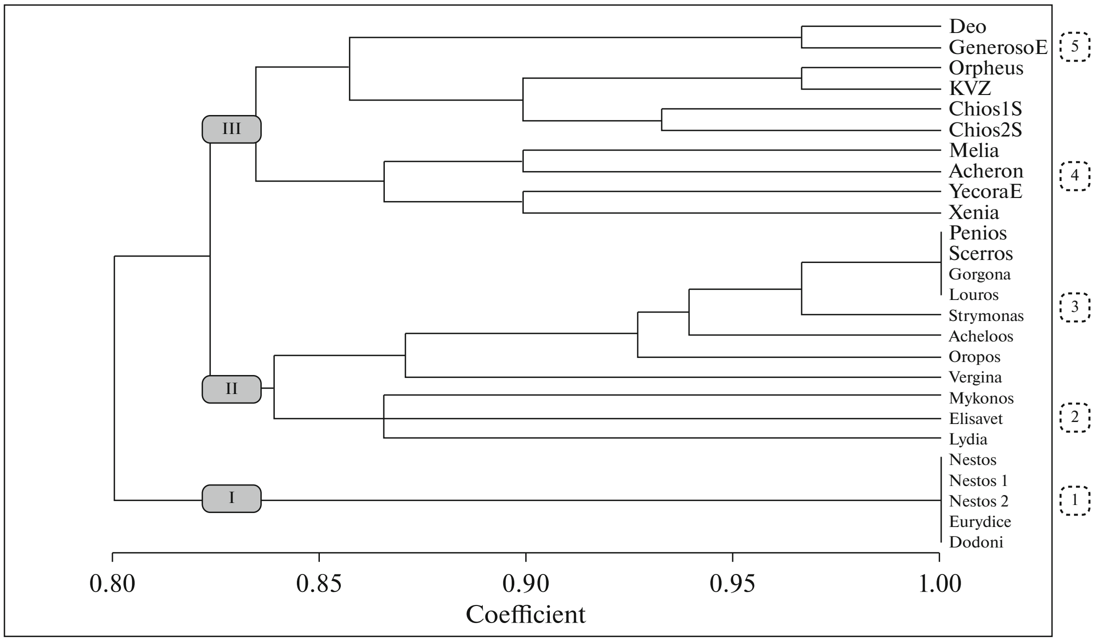

Fig. 1. Dendrogram of existing similarities among and within the examined Hellenic bread wheat cultivars, constructed according to the presence of alleles encoding seed proteins (Xynias et al. unpublished data).

and in some cases for making bread [45]. As a crop, it is well adapted in the warm and dry areas of the Mediterranean region. The vast diversity of the Hellenic countryside, with thousands of bigger and smaller islands resulted in the development and preservation of many isolated local varieties and populations of durum wheat. As in the case of bread wheat, this germplasm was effectively used by breeders, who produced some excellent cultivars in terms of quality. Hellenic durum cultivars belong to the spring-type wheats, and for this a special effort was given by local breeders to produce durum germplasm which at least could tolerate the low temperatures prevailing in winter of the region. Thus, the majority of modern cultivars are at least moderate resistant to the low temperature of winter and spring (Table 4). They are also characterized by moderate tillering efficiency and the majority of them are adequately resistant to lodging [10–12]. The involvement of CIMMYT's germplasm in Hellenic breeding programs resulted in the production of broadly adapted cultivars, which combine the traits of the local varieties and those of CIMMYT's germplasm.

The main technological traits of the modern durum wheat cultivars illustrate the progress that has been achieved during the last decades in Hellenic wheat breeding programs (Table 5). As it was mentioned before, based on old local varieties, Hellene breeders succeeded in producing new germplasm, combining the Hellenic gene pool with CIMMYT's elite wheat germplasm. According to the CCTD of the Cereal Institute of Thessaloniki, durum wheat varieties are classified for pasta making quality in three categories: High (A), Intermediate (B) and Low (C). For this classification the following formula developed by the CCTD of Cereal Institute [31] is used:

$$\text{CId} = (50P + 10G)/2,$$

where P is the protein content and G is the percentage of vitreous grains. When $\text{CId} < 500$ the quality is low, when $500 < \text{CId} < 700$ the quality is intermediate and when $\text{CId} > 700$ the quality is high.

It becomes evident from Table 5 that most of the modern Hellenic cultivars produce very qualitative products. This is evident even though the allele *Gli-B1in**, with the component γ-42, similar to the allele *a* according to Kudryavtsev [46] was detected in two of the transferring cultivars ("Lemnos" and "Syros") [47]. Similar results for "Lemnos" were reported by Yupsanis [48]. It was demonstrated that γ-gladins encoded by genes at the *Gli-B1* locus could serve as genetic markers for gluten quality [49]. This observation is based mostly to their linkage with low molecular weight gliadins (LMW-GS) encoded by genes at the *Glu-B3* locus [50]. Later studies have shown that virtually always the presence of the gladin γ-42 component was associated with the LMW GS alleles *Glu-B3b* and *i* and is related with poor pasta quality [38, 47, 51].

Xynias et al. [47] studied 24 Hellenic durum cultivars and local populations using biochemical genetics methods based on gliadin and high-molecular-weight glutenin subunit loci (Table 6). In that study it was demonstrated that three of the local populations registered as durum were actually bread wheat. Further-

Table 4. Physiological, agronomical and technological traits of the Hellenic durum wheat cultivars [10–12]

Cultivar	Physiological traits		Agronomic traits			
	resistance					
	cold (winter)	cold (spring)	tillering	lodging	yield, kg/1000 m^2	adaptation
Mexicalli-81	mod	mod	mod	resistant	470	broad
Kallithea	good	mod	mod	minor	370	broad
Athos	good	mod	mod	minor	380	broad
Selas	mod	mod	vg	mod	460	broad
Skiti	mod	mod	mod	good	420	broad
Sarti	good	mod	mod	good (+)	400	narrow[a]
Sapfo	mod	mod	mod	good	350	broad
Samos	mod	mod	mod	good	370	broad
Syros*	mod	mod	mod	good (+)	380	broad
Sifnos	good	good	mod	good (+)	470	broad
Skyros	mod	mod	mod	good (+)	420	broad
Santa	good	mod	mod	good (+)	400	narrow[a]
Pontos	mod	mod	mod	good (+)	–	broad
Papadakis	mod	mod	mod	mod	–	broad
Anna	mod	mod	mod	good (+)	–	broad
Lemnos*	mod	good	vg	minor	–	narrow[a]
Electra	minor	mod	mod	mod	–	narrow[a]

mod: moderate; vg: very good; * γ *42*; [a] cold environment during maturity.

Table 5. Technological traits of the Hellenic durum wheat cultivars, registered in the National Catalogue of Cultivated Plant Varieties [10–12, 16–31]

Cultivar	1000 kernel weight, g	Vitreous grains, %	Protein, %	Wet gluten, %	Gluten index	β-carotene	CId
Mexicalli-81	44	67	13.5	27.4	75.5	5.8	672.5
Kallithea	40	70	14	29.2	61	5.8	700.0
Athos	40	75	14.5	29.9	28.3	5.2	737.5
Selas	45	70	13.8	27.8	97.6	6.6	695
Skiti	40	80	14.4	26.5	59.9	4.9	760
Sarti	41	70	15	38.8**	65**	5	725
Sapfo	37	80	15.2	28.9**	3**	4.3	780
Samos	38	78	14.8	28.2***	75.5***	5.3	760
Syros*	39	75	15.1	31**	3**	6.9	752.5
Sifnos	45	70	14.2	31.1	88.5	6.7	705
Skyros	42	78	14.9	32.3	6	5.7	762.5
Santa	40	78	15.2	39.4***	47***	6.1	770
Pontos	43	85	14.6	35***	66***	6.9	790
Papadakis	41	87	15	32	91.3	8.1	810
Anna	42	75	14.5	35.6	79	5.2	737.5
Aeas	42	90	14.9	40.8**	49**	8.7	822.5
Lemnos*	43.5	81	12.5	36.6**	77**	6.7***	717.5
Electra	42	78	12.7	21.4**	2**	–	707.5

* γ *42*; [a] cold environment during maturity, ** one year data, *** two years data.

Table 6. Hellenic durum wheat germplasm and frequencies of different biotypes according to the presence of gliadin and high-molecular-weight glutenin subunit loci [47]

Cultivar	Type	*Gli-A1*	*Gli-B1*	*Glu-A1*	*Glu-B1*	*Gli-A2*[1]	*Gli-B2*[2]
Mexicalli-81	RC	*r*	*h*	*c*	*b*	*1*	*1*
Athos	RC	b^{d*}	*h*	*c*	*e*	*2*	*4*
Selas	RC	*r*	*h*	*c*	*b*	*1*	*1*
Skiti	RC	*r*	*h*	*c*	*d*	*1*	*2*
Syros	RC	*r*	*in**	*c*	*b*	*2*	*3*
Sifnos	RC	*r*	*h*	*c*	*b*	*1*	*1*
Kallithea	RC	*r + g*	*h*	*c*	*e*	*2*	*4*
Pontos	NR	*r*	*h*	*c*	*b*	*1*	*1*
Papadakis	NR	*r*	*h*	*c*	*b*	*1*	*7*
Anna	NR	*r*	*h*	*c*	*b*	*1*	*1*
Aegean black-awn	P	*r*	*h*	*c*	*e*	*2*	*1*
Lemnos	PC	*m*	*in**	*c*	*e*	*5*	*5*
DiminiAetoloakarnanias	LP	*r*	*hn**	*c*	*d*	*1*	*4*
Mavratheri	LP	*r*	*h*	*c*	*e*	*2*	*1*
Local of Thessalia	LP	*p*	*hn**	*c*	*d*	*2*	*1*
Population of Kos	LP	*r*	*h*	*c*	*e*	*2*	*4*
Nteves	PC	*r*	*hno* + d*	*a + b*	*e*	*2*	*6*
Population of Samos	LP	*r*	*h*	*c*	*e*	*2*	*1*
Local of Heraklion	LP	br^{d*}	*in**	*c*	*d*	*2*	*6*
Chios white-awn	LP	*r*	*h*	*c*	*d + b*	*1*	*2*
Chios red wheat	LP	*rn**	*h1**	*a + b*	*h*	*2*	*1*
Ac. No 4679	LP	*r*	*h*	*c*	*e*	*2*	*1*
Electra	PC	*r*	*h*	*c*	*e*	*2*	*4*
Population of Chios	P	*rn**	*h*	*c*	*f*	*2*	*4*

RC: Regular Cultivar, NR: New Release, P: Population, PC: Past Cultivar, LP: local population; * new alleles; [1, 2] Designations of alleles at *Gli-A2* and *Gli-B2* in this set of samples (not according to any catalogue), similar numbers refer to similar alleles.

more, it was revealed that most modern Hellenic durum cultivars, including the newly-released ones, carry the allele combination *Gli-A1r*, *Gli-B1h*, *Glu-A1c*, *Glu-B1b*, *Gli-A2-1*. This combination is most likely due to the association of these alleles with grain quality [45]. A similar predominant association is observed also in the Hellenic local populations at three marker loci: *Gli-A1r*, *Gli-B1h*, *Glu-A1c*. Besides the association with grain quality, the presence of similar predominant alleles at the storage protein loci both in cultivars and local populations may indicate their adaptive value: the presence of these marker alleles may be associated with tolerance to stress factors during vegetation. At least partial adaptive value of protein polymorphism was demonstrated in emmer wheat by Nevo et al. [52]. Correlation of the genetic variation and the allele frequencies at HMW glutenin subunit loci in wild emmer wheat and their associations to the climatic and natural factors were also revealed [53, 54].

Most of current durum wheat Hellenic cultivars were found to be more or less identical at the loci studied (Fig. 2). This elucidates the narrowing of the genetic background of the crop (especially at certain loci), suggesting that more variability should be incorporated in modern breeding programs. A part of this variability could be mined in the local populations, which forms, and the second major group of the present study. The local “population of Thessalia” (Central Hellas) was more related to the respective “population of Heraklion” (Crete island), probably indicating some common dietary practices of local populations. The old cultivar “Lemnos” was found to be less related to other Hellenic cultivars and populations. This cultivar, as was previously referred, carries the gene locus *Gli-B1* component γ *42*, which is associated with inferior quality [49], and this was verified by all relevant quality tests (Cereal Institute of Thessaloniki, unpublished data). The cultivar “Lemnos” is a tall cultivar, susceptible to lodging. However, due to its cold resistance, especially in spring, and its early head-

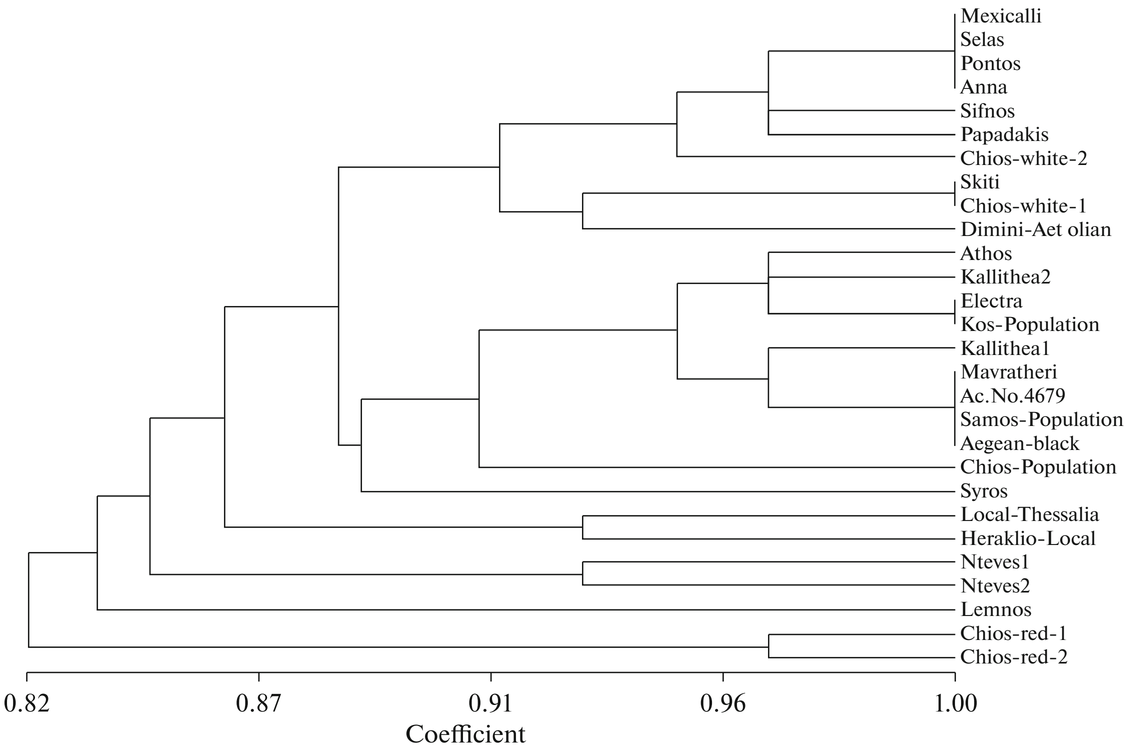

Fig. 2. Dendrogram of existing similarities among and within the examined Hellenic durum wheat cultivars and populations, constructed according to the presence of alleles encoding seed proteins [47].

ing emergence [10] it is still quite a popular germplasm used in specific breeding projects.

The allelic diversity of the storage protein loci of the homoeologous group 1 chromosomes (*Glu-A1*, *Glu-B1*, *Gli-A1*, *Gli-B1*), which are more associated with quality compared to the *Gli-2* locus [49], was broader in the Hellenic local populations of durum wheat than that recorded in modern Hellenic varieties. This indicates their potential utility in breeding programs for widening the gene pool of commercial cultivars.

FUTURE PROSPECTS AND CONCLUSIONS

The application of anther-culture technique for breeding new bread wheat germplasm is expected to contribute in producing new, high-quality cultivars [55, 56]. The results of this application until now are promising because two doubled-haploid lines (DHL 16 and DHL 17, originating from the cross "Penios" × "KVZ/Cgn"), were found to carry the gliadin allele *Gli-B1l* (*Gli-B1-3*) which as mentioned before marks the wheat-rye 1BL.1RS translocation [57]. These lines showed the highest indices of resistance to powdery mildew, leaf rust and *Septoria tritici* Blotch during all the vegetation stages [58]. They carried the *Glu-A1b* and *Glu-D1d* alleles [57] associated with high quality [59], supporting the view that high-quality cultivars could be produced, despite the presence of the 1BL.1RS wheat-rye translocation.

The majority of the new Hellenic wheat germplasm, either durum or bread, carry very good agronomical and qualitative traits and thus are adapted to SE Mediterranean conditions. Unique gene combinations present in old and local durum varieties are an interesting source for breeding new cultivars. The presence of resistant genes, and of course the presence of the wheat-rye 1BL.1RS translocation, could be very helpful in reducing chemical application during cropping under Mediterranean environment. Thus, wheat cultivation in Hellas, under the quite optimal for the crop growing conditions, guaranties the production of safe and qualitative end products. The involvement of old local germplasm at higher rates in wheat breeding programs, along with the application of cytogenetic, biochemical and molecular approaches, promises that new and more sophisticated varieties could be produced in the future.

COMPLIANCE WITH ETHICAL STANDARDS

The authors declare that they have no conflict of interest. This article does not contain any studies involving animals or human participants performed by any of the authors.

ADDITIONAL INFORMATION

The present work is dedicated to the memory of Dr. Elpis Skodra for her contribution in wheat breeding in Hellas.

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