

Screening Bread Wheat Genotypes for High Molecular Weight Glutenin Subunits and Some Quality Parameters

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ABSTRACT

High Molecular Weight Glutenin Subunits (HMW-GS) compositions of 122 genotypes from bread wheat crossing block were investigated in terms of some quality traits such as grain Protein Content (PC), Sodium Dodecyl Sulphate (SDS), the Particle Size Index (PSI), and Thousand Kernel Weight (TKW), by using SDS-PAGE. In total, 12 different HMW-GS combinations were determined. Considerable diversity in terms of three *Glu-A1*, *Glu-B1* and *Glu-D1* loci were identified. In *Glu-A1* locus, 1/2*, 1 and 2* alleles were found with the frequency of 2.5, 12.3 and 85.5%, respectively. Whereas, in *Glu-B1*, out of 7 reported alleles, 7+8 (20.5%) and 17+18 (17.2%) were detected. Existence of 2 alleles at the locus *Glu-D1* was revealed; in fact, 54.1% of them demonstrated the subunits 5+10 correlated with good bread making properties. The *Glu-1* score of genotypes ranged from 6 to 10. Among the genotypes, only 23 (18.9%) had 10 *Glu-1* quality score value. In the evaluation using the Genotype-Traits (GT) Biplot graph, PC and PSI were involved in section I while SDS sedimentation value and *Glu-1* score were involved in section II. On the other hand, section III included the only TKW which was negatively associated with other traits. The desired genotypes can be used for the crossing programs to improve technological quality of bread wheat.

Keywords: Biplot, HMW-GS, Landraces, Quality.

INTRODUCTION

Wheat is one of the most important products in the world with the due to its ability to adapt to environmental conditions and its use for a wide diversity of food products (Shewry and Tatham, 1997). Also, wheat is among the leading cereals in Turkey (TÜİK, 2014). Wild emmer wheat (*Triticum dicoccoides* Körn ex Asch. and Graebn.) Thell. is the wild progenitor of domesticated wheat. Natural populations of the species are confined to the Fertile Crescent (Zohary and Hopf, 1993; Jaradat, 2011). Nowadays, *Aegilpos speltoides*, *Triticum monococcum* and *Triticum dicoccoides* grow spontaneously on the

basaltic rocky slopes of the Karacadag Mountains in southeastern Anatolia. Bread wheat improvement of south-eastern Anatolia is mainly targeted to develop high yielding, widely adapted and disease resistant varieties; with inadequate emphasis on grain quality. Different genotypes are necessary in favourable environments and breeder may contribute to the improvement of yield and baking quality (Tarakanovas and Ruzgas, 2007). In breeding programs, the main objective is to improve the quality of the germplasm bank in order to make it possible to develop wheat with adequate gluten strength and extensibility for bread-making (Costa *et al.*, 2013). Bordes *et al.* (2008) have reported that wheat produced in

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different parts of the world differ greatly in their actual protein qualities and quantities, the quantity is affected mainly by environmental factors, but the protein quality is primarily a heritable characteristic. Improvement of wheat genotypes with good bread making quality is a most important goal for many wheat breeders. Gluten, which is a sub unit of protein, is responsible for bread making quality (Branlard and Dardevet, 1985). Gluten is a storage protein found in the endosperm of the grain and composed of two prolamine groups, gliadins, and glutenin. Gluten is composed of glutenins, which consist of Low- and High-Molecular-Weight (LMW and HMW) complex subunits and constitute about 30-40% of flour protein (Kaya and Akçura, 2014). The quality of wheat flour for bread making depends on the viscoelastic properties of the dough, which are influenced by the quantity and quality of the gluten-forming storage proteins of the endosperm. These proteins consist of two classes, i.e. monomeric gliadins and polymeric glutenins (Weegels et al., 1996; Pflugner, 2007). Glutenin subunits can be divided in two main groups: HMW-GS and LMW-GS, based on the relative mobilities in SDS-polyacrylamide gel electrophoresis (SDS-PAGE). Three different loci, located on the long arms of group 1 chromosomes, code for the HMW-GS *Glu-A1*, *Glu-B1* and *Glu-D1*. (Payne, 1987). The SDS-PAGE electrophoresis test is a conventional method utilized for separating protein components. It allows the division of the subunits from gluten proteins by detecting the glutenin subunits of HMW-GS (Keser and Pena, 2004; Liang et al., 2010; Zheng et al., 2011). Molecular studies have shown that the HMW-GS have the highest effect on the rheological properties of dough and bread-making quality (Zheng et al., 2011; Hernandez et al., 2012). He et al. (2005) reported that the alleles 1 and 2* of *Glu-A1* have been discovered to have a better effect on bread-making quality when compared to a null allele. The 5+10 alleles of the *Glu-D1* have been correlated with higher dough

strength, while the 2+12 alleles have been correlated with low bread-making quality (Gianibelli et al., 2001). Payne et al. (1987) have identified a score of each HMW-GS which allowed a statistical evaluation of the amount of variation in bread-making quality attributable to the HMW-GS. For British- and Spanish-grown wheat cultivars, 47 and 68%, respectively, of the variation in quality is directly related to *Glu-1* score (Payne et al., 1987; Payne, 1988). For Canadian-grown wheat, 59-69% of the variation in bread-making quality is directly related to this score (Lukow et al., 1989). The objectives of this research were to: (i) Determine the interrelationship among wheat traits using GT biplot procedure, and (ii) Provide information on HMW-GS variation of wheat (*Triticum aestivum* L.) breeding lines and cultivars. This will benefit the improvement of wheat quality in breeding programs.

MATERIALS AND METHODS

In this study, 122 wheat (*Triticum aestivum* L.) genotypes (14 of which were registered as cultivars of Turkey, 15 of which were local and 93 were from foreign lines) from the crossing blocks of the bread wheat breeding program were used. The genotypes are listed in Table 3. The experiment was located at Diyarbakır, Turkey, with an altitude of 602 m; clay loam soil and with a mean annual rainfall of 501 mm. The seeds were sown in experimental field of GAP-IARTC in the city of Diyarbakır, Turkey in 2001-2002 growing season. The plots were fertilized with 60 kg N ha⁻¹ and 60 kg P₂O₅ ha⁻¹ at the planting and 60 kg N ha⁻¹ in spring at stem elongation for drought conditions. Grain Colour (GC), Thousand Kernel Weight (TKW), grain Protein Content (PC), and Particle Size Index (PSI) for each wheat genotype were determined by the method of Williams et al. (1988). SDS-sedimentation volume was determined according to the method described by Pena et al. (1990).

SDS-PAGE Electrophoresis

Seeds crushed into a fine powder were used to extract the endosperm storage proteins. Electrophoresis of glutenins was performed on vertical gel according to the SDS-PAGE protocol described by Singh *et al.* (1991) and fractionated in vertical SDS-PAGE slabs at a polyacrylamide concentrations of 8 and 10% (w/v, C: 1.28%) with and without 4 M urea according to Lafiandra *et al.* (1993). Electrophoresis was applied at a constant current of 30 mA gel⁻¹ at 18°C. After 18 hours, the gels were stained in 12.5% (w/v) trichloroacetic acid, 0.01% (w/v) Coomassie Brilliant Blue R250 and destained with distilled water (Akhtar *et al.*, 1994). The HMW -GS were identified using the numbering system of Payne and Lawrence (1983). Quality and HMW-GS analysis were made by Field Crops Central Research Institute laboratory. The *Glu-1* score was calculated according to the catalogue of alleles for HMW-GS (Payne *et al.*, 1987) (Table 1).

Statistical Analysis

The Genotype Trait (GT) biplot method, as described by Yan and Rajcan (2002), was established by plotting the First Principal Component (PC1) scores of the genotypes and the traits against their respective scores

for the Second Principal Component (PC2). The correlation coefficient between any two traits was approached by the cosine of the angle between their vectors. Acute angles indicated positive correlations, wide angles negative correlations, and right angles no correlation. A short vector may suggest that the trait is not related to other traits (Mohammadi and Amri, 2011). The biplot method presented in this study was generated using Gen Stat 12th statistical software (Payne *et al.*, 2009).

RESULTS AND DISCUSSION

Physicochemical Characterization of the Wheat Grains

The results obtained by evaluation of grain quality are summarized in Tables 1 and 3. Williams *et al.* (1988) reported that bread wheat quality may be classified by its PC as very low (< 9.0%), low (9.1-11.5%), medium (11.6-13.5%), high (13.6-15.5%), very high (15.6-17.5%), and extra high (> 17.6%). In this study, the genotypes mean values of PC ranged from 9.3-16.1%, PSI from 33.9 to 80.5%, SDS sedimentation values from 13.0 to 34.0 mL, TKW from 25.1 to 42.2 g. The HMW-GS play the major role in determining the functional properties of flour and dough (Shewry and Jones, 2012). The SDS-sedimentation volume

Table 1. HMW-GS compositions, PSI, TKW, PC, GC and SDS-sedimentation volume of 122 wheat genotypes at the three loci.

	Subunits	PSI%	TKW g ⁻¹	PC%	SDS ml ⁻¹	Red grain%	White grain%
<i>Glu-A1</i>	1	59.2	31.3	13.2	27.3	37.5	62.5
	2*	56.7	32.2	13.0	24.5	49.5	50.5
	1/2*	59.7	29.4	13.2	23.0	33.3	66.7
<i>Glu-B1</i>	13+16	55.4	31.9	12.9	24.0	33	67
	17+18	55.8	31.0	12.6	27.0	19	81
	6+8	68.9	33.2	12.2	23.4	40	60
	7+8	60.6	31.3	13.4	24.5	44	56
	7+9	54.8	32.4	13.1	24.7	52.8	47.2
	7	59.7	32.7	13.0	23.3	77	33
	7+8/7+9	54.2	32.5	12.8	24.0	100	0
<i>Glu-D1</i>	5+10	55.8	31.8	12.8	25.3	51	49
	2+12	58.7	32.1	13.2	24.3	41	59



correlated with the amount of total HMWG subunits and individual HMWG subunits (Kanenori *et al.*, 2003). Also, Tahir (2009) reported that the SDS sedimentation volume correlated with the amount of total HMW-GSs and individual HMWG subunits. Some subunits were positively correlated, and the others were negatively correlated with sedimentation volume (Seilmeier *et al.*, 1991). The HMW subunits play the major role in determining the functional properties of flour and dough.

Composition of HMW-GS

Allelic variations at *Glu-1* loci in wheat samples separated by SDS-PAGE are represented in Tables 1, 2, and 3. From all genotypes, 12 different subunits of HMW-GS were observed. While the most frequent patterns were 2*, 7+8, 7+9, 5+10 and 2+12, other subunits were found less frequent. The HMW-GS of all of the genotypes (Table 2) were found to have three allelic variations in *Glu-A1* [subunits 2* (85.5%), 1 (12.3%), and 1/2* (2.5%)], seven in *Glu-B1* [subunits 7+9 (45.1%), 7+8 (20.5%), 17+18 (17.2%), 7 (9%), 13+16 (6%) and 6+8(4.1%)], and two in *Glu-D1* [subunits 5+10 (54.1%), 2+12 (45.9%)]. The two major alleles at the *Glu-D1* locus, 5+10 and 2+12, have repeatedly shown a contrasting effect on quality traits (Gupta *et al.*, 1994; He *et al.*,

2005; Guzmán *et al.*, 2016). Whereas, correlations and genetic studies of HMW-GS (Pogna *et al.*, 1986; Payne *et al.*, 1987) established subunits with both positive (5+10) and negative (2+12) effects on bread making quality.

The *Glu-1* quality score of the genotypes varied from 6 to 10 (Table 2). The scores 9 and 10 were the most frequent due to the higher frequency of 2* allele in *Glu-A1*, 7 + 9 alleles in *Glu-B1*, and 5+10 alleles in *Glu-D1*. Thus, Costa *et al.* (2013) reported that there was a positive correlation between the *Glu-1* quality score and the volume of sedimentation ($r=0.521$) and the TKW ($r=0.510$).

The mean values of quality parameters of the genotypes grouped by individual glutenin subunits are demonstrated in Table 3. At locus *Glu-A1*, the genotypic groups possessing subunits 1 and 2*; at locus *Glu-B1*, subunits 17+18 showed higher values of wheat on SDS sedimentation value than the other group of subunits. Also, subunits 1 and 2*, therefore, have positive effects on the dough strength parameters (Liang *et al.*, 2010). These results agree with those of Lukow *et al.*, 1989; Keser and Pena, 2004, and Yıldız, 2011. Within the Turkish commercial varieties, “Bezostaya, Gerek-79, Pehlivan, Dağdaş-94 and Gün-91” are mostly grown in winter zone of Turkey and these varieties have 2*, 7+9, 5+10; 2*, 7+8, 2+12; 2*, 7+9, 2+12; 2*, 7+8, 5+10; 2*,

Table 2. *Glu-1* quality score and allele frequencies of HMW-GS studied by SDS-PAGE in bread wheat genotypes.

Locus	HMW-GS	Frequency	%	<i>Glu-1</i> score
<i>Glu-A1</i>	1	15	12.3	3
	2*	104	85.5	3
	1/2*	3	2.5	3
<i>Glu-B1</i>	17+18	21	17.2	3
	7+8	25	20.5	3
	13+16	6	4.9	3
	7+9	55	45.1	2
	7	9	7.4	1
	6+8	5	4.1	1 (Poor)
	7+8/7+9	1	0.82	-
<i>Glu-D1</i>	5+10	66	54.1	4 (Good)
	2+12	56	45.9	2

Table 3. Pedigree, quality traits, HMW-GS and *Glu-1* score of the 122 bread wheat genotypes evaluated.

No	Name	Orig	GC	PSI	TKW	PC	SDS	HMW-GS			<i>Glu-1</i> score*
				%	g ⁻¹	%	ml ⁻¹	<i>Glu-A1</i>	<i>Glu-B1</i>	<i>Glu-D1</i>	
G1	Kırkpınar-79	C	W	50.7	29.9	10.8	25	2*	13+16	5+10	10
G2	Cumhuriyet-50-1	BL	W	56.5	39.1	10.3	25	2*	17+18	5+10	10
G3	Gerek 79	C	W	76.6	30.0	13.1	27	2*	7+8	2+12	6
G4	Dağdaş-94	C	W	58.1	31.8	13.7	23	2*	7+8	5+10	10
G5	Gün-91	C	R	62.7	28.9	13.7	34	2*	17+18	5+10	10
G6	Kınacı-97	C	R	71.4	27.2	13.5	26	1	7+8	5+10	10
G7	Pehlivan	C	R	58.5	42.2	13	30	2*	7+9	2+12	7
G8	Bezostaja-1	C	R	34.4	35.7	12.1	26	2*	7+9	5+10	9
G9	Katae A-1	C	R	52.0	31.4	12.3	28	1	7+8	2+12	8
G10	Malabadi	C	W	50.7	28.0	12.2	29	2*	17+18	2+12	8
G11	Gemini	C	R	55.5	28.2	12.9	21	2*	7	2+12	6
G12	Flamura-85	C	R	65.5	35.2	14	28	2*	7+8	5+10	10
G13	Yüreğir-89	C	W	54.2	34.0	12.5	30	2*	17+18	2+12	8
G14	Nurkent	C	W	59.0	30.2	12.5	22	1/2*	17+18	2+12	8
G15	Seyhan-95	C	W	57.2	29.6	12.9	24	2*	7+9	5+10	9
G16	Kırmızı Buğday	L	R	54.2	32.5	12.8	24	2*	7+8/7+9	5+10	7
G17	Ağdenli	L	W	42.7	29.6	11.1	25	2*	17+18	2+12	8
G18	Dışbudak	L	R	62.3	37.8	14.2	26	2*	7	2+12	6
G19	Cumakalesi	L	W	49.0	28.4	12.3	27	2*	17+18	5+10	10
G20	İsimsiz	L	W	60.2	29.9	14.9	25	2*	17+18	2+12	8
G21	İsimsiz	L	W	64.1	38.2	13.2	18	2*	7+8	2+12	8
G22	Beytülşebap-Beyaz	L	W	70.2	28.3	13.9	15	2*	7+8	2+12	8
G23	Buhare-Beytülşebap	L	K	63.9	26.3	16.5	26	2*	7+8	2+12	8
G24	Şırnak	L	R	71.8	34.0	14.1	20	2*	7+8	2+12	8
G25	Beytülşebap- Kırmızı	L	R	70.2	31.8	14.4	25	2*	7	2+12	6
G26	Lanchester-Kızıltepe	L	W	61.3	33.7	13.5	28	2*	13+16	5+10	10
G27	Akbaşak-Malatya	L	W	69.6	38.1	14.3	22	2*	7+8	2+12	8
G28	Zerun-Malatya	L	W	69.6	32.0	14.6	30	2*	7+8	2+12	8
G29	Aşure	L	W	70.8	32.8	14.4	26	2*	7+8	2+12	8
G30	Serdari	L	W	73.0	40.8	12.2	20	2*	6+8	2+12	6
G31	Sevinç-Azeri	L	R	61.1	32.9	14.5	18	2*	7+8	2+12	8
G32	Cham 6 (S/F)	F	W	62.5	29.6	10.8	27	2*	6+8	2+12	6
G33	Ykt-406	F	R	39.1	32.5	12	24	2*	7+8	2+12	8
G34	Partizanka	F	R	51.6	34.9	11.6	27	2*	7+9	5+10	9
G35	Zg.1004-82	F	R	57.5	37.0	13.1	18	2*	7+9	5+10	9
G36	Sremica	F	R	56.4	30.7	14.4	30	2*	7+9	5+10	9
G37	Mv-4	F	R	43.0	35.1	12.7	30	1	7	2+12	6
G38	Emu/Rmn	F	W	52.2	32.8	12.8	25	2*	7+9	5+10	9
G39	Kanred/Funo	F	R	52.3	34.8	11.9	23	2*	7+9	5+10	9
G40	Tamw-105	F	R	46.4	25.5	13.1	21	2*	7+8	5+10	9
G41	Cleo-74	F	W	58.9	31.7	11.9	26	2*	7+8	5+10	10
G42	Anza	F	W	47.1	28.6	12.2	24	2*	7+8	2+12	10
G43	Festa	F	R	61.3	33.0	14	32	2*	7+9	5+10	9
G44	Vilmorin 23 (W)	F	W	73.8	27.9	14.6	25	2*	7+8	2+12	8
G45	Emu"s"	F	R	52.3	34.6	12	24	2*	7+8	2+12	8
G46	Nacozari-76	F	R	39.2	29.7	12.1	24	2*	17+18	2+12	8
G47	Fengang-15	F	R	42.8	30.0	11.8	30	2*	7+8	2+12	8
G48	Ildiko/F.29-76	F	R	68.8	34.1	12.5	18	2*	7	5+10	8
G49	Mini Mano	F	R	60.9	34.7	14.5	13	2*	7+9	2+12	7
G50	Falcon	F	R	69.0	35.0	12.1	23	2	17+18	2+12	6
G51	Mol	F	W	56.9	25.7	13.5	29	1	17+18	2+12	8
G52	Pvn 1R (1B)	F	W	61.3	25.3	13.8	27	1/2*	7+9	5+10	9
G53	Heines Kolben (S)	F	R	74.3	29.2	15.2	27	1	7+9	5+10	9
G54	Clement (W)	F	R	76.4	29.1	13.3	18	2*	6+8	2+12	6
G55	Au	F	R	50.1	34.5	13.8	20	2*	7+9	2+12	7
G56	Pj-62/Abn-43	F	R	45.0	30.6	12.4	24	2*	7+9	5+10	9
G57	Nai-60/Hn-7//Buc	F	W	48.8	34.8	12.4	24	2*	7+9	5+10	9

Table 3 continued...



Continued of Table 3.

No	Name	Orig	GC	PSI	TKW	PC	SDS	HMW-GS			Glu-1 score*
				%	g ⁻¹	%	ml ⁻¹	Glu-A1	Glu-B1	Glu-D1	
G58	Mit	F	R	46.0	25.2	12.5	22	2*	7+8	5+10	10
G59	138.1.2/Nad//Bez/3/Coc	F	R	56.1	36.7	11.7	25	2*	6+8	5+10	8
G60	Lee/Kkz/3/Cc//Ron/Cho	F	W	52.8	28.5	11.8	24	2*	7+8	5+10	10
G61	Buc"s"/Pvn"s"	F	W	48.0	33.9	11.2	25	2*	7+9	2+12	7
G63	Line.1280-170/Nar-79	F	W	45.9	33.8	12.3	34	2*	7+8	2+12	8
G64	Gvz/Gv	F	W	47.3	32.6	12.1	32	1	17+18	5+10	10
G65	S.Sfm//Soty/Jn(3)	F	R	44.7	32.2	11.8	30	2*	7+9	5+10	9
G66	Carpentero/Carp	F	R	33.9	32.4	11.8	26	2*	7+9	5+10	9
G67	Prl"s"	F	W	43.0	33.3	10.7	29	2*	7+9	2+12	7
G68	C.183-24.C.168/3/Cno/7C*2//Cc/Tob	F	W	35.2	36.1	10.6	22	2*	7+9	5+10	9
G69	C.182-24.C.168/3/Cno/7C*2//Cc/Tob	F	W	39.4	32.3	10.9	24	2*	7+9	5+10	9
G70	Gen/Pew"s"	F	K	40.5	31.7	11.7	24	2*	7+9	5+10	9
G71	Nac/Trm	F	W	37.7	29.5	11.5	25	2*	17+18	2+12	8
G72	Jup/Bjy"s"//Ures=Kauz"s"	F	W	57.9	28.0	12.6	20	2*	7	5+10	9
G73	Mn-72131/Mor"s"	F	W	62.7	32.7	13.1	26	2*	7	5+10	9
G74	Chr/4/Inia"s"/7C//Cno"s"/Gll/3/Pci"s"//Bb	F	W	47.6	31.7	12.6	21	2*	7	2+12	6
G75	85-7	F	W	73.5	32.4	14.7	28	2*	7+8	2+12	8
G76	85-19	F	W	70.4	27.0	12.4	24	2*	17+18	2+12	8
G77	(N-10/B-1)	F	R	62.0	33.8	14	22	2*	7+9	2+12	7
G78	Brg/Kkz	F	R	58.1	33.6	14.5	15	2*	7+9	2+12	7
G79	Edch/Cfn"s"//Au/Era	F	W	59.2	30.7	13.6	18	2*	7+9	2+12	7
G80	Asp"s"//Hys/Peep"s"	F	R	69.7	33.0	13.1	33	2*	7+9	2+12	7
G81	Prl"s"	F	W	56.0	31.9	13	25	2*	7+9	5+10	9
G82	Prl"s"//Car-422/Ana	F	W	62.8	32.1	13.7	26	2*	7+9	5+10	9
G83	Bow""s"	F	W	68.5	30.4	9.3	24	2*	7+9	5+10	9
G84	Dove"s"/Bow"s"	F	W	50.9	31.6	12.9	24	2*	17+18	5+10	10
G85	Rbs/Anza/3/Kvz/Hys//Ymh/Tob/4/Bow"s"	F	W	53.4	30.2	13.3	25	2*	7+9	2+12	7
G86	Rbs/Anza/3/Kvz/Hys//Ymh/Tob/4/Bow"s"	F	W	50.0	28.1	13.9	24	2*	7+9	2+12	7
G87	Rbs/Anza/3/Kvz/Hys//Ymh/Tob/4/Bow"s"	F	W	58.4	26.7	13.7	26	1	7+9	2+12	7
G88	Bow"s"/Vee"s"	F	W	58.1	34.0	13.5	26	2*	7+9	2+12	7
G89	Tr.380-16-3A614/Chat"s"	F	W	55.4	35.1	13	25	2*	7+9	2+12	7
G90	Nac F.76/Ald"s"	F	W	53.5	31.3	13.4	28	2*	17+18	5+10	10
G91	Gh"s"/Anza	F	W	64.9	35.9	13.6	23	2*	17+18	5+10	10
G92	Br-6427	F	R	58.7	34.9	13.3	30	2*	17+18	5+10	10
G93	Anza/3/Pi/Nar//Hys/4/Vee"s"	F	R	55.2	27.5	13.1	25	1	7+9	2+12	7
G94	Buc"s"//7c/Ald"s"	F	W	60.2	35.9	12.4	30	1	7+9	5+10	9
G95	Bow"s"/Vee"s"//71 St 2959/Crow"s"	F	R	58.6	25.1	14.3	25	2*	7+9	5+10	9
G96	Ns.732/Her	F	W	60.2	33.9	12.6	20	2*	17+18	2+12	8
G97	Ures/Bow"s"	F	W	57.4	37.0	12.7	27	1	7+9	5+10	9
G98	Buc"s"/Dga/Hpo"s"	F	R	65.6	31.1	13.2	26	2*	7+9	5+10	9
G99	Hahn"s"/Mji/Lira"s"	F	W	59.6	32.2	15.1	27	1	7+9	5+10	9
G100	Kauz"s"	F	W	59.2	34.4	15.1	22	2*	7+9	2+12	7
G101	Myna"s"/3/F 35.70/Mo/Nac	F	R	59.2	29.9	13.1	22	2*	7+9	5+10	9
G102	Ns.732/Her	F	R	59.2	30.1	12.2	22	2*	7+9	5+10	9
G103	Chen/Aegilops squarrosa (Taus)//Bcn	F	W	58.8	32.6	13.3	20	1/2*	7+9	5+10	9
G104	Chen/Aegilops squarrosa (Taus)//Bcn	F	W	67.1	33.3	13.5	28	2*	7+8	5+10	10
G105	Era/Chm//Sal.75/3/Cndr"s"//Ana//Cndr"s"	F	R	50.9	31.0	12.9	22	2*	13+16	5+10	10
G106	Au//Kal/Bb/3/Bon/4/Bow"s"	F	R	55.9	30.7	14	28	2*	7+9	5+10	9
G107	Dowe"s"/Tsi/5/Gu/4/D.6301/Nai/Wrm	F	R	52.5	34.5	12.6	22	1	13+16	2+12	8
G108	Flk"s"/Hork/6/Wa.4767/391//56D.8114.53	F	W	70.8	30.9	11.7	30	1	17+18	5+10	10
G109	Kvz//Cno/Pj.62/5/Tuc"s"//4/Tob/Cc//Pato/	F	R	61.4		13.6	32	2*	7+9	5+10	9
G110	Kvz/Pak.20/5/Maya-74"s"//On//II 60-	F	W	54.8	34.1	14.6	28	1	7+9	5+10	9
G111	Au//Kal/Bb/3/Bon/4/Kvz//Cno/Fj-62	F	W	80.5	30.4	13.5	22	2*	7+8	2+12	7
G112	Kvz/Pak.20/5/Maya-74"s"//On//II 60-147/	F	R	57.5	35.4	13.8	19	2*	7+9	5+10	9
G113	Sn.64/Hn.4//Rex/3/Edch/Mex/4/SIs"s"//	F	W	56.6	35.6	12.9	21	2*	7+9	5+10	9
G114	Ures.81//Hd.2206/Hork"s"	F	W	45.9	33.6	14.2	23	2*	7+9	2+12	7
G115	Cno//Lr/Son.64/3/Rbs 47.51/4/7	F	R	64.7	31.9	13.4	30	2*	17+18	2+12	8

Table 3 continued...

Continued of Table 3.

No	Name	Orig	GC	PSI	TKW	PC	SDS	HMW-GS			Glu-1 score*
				%	g ⁻¹	%	ml ⁻¹	Glu-A1	Glu-B1	Glu-D1	
G115	Cno//Lr/Son.64/3/Rbs 47.51/4/7	F	R	64.7	31.9	13.4	30	2*	17+18	2+12	8
G116	Kasyon/Glennson.81	F	R	57.2	34.5	13.4	26	2*	7+9	5+10	9
G117	Sn.64/Hn.4//Rex/3/Edch/Mex/4/Sls"s"/5/	F	W	62.8	33.2	14.2	24	2*	13+16	5+10	10
G118	Au//Kal/Bb/3/Bon/4/Bow"s"	F	R	60.0	28.5	14	23	2*	7+9	5+10	9
G119	Seri-82/5/Ald"s"/4/Bb/Gll//Cno.67/7c//Kvz	F	W	57.5	29.5	12.9	20	2*	7+9	5+10	9
G120	Sn.64/Hn.4//Rex/3/Edch/Mex/4/Sls"s"/5/Bo	F	W	54.4	29.1	13.3	23	1	13+16	5+10	10
G121	Vee"s"//Sannine/Ald"s"	F	W	62.3	27.9	13.3	32	1	17+18	5+10	10
G122	Vee"s"/5/Skh.8/4/Rrv/Ww.15/3/Bj"s"//On*	F	R	52.8	28.0	14.2	23	2*	7+9	5+10	9
Means				57.1	32.0	13.0	24.9				
Sd				9.71	3.31	1.59	3.99				

*According to the Payne and Lawrence nomenclature (1983), BL: Breeding Line; C: Commercial; F: Foreign; GC: Grain Color; W: White; R: Red; PSI: Part Size Index; TKW: Thousand Kernel Weight, SDS: Sedimentation volume.

17+18, 5+10, respectively. Bezostaya is accepted as high quality variety, while Gerek-79 is accepted as medium quality by milling and baking industry (Demir *et al.*, 2015). In Turkish commercial winter varieties, subunit 5+10, associated with good bread-making quality, appeared to have higher frequencies than in Turkish spring varieties.

Additionally, quality scores were assigned to each subunit band produced by alleles at the *Glu1* loci of chromosomes A, B, and D as defined by Payne *et al.* (1987). Quality scores demonstrated high significant correlation with dough strength, thus, providing a useful method for selecting HMW glutenin compositions with good quality (Belderol *et al.*, 2000). In order to predict the bread-making quality of wheat genotypes, *Glu-1* score was calculated for the wheat genotypes on the basis of HMW glutenin subunits detected. Our data demonstrated that the *Glu-1* score in Turkish commercial wheat varieties varied within an interval from 6 to 10. The lowest *Glu-1* score was recorded in cultivars Gemini, Pehlivan and Gerek-79. However, the cultivars Dağdaş-94, Gün-91, Kınacı-97 and Flamura-85 accounted for the highest *Glu-1* score, reflecting high baking quality (Table 3). These results are in accordance with those reported by Keser and Pena (2004); Demir *et al.* (2015), and Yıldız (2011). Within local genotypes, the highest value of

Glu-1 score was achieved by Cumakalesi, while Dışbudak showed the lowest score value (Table 3).

Principal Component Analysis

The Genotype-by-Trait (GT) biplot is a statistical tool for evaluating cultivars based on multiple traits and for identifying lines that are superior (Mishra *et al.*, 2015). The GT biplot explains superior genotypes with favourable traits effect which would be useful for the breeding of new genotypes for each target entry, thus, it will help breeders explore the interactions among entries and subsets of tester (Dehghani *et al.*, 2008). Also, GT biplot was built to identify the genetic variability and the relationships among wheat genotypes.

Figure 1 represents polygon view of a GT biplot generated from 4 quality traits and *Glu-1* score of 122 genotypes data. Biplot analysis was used to examine the relationships between the genotypes and quality traits studied together with *Glu-1* score (Figure 1). The first two PCAs (Principal Components 1 and 2) accounted for 56.17% (PC1= 31.98% and PC2= 24.19%) of the relationships between the genotypes and quality traits. The PC, PSI and *Glu-1* score had long vectors, suggesting that there was a relatively large variation among genotypes. In contrast, TKW and

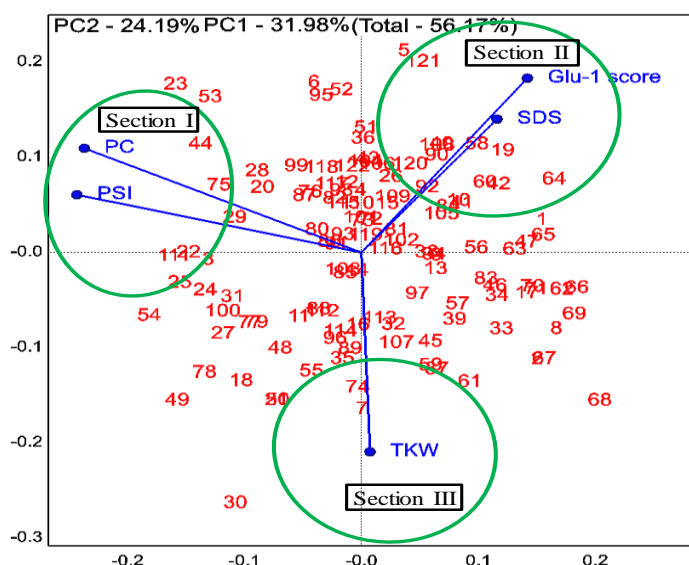


Figure 1. The biplot showing the relation among genotypes and quality traits.

SDS had shorter vectors, suggesting that there were relatively little variation among genotypes. The cosine of the angle between the vectors of two traits measures the correlation between them relative to their variation among genotypes. Two traits are positively correlated if the angle between their vectors is $< 90^\circ$, negatively correlated if the angle is $> 90^\circ$, and independent if the angle is 90° (Dehghani *et al.*, 2012). Therefore, *Glu-1* score and SDS had acute ($< 90^\circ$) angles between them, demonstrating that their variations were similar. On the contrary, TKW had obtuse ($> 90^\circ$) angles with *Glu-1* score, SDS, PC and PSI, indicating negatively correlated variation. Traits were grouped into three sections and are presented in Figure 1. Protein Content (PC) was positively correlated with PSI at section I. Salmanowicz *et al.* (2012) reported that the relationship between grain hardness and PC was uncertain. Section II included *Glu-1* score which was strongly correlated with SDS sedimentation. These were in agreement with results of Schuster *et al.* (1997) that reported positive and significant relationship between *Glu-1* score and SDS sedimentation test and baking strength ("W"). Therefore, *Glu-1* score can be used as a helpful guide in selection for bread-making quality in the first generation

of the breeding programs, when quantities of seeds necessary for the conventional test are not available (Schuster *et al.*, 1997). Section III included the only TKW which was negatively associated with other traits. Our findings were in agreement with results of Şahin *et al.* (2001) and Akçura (2011). In a previous study, O'Brien and Ronalds (1984) reported negative relationship between TKW and Zeleny SDS sedimentation test and PC. The Genotype by Trait (GT) biplot can be used to compare cultivars on the basis of multiple traits and to identify cultivars that are particularly good in certain traits and, therefore, can be candidates for parents in plant breeding program (Dolatabad *et al.*, 2010). Figure 1 is a GT biplot with a polygon view that presents the data of 122 wheat genotypes. It seems that G121, G58, Cumakalesi, and G64 had the highest values of *Glu-1* score and SDS; G44, G75, G22 and G114 had the highest values of PC and PSI. Also, Figure 1 indicates that Pehlivan and G74 were highest in TKW.

CONCLUSIONS

This study concerning HMW-GS and some quality traits evaluation of local, old, and new genotypes and breeding lines

revealed that bread wheat (*Triticum aestivum* L) crossing blocks have potential value in wheat breeding programs. Twenty three of the studied genotypes with the highest ranking in HMW *Glu-1* score (*Glu-1* score > 10) have the potential for breeding wheat varieties with higher protein quality. The *Glu-1* quality score can be used as a parameter for selecting lines in terms of the baking quality of bread in Turkish wheat breeding programs.

REFERENCES

1. Akçura, M. 2011. The Relationships of Some Traits in Turkish Winter Bread Wheat Landraces. *Turk. J. Agric.*, **35**: 115-125
2. Akhtar, H. and Odean, M. L. 1994. Characterization of the IB/IR Translocation in Wheat Using Water Extractable Protein Concentrate. *Euphytica*, **78**: 109-113.
3. Beldeir B., Mesdag, I. and Donner, D. A. 2000. *Bread Making Quality of Wheat: A Century of Breeding in Europe*. Ebook, Springer Science+Business Media, BV, 262 PP.
4. Bordes, J., Branlard, G., Oury, F. X., Charmet, G. and Balfourier, F. 2008. Agronomic Characteristics, Grain Quality and Flour Rheology of 372 Bread Wheat in a Worldwide Core Collection. *J. Cereal Sci.*, **48**: 569-579.
5. Branlard, G. and Dardevet, M. 1985. Diversity of Grain Protein and Bread Wheat Quality. II. Correlation between High Molecular Weight Subunits of Glutenin and Flour Quality Characteristics. *J. Cereal Sci.* **3**:345-354.
6. Costa, M. S., Scholz, M. B. S. and Franco, C. M. L. 2013. Effect of High and Low Molecular Weight Glutenin Subunits, and Subunits of Gliadin on Physicochemical Parameters of Different Wheat Genotypes *Ciênc. Tecnol. A Liment. Campinas*, **33**(1): 163-170.
7. Dehghani, D., Omid, H. and Sabaghnia, N. 2008. Graphic Analysis of Trait Relations of Canola (*Brassica napus* L) Using Biplot Method. *Agron. J.*, **100**: 760-764.
8. Dehghani, H., Dvorak, J. and Sabaghnia, N. 2012. Graphic Analysis of Biomass and Seed Yield of Beard Wheat in Salt Stress Condition. *Annal. Biol. Res.*, **3**(9): 4246-4253.
9. Demir, Z., Atlı, A. and Baran, I. 2015. *Glutenin Subunit Composition of Some Old and New Wheat Varieties in Winter Wheat Growing Regions of Turkey*. Website: <http://wheat.pw.usda.gov/ggpages/DEM/91WGS/glutenin.html>
10. Dolatabad, S. S., Choukan, R., Hervan, E. M. and Dehghani, H. 2010. Multi-Environment Analysis of Traits Relation and Hybrids Comparison of Maize Based on the Genotype by Trait Biplot. *Am. J. Agric. Biol. Sci.*, **5**(1): 107-113.
11. Gianibelli, M. C., Larroque, O. R., MacRitchie, F. and Wrigley, C. W. 2001. Biochemical, Genetic and Molecular Characterization of Wheat Endosperm Proteins. *Am. Assoc. Cereal Chem.*, **1**: 158-236
12. Gupta, R. B., Paul, J. G., Cornish, G. B., Palmer, G. A., Bekes, F. and Rathjen, A. J. 1994. Allelic Variation at Glutenin Subunit and Gliadin Loci, *Glu-1*, *Glu-3* and *Gli-1*, of Common Wheats. I. Its Additive and Interaction Effects on Dough Properties. *J. Cereal Sci.*, **19**: 9-17
13. Guzmán, C., Yonggui, X., Crossa, J., Santoyo, H. G., Huerta, J., Singh, R. and Dreisigacker, S. 2016. Sources of the Highly Expressed Wheat Bread Making (wbm) Gene in CIMMYT Spring Wheat Germplasm and Its Effect on Processing and Bread-Making Quality. *Euphytica*, **209**(3): 689-692.
14. He, Z. H., Liu, L., Xia, X. C., Liu, J. J. and Eña, R. J. P. 2005. Composition of HMW and LMW Glutenin Subunits and Their Effects on Dough Properties, Pan Bread, and Noodle Quality of Chinese Bread Wheats. *Cereal Chem.*, **82**: 345-350.
15. Hernández, Z. J. E., Figueroa, J. D. C., Duarte, P. R., Martínez-Flores, H. E., Arámbula, G. V., Luna, G. B. and Peña, R. J. 2012. Influence of High and Low Molecular Weight Glutenins on Stress Relaxation of Wheat Kernels and the Relation to Sedimentation and Rheological Properties. *J. Cereal Sci.*, **55**:344-350
16. Jaradat, A. A. 2011. Ecogeography, Genetic Diversity, and Breeding Value of Wild Emmer Wheat (*Triticum dicoccoides* Körn ex Asch. and Graebn.) *Thell. Aust. JCS*, **5**(9): 1072-1086



17. Kanenori, T., Zenta, N., Wakako, F., Tatsuo, K. and Hiroaki, Y. 2003. Difference in Combination between *Glu-B1* and *Glu-D1* Alleles in Bread-Making Quality Using Near-Isogenic Lines. *Food Sci. Tech. Res.*, **9(1)**: 67–72.
18. Kaya, Y. and Akcura, M. 2014. Effects of Genotype and Environment on Grain Yield and Quality Traits in Bread Wheat (*T. aestivum* L.). *Food Sci. Tech. Campinas*, **34(2)**: 386-393.
19. Keser, M. and Pena, R. J. 2004. Kışlık Ekmeklik Buğdayda Yüksek Molekül Ağırlıklı Glutenin alt Uniteleri ve Bazı Kalite Parametreleri ile İlişkileri: Kuru Koşullar. *Tarla Bitkileri Merkez Araştırma Enstitüsü Dergisi*, **10(1-2)**: 67-74
20. Lafiandra, D., D'Ovidio, R., Porceddu, E., Margiotta, B. and Colaprico, G. 1993. New Data Supporting High Mr Glutenin Subunit 5 as Determinant of Qualitative Differences in the Pairs 5+10 vs. 2+12. *J. Cereal Sci.*, **18**: 197-205.
21. Liang, D., Tang, J., Pena, R. J., Singh, R., He, X., Shen, X., Yao, D., Xia, X. and He, Z. 2010. Characterization of CIMMYT Bread Wheats for Highland Low-Molecular Weight Glutenin Subunits and Other Quality-Related Genes with SDS-PAGE, RP-HPLC and Molecular Markers. *Euphytica*, **172**: 235–250.
22. Lukow, O. M., Payne, P. I. and Tkachuk, R. 1989. The HMW Glutenin Subunit Composition of Canadian Wheat Cultivars and Their Association with Bread Making Quality. *J. Sci. Food Agri.*, **46(4)**: 451-460.
23. Mohammadi, R. and Amri, A. 2011. Graphic Analysis of Trait Relations and Genotype Evaluation in Durum Wheat. *J. Crop Improv.*, **25**: 680–696.
24. Mishra, C. N., Tiwari, V., Satish-Kumar, V. G., Gupta, V., Kumar, A. and Sharma, I. 2015. Genetic Diversity and Genotype by Trait Analysis for Agromorphological and Physiological Traits of Wheat (*Triticum aestivum* L.). *Sabao J. Breed. Genet.*, **47(1)**: 40-48.
25. O'Brien, L. and Ronalds, J. A. 1984. Yield and Quality. Interrelationships amongst Random F3 Lines and Their Implications for Wheat Breeding. *Aust. J. Agri. Res.*, **35(4)**: 443-451
26. Payne, P. I. and Lawrence, G. J. 1983. Catalogue of Alleles for the Complex Gene Loci, *Glu-A1*, *Glu-B1* and *Glu-D1* which Code for the High-Molecular Weight Subunit of Glutenin whose in Hexaploid Wheat. *Cereal Res. Comm.*, **11(1)**: 29-35.
27. Payne, P. I. 1987. Genetics of Wheat Storage Proteins and the Effect of Allelic Variation on Bread-Making Quality. *Annu. Rev. Plant Physiol.*, **38**: 141–153. doi:10.1146/annurev.pp.38.060187.001041
28. Payne, P. I., Nightingale, M. A., Krattiger, A. F. and Holt, L. M. 1987. The Relation between the HMW Glutenin Subunit Composition and the Bread-Making Quality of British Grown Wheat Varieties. *J. Sci. Food Agric.*, **40**: 51-65.
29. Payne, P. I. 1988. Endosperm Proteins. In: “*Plant Gene Research: a Genetic Approach to Plant Biochemistry*”, (Eds.): Blonstein, A. D. and King, P. J. Plant Breeding Institute, Cambridge.
30. Payne, W. R., Murray, D. A., Harding, S. A., Baird, D. B. and Sauter, D. M. 2009. *GenStat for Windows*. 12th Edition, Introduction WSN International Hemel Hempstead. Website: <http://www.vsni.co.uk/downloads/genstat/release12/doc/IntroGuide.pdf>
31. Pena, R. J., Amaya, A., Rajaram, A. S. and Mujeeb-Kazi, A. 1990. Variation in Quality Characteristics Associated with Some Spring 1B/1R Translocation Wheats. *J. Cereal Sci.*, **12**: 105.
32. Pfluger, L. 2007. *Marker Assisted Selection in Wheat. Quality Traits. Gluten Strength*. Borloug Global Initiative, <http://maswheat.ucdavis.edu/protocols/Gluten/index.htm>
33. Pogna, N. E. and Mellini, F. 1986. Alla Ricerca Delle Basi Biochimiche e Genetiche Della Qualita del Glutine. *L'Inform Agr.*, **42**: 65-66
34. Salmanowicz, B. P., Adamski, T., Surma, M., Kaczmarek, Z., Karolina, K., Kuczyńska, A., Banaszak, Z., Ługowska, B., Majcher, M. and Obuchowski, W. 2012 The Relationship between Grain Hardness, Dough Mixing Parameters and Bread-Making Quality in Winter Wheat. *Int. J. Mol. Sci.*, **13(4)**: 4186–4201.
35. Schuster, I., Moacil de, D., Cardoso, A. A., Sedyama, C. S. A. and Moreira, M. 1997. Correlation between High Molecular Weight Gluten Subunits Composition and Bread-Making Quality in Brazilian Wheat. *Braz. J. Genet.*, **20(4)**:

- Website: <http://dx.doi.org/10.1590/S0100-84551997000400019>
36. Seilmeier, W., Belitz, H. D. and Weiser, H. 1991. Separation Quantitative Determination of High-Molecular-Weight Subunits of Glutenin from Different Wheat Varieties and Genetic Variants of the Variety Sicco. *Z. Lebensm Unters Forsch*, **192**: 124–129.
 37. Shewry, P. R. and Tatham, A. S. 1997. Biotechnology of Wheat Quality. *J. Sci. Food Agr.*, **73**: 397–406.
 38. Shewry, P. R. and Jones, H. D. 2012. *Improving Protein Quality for Breadmaking: The Role of Biotechnology. Bread Making Improving Quality*. (Ed.): Stanley P. C. Woodhead Publishing. Limited, PP. 237-258
 39. Singh, N. K., Shepherd, K. W. and Cornish, G. B. 1991. A Simplified SDS-PAGE Procedure for Separating LMW Subunits of Glutenin. *J. Cereal Sci.*, **14**: 203–208
 40. Şahin, M., Akçacık, A. and Aydoğan, S. 2001. Bazı Ekmeklik Buğday Genotiplerinin tane Verimi ile Kalite Özellikleri Arasındaki İlişkiler ve Stabilité Yetenekleri. *Anadolu J. AARI*, **21(2)**: 39 - 48
 41. Tahir, N. A. R. 2009. Evaluation of Hexaploid Wheat Varieties for Making Bread by High Molecular Weight (HMW) and Low Molecular Weight (LMW) Analysis. *Jordan J. Biol. Sci.*, **2(2)**: 55-62.
 42. Tarakanovas, P. and Ruzgas, V. 2007. Study of Genotype–Environment Interaction of Winter Wheat Varieties with Respect to Grain Yield. *Zemdirbyste-Agriculture*, **94(2)**: 96–109.
 43. TÜİK. 2014. *Bitkisel Üretim İstatistikleri*. Website: <http://tuikapp.tuik.gov.tr/bitkiselapp/bitkisel.zul>. Erişim Tarihi: 22.07.2015.
 44. Weegels, P. L., Hamer, R. J. and Schofield, I. D. 1996. Functional Properties of Wheat Glutenin. *J. Cereal Sci.*, **23**: 1-18
 45. Williams, P., El-Haremein, F. J., Nakkoul, H. and Rihavi, S. 1988. *Crop Quality Evaluation Methods and Guidelines*. Technical Manual 14 (Revision 1), ICARDA.
 46. Yan, W. and Rajcan, I. R. 2002. Biplot Analysis of Test Sites and Trait Relations of Soybean in Ontario. *Can. J. Plant Sci.*, **42**: 11–20.
 47. Yıldız, A. 2011. Bazı Kışlık Buğday (*T. aestivum L.*) Genotiplerinde Yüksek ve Düşük Molekül Ağırlıklı Glutenin Bant Desenlerinin Belirlenmesi ve Kalite İslahında Kullanımı. Ankara Üniversitesi Fen Bilimleri Enstitüsü Doktora Tezi, 144 Sayfa.
 48. Zheng W., Yanchun, P., Junhong, M., Rudi, A., Dongfa, S. and Wujun, M. 2011. High Frequency of Abnormal High Molecular Weight Glutenin Alleles in Chinese Wheat Landraces of the Yangtze-River Region. *J. Cereal Sci.*, **54**: 401-408.
 49. Zohary, D. and Hopf, M. 1993. *Domestication of Plants in the Old World*. 2nd Edition, Clarendon Press, Oxford, UK.

غربالگری ژنوتیپ های گندم نان برای زیرواحدهای گلوتنین با وزن مولکولی بالا و برخی صفات کیفیتی

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چکیده

در این پژوهش، در ۱۲۲ ژنوتیپ گندم نان محلی برگرفته از بلوک های دو رگ گیری، ترکیب زیرواحدهای گلوتنین با وزن مولکولی بالا (HMW-GS) برحسب چند صفت کیفیتی مانند محتوای پروتئین (PC)، سولفات دودسیل سدیم (SDS)، نمایه اندازه ذرات (particle size index)، و وزن هزار دانه (TKW) با روش SDS-PAGE بررسی شد. در کل، ۱۲ ترکیب متفاوت HMW-



GS تعیین شد. همچنین، بر حسب جایگاه (loci) آلل های *Glu-B1*، *Glu-A1* و *Glu-D1* گوناگونی و تنوع زیادی شناسایی شد. در جایگاه *Glu-A1*، بسآمد آلل های $1/2^*$ ، 1 و 2^* به ترتیب $2/5\%$ ، $12/3\%$ و $85/5\%$ شناسایی شد، در حالیکه در *Glu-B1*، از ۷ آلل گزارش شده، آلل $7+8$ $20/5\%$ و $17+18$ $17/2\%$ شناسایی شد. وجود دو آلل در جایگاه *Glu-D1* نیز آشکار شد. در واقع، $54/1\%$ آنها نشان دادند که زیر واحد های $5+10$ با خواص نانوائی خوب همبستگی داشتند. امتیاز جایگاه *Glu-1* ژنوتیپ ها در محدوده ۶ تا ۱۰ بود. در میان این ژنوتیپ ها، فقط ۲۳ تا $18/9\%$ دارای امتیاز 10 *Glu-1* بودند. در ارزیابی ژنوتیپ-صفت (GT) با استفاده از نمودار بای پلات، صفات PC و PSI در بخش I نقش داشتند در حالیکه معیار ته نشینی SDS و امتیاز *Glu-1* در بخش II نقش داشتند. از سوی دیگر، بخش III تنها TKW را شامل بود که با صفات دیگر همراهی منفی داشت. بنا بر این، ژنوتیپ های مطلوب را می توان برای برنامه های دو رگ گیری به منظور بهبود کیفیت تکنولوژیکی گندم های نان استفاده کرد.