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GENETIC DIVERSITY OF WHEAT CULTIVARS FROM TURKEY AND U.S. GREAT PLAINS

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GENETIC DIVERSITY OF WHEAT CULTIVARS FROM

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Genetic diversity of wheat cultivars from Turkey and the Great Plains was studied under the hypothesis 'Turkey' wheat originated from Turkey and is the original hard red winter wheat landrace in the Great Plains. Wheat cultivars in Turkey and the Great Plains were selected for adaptation in two countries which were similar in climate. Twenty-two Turkish and twenty-three Great Plains wheat cultivars were selected for this study using SSR markers, agronomic, and end-use quality traits data. Wheat cultivars were clustered into five groups based on SSR markers and the clustering largely followed their countries of origin and pedigree. Modern Great Plains wheat cultivars diverged from Turkey wheat and historic Great Plains wheat cultivars. Although cultivars from one gene pool were predominant in each cluster, cultivars from another gene pool were also present indicating genetic similarity. Field experiments were conducted in six environments in Nebraska. The cultivars and cultivar by environment interactions for nine agronomic and four end-use quality traits were significant. Most Turkish wheat cultivars were injured by the Nebraska winter; hence showed lower grain yields. Great Plains wheat cultivars diverged from Turkish wheat cultivars due to breeding for adaptation based on agronomic traits. Turkish and U.S. wheat cultivars clustered together for end-use quality traits indicating similar selection criteria. Cluster analysis based on agronomic and end-use

quality combination indicated that wheat cultivars from two countries had separated. The original Great Plains wheat cultivars (Turkey and Kharkof) were clustered separately from modern Great Plains wheat cultivars by both SSR and combination of agronomic and end-use quality data. Our results suggested that breeding programs in both countries improved wheat cultivars for specific environment as the genetic diversity based on agronomic traits; nevertheless, SSR markers indicated that 130 years after the introduction of Turkey wheat, much of the genetic background of two wheat groups has been maintained. The better adapted Turkish wheat cultivars in Nebraska were Karasu-90, Alpaslan, Lancer, Dogu-88, Harmankaya, and Yildirim which can be used as parents.

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CHAPTER 1

Estimating Genetic Diversity in Wheat Cultivars from Turkey and U.S. Great Plains Using SSR Markers

ABSTRACT

The first successfully cultivated hard red winter wheat (*Triticum aestivum* L.) introduced to the U.S. Great Plains was 'Turkey' wheat. Turkey wheat originated from Turkey and many modern Great Plains wheat cultivars are derived from it or its related lines. To investigate the genetic diversity between the Turkish and Great Plains gene pools as they evolved, simple sequence repeat (SSR) markers were used to compare Turkish wheat cultivars to some historic and modern Great Plains wheat cultivars. Based on 55 polymorphic SSR markers, two similarity coefficient analyses and two cluster methods were performed. Dice similarity and Nei standard distance coefficients ranged from 0.3478-0.8489 and 0.142-0.674, respectively. As expected, the most closely related pairs of lines were within each gene pool (Millennium and NE01643, and Aytin-98 and Gerek-79). Unweighted paired group method using arithmetic averages (UPGMA) and Neighbor–Joining method (NJ) clustered wheat cultivars from Turkey and USA into five groups. Often lines from one gene pool were predominant in each cluster; however, lines from the other gene pool were also present indicating similar genetics. Modern Great Plains wheat cultivars have diverged from historic Great Plains and Turkish wheat cultivars most likely due to breeding for adaptation. Ancestral Great Plains wheat cultivars were clustered with both older and some modern Turkish wheat cultivars. A few modern Turkish wheat cultivars were clustered in the group of modern Great Plain wheat

cultivars possibly because of germplasm exchange between the two countries or similar breeding criteria.

INTRODUCTION

Hard red winter wheat (HRWW, *Triticum aestivum* L.) is widely grown in the Great Plains (an area from North Dakota to Texas and from Nebraska to the Rocky Mountains) of the United States and represents about 40% of U.S. wheat production (Acquaah, 2007). The Great Plains became the main region for HRWW production after the first HRWW called “Turkey wheat” was introduced by Mennonite settlers who came from Ukraine to Kansas in 1874 (Quisenberry and Reitz, 1974; Paulsen and Shroyer, 2008; Ross, 1969). Quisenberry and Reitz (1974) stated that the Mennonite settlers called the wheat ‘Turkey’ because they obtained it from a little valley in Turkey. Turkey wheat replaced spring wheat cultivars in Nebraska and soft red winter wheat cultivars in Kansas, Oklahoma, and Texas due to its superior winter hardiness in 1894-1896 (Quisenberry, 1974). In 1919, Turkey wheat was grown on 83, 82, 69, 67, and 34 percent of the wheat hectareage in Nebraska, Kansas, Oklahoma, Colorado, and Texas, respectively (Quisenberry and Reitz, 1974). Although Turkey wheat had excellent adaptation to the Great Plains, other Turkey-type HRWW such as ‘Crimean’ and ‘Kharkof’ were introduced in 1900’s and all three cultivars were used as parents in the wheat improvement programs in the U.S. leading to the development of cultivars ‘Blackhull’ (released in 1917), ‘Nebraska No 28’ (released in 1916), and ‘Nebred’ (released in 1938). ‘Cheyenne’ (released in 1933), the foundation of the Nebraska wheat breeding program, was selected from Crimean. Breeding for adaptation resulted in modern HRWW cultivars with improved grain yield, lodging, disease and insect resistance, and baking quality. However, all modern Great Plains wheat cultivars trace back to Turkey wheat (Paulsen and Shroyer, 2008; Cox and Shroyer, 1984; Quisenberry, 1974). Since Turkey wheat was important to the Great Plains wheat improvement, it was hypothesized that both Turkish and US Great Plains wheat might be genetically similar. To evaluate this hypothesis, the genetic relationship among Turkish wheat and HRWW cultivars grown in the Great Plains was determined in terms of genetic similarity/distance. Genetic distance (or similarity) can reveal the genetic diversity of individuals (Stachel et al., 2000).

Genetic diversity is defined as the amount of genetic variability which is reflected in differences of DNA sequence, biochemical characteristics, physiological properties, or morphological characters among individuals of a variety or a population. Genetic diversity can also be estimated by pedigree analysis. Plant genetic diversity is changed by evolution and by breeding history during which intensive selection often reduces genetic diversity in the elite germplasm pool (Rao and Hodgkin, 2002; Brown, 1983; Zhang et al., 2005). Genetic diversity information among elite germplasm or cultivars is useful to (i) classify lines for desirable traits (Mahmood et al., 2004; Ali et al., 2008), (ii) determine the genetic diversity reduction due to long term plant breeding programs (Fu and Somers, 2009), and (iii) evaluate genetic differentiation by different breeding programs (Stachel et al., 2000). Molecular marker data are often used for genetic diversity assessment because the markers can be codominant and have a large number of alleles without genetic effects such as epistasis or pleiotropy (Tanksley, 1983).

Microsatellite markers, also known as simple sequence repeats (SSR) markers, are molecular markers based on the tandem repeats of 1-6 nucleotide core elements. Simple sequence repeats are codominant markers dispersed throughout the genome, have multiple alleles and often have conserved loci between related species (Brown et al., 1996). Simple sequence repeat markers have been used for genome analyses and plant breeding studies such as genetic evolution, quantitative trait loci (QTL) mapping, gene tagging based on map position, cultivar identification, and genetic diversity analysis in germplasm (Liu and Zhang, 2008). Simple sequence repeats have the ability to discriminate among closely related individuals for diversity and allelic variation across a wide range of germplasm, and have the advantage over other markers to trace pedigrees in plants (Powell et al., 1996).

In rice (*Oryza* spp.), SSRs were used to distinguish wild species (*O. rufipogon* and *O. nivara*) and two subspecies of *O. sativa* (*indica* and *japonica*) (Ni et al., 2002). Thirty one wild and 73 sorghum (*Sorghum bicolor*) landraces were classified using 98 SSR loci (Casa et al., 2005). Ali et al. (2008) classified 72 sweet sorghum accessions into groups that agreed with their pedigree information and sugar content. In wheat, 16 durum wheat (*T. turgidum var durum*) cultivars were identified by 7 SSR markers with high polymorphism information content (PIC) which agreed with their pedigree information (Dograr et al., 2000). Maccaferri et al. (2007) was able to classify 58 durum wheat accessions in agreement with their origin and pedigree. Thirty hard red winter wheat cultivars grown in the Great Plains were also grouped using SSR markers that agreed with pedigree information (Fufa et al., 2005).

In a study, to determine how genetic diversity has been altered by breeding efforts, modern spring bread wheat cultivars released between 1950 and 1989 were found to have narrow genetic diversity, but landraces and *Triticum tauschii* (Coss.) Schmalh represented a much broader genetic base (Reif et al., 2005). Stachel et al. (2000) via SSR analysis, concluded that breeding for end-use quality and specific environmental conditions caused genetic differentiation among bread wheat lines from Germany, Australia and Hungary. Simple sequence repeats have been used to study genetic diversity of wheat cultivars in Argentina (Manifesto, et al., 2001), Egypt (Salem et al., 2008), France (Roussel et al., 2004), Iran (Eivazi et al., 2008; Mohammadi, et al., 2009), US (Mahmood et al., 2004; Fufa et al., 2005; and Chao et al., 2007), and Turkey (Akkaya and Buyukunal-Bal, 2004 and Altintas et al., 2008). However, few studies have look at the diversity between a source country and the country where the line became the foundation parent.

Molecular markers are very useful in studying the relationship of closely related lines as they allow calculation of genetic distance based on allele frequencies. The SSR markers are usually scored in terms of presence or absence of a band which can be described as a binary variable. There are several methods to calculate distance/similarity coefficient of paired cultivars (Johnson and Wichern, 2007; Mohammadi and Prasanna, 2003). Dendrogram construction relies on a clustering method and a distance coefficient (Nei et al., 1983). Dice (1945), also known as Nei and Li's (1979) distance coefficients, are used when inheritance from a common ancestor is expected and they exclude the negative matching from non-amplified bands. In addition, distance-based clustering methods such as hierarchical methods are generally used for genetic diversity analysis in plants. For example, the Unweighted Paired Group Method using Arithmatic Averages (UPGMA) is commonly used for cluster analysis (Mohammadi and Prasanna, 2003; Reif et al., 2005). Saitou and Nei (1987) recommended Neighbor–Joining method (NJ) to construct dendrograms based upon the closest neighboring pair that minimizes the total branch length of operational taxonomic units (OUTs). The UPGMA clustering method was used assumming a constant rate of evolution. In contrast, NJ method is based on the assumption of the minimum evolution (Nei, 1991). However, Nei et al. (1983) suggested that the accuracy of a phylogenetic tree depends on tree construction method and distance coefficients. They also recommended that more than 30 loci should be used to obtain phylogenetic trees. Kim et al. (1993) compared the accuracy of UPGMA, Maximum Parsimony, and the NJ method and found that no one method was more accurate than others and more than one method should be employed for phylogenic tree construction (Kim, 1993).

The objectives of this study were to: (i) investigate the genetic diversity of some hard red winter wheat cultivars from U.S. Great Plains and from Turkey using SSR markers, (ii) compare Turkish wheat cultivars to some historic and modern Great Plains wheat cultivars to see how the two gene pools have diverged over time using two cluster analysis methods.

MATERIALS AND METHODS

Plant Materials

Forty-five wheat cultivars including 22 Turkish wheat cultivars (released between 1917 and 2002) and 23 Great Plains HRWW cultivars (released between 1874 and 2006) were used in this study. For the purpose of this research, 'Bezostaya-1' which was originally from Russia, but widely grown in Turkey and used as a parent in both Turkish and U.S. breeding programs was grouped with the Turkish wheat cultivars. The pedigree information on the cultivars was obtained from GRIN website (Germplasm Resource Information network; http://www.ars-grin.gov) and Wheat Pedigree and Identified Alleles of Gene On Line, Czech Republic (http://genbank.vurv.cz/wheat/pedigree/) (Table 1).

DNA extraction method

Genomic DNA of each cultivar was extracted from greenhouse leaf samples using cetyltrimethyl ammonium bromide (CTAB) protocol (Mahmood, 2004). The grind tissue was incubated in extraction buffer (50 mM Tris-HCl, 25 mM EDTA, 1 M NaCl, 1% CTAB, 1mM 1,10-phenathroline and 0.15% 2-mercaptoethanol) at 60-65^{o}C for 1 hr; then added equal volume of chloroform:isoamyl alcohol (24:1). After centrifugation at 12,500 rpm, the supernatant was removed to new tube and DNA was precipitated by adding the equal volume of cold isopropanol. DNA was died at room temperature and resuspended by TE buffer (10 mM Tris-HCL, 0.1 mM EDTA, pH 8.0) plus 20 ng RNase and incubated at 37 ^{o}C overnight. Chloroform isoamyl alcohol (24:1) was added in equal volume and the supernatant was transferred to new tube after centrifugation. Two times volume of cold absolute ethanol and 5µl of 8M ammonium acetate were added for DNA precipitation. DNA pellet was dried at room temperature and then, resuspened by 200 µl TE buffer. DNA concentration was quantified by spectrophotometer (TKO 100 Fluorometer, Hoefer Scientific Instruments, San Francisco, Calif).

Simple Sequence Repeats Analysis

Ninety SSR primers sequence (GWMs, BARC, and WMC) that were obtained from Grain Gene: a database for Triticeae and Avene website (http://wheat. pw.usda.gov/cgi-bin/graingenes/browse.cgi?class=marker) representing at least one SSR locus from each chromosome were screened and SSR marker assays were conducted following the procedure of Kuleung et al. (2004) with 25 µl total/reaction consisting of 75 ng genomic DNA, 100 ng SSR primers, 125 µM dNTP, 50 mM KCl and 10 mM Tris-HCL, 2mM $MgCl_2$, and 1 unit *Taq* polymerase. The amplification step was (i) 1 cycle at 94°C for 3 min, (ii) 30 cycles containing 94°C for 1 min, annealing temperature (determined for each primer pair) for 1 min plus 72°C for 1 min, (iii) 1 cycle of final extension at 72°C for 5 min. Amplification products were detected using 12% non-denatured polyacrylamide gel (37:1 acrylamide:bis-acrylamide) electrophoresis and the gels were stained in 1 mg/ml ethidium bromide for 10 min, destained in deionized water for 15 min; then, photographed using the Gel Doc2000 (Bio-Rad, Hercules, Calif.).

Data Analysis

Two genetic distance and clustering methods were used in this study to determine how the U.S. and Turkish lines were related. The band scoring was coded as “1” and “0”, where “1” indicated the presence of an allele and “0” when absent. Polymorphism information content (PIC) values were obtained using the formula developed by Anderson et al. (1993) which assumed homologous alleles from inbred wheat cultivars.

$$PIC = 1 - \Sigma P_{ij}^2$$

where P_{ij} is the frequency of j^{th} allele of i^{th} locus, summed across all the alleles for the locus over all lines. A *PIC* value > 0.5 is considered as being highly informative marker while 0.5 > *PIC* > 0.25 is an informative marker, and *PIC* is 0.25 a slightly informative marker (Botstein et al., 1980),

The genetic diversity was estimated by similarity index calculation from band sharing data of each pair of DNA fingerprints. Genetic similarity (*GS*) between cultivars *i* and *j* was calculated using all loci of SSR markers according to the formula for estimating coefficient of similarity known as Dice's coefficient or Nei and Li (1979) coefficient (Weising et al., 2005) based on shared allele frequency:

$$S = 2n_{ab}/(n_a+n_b),$$

where *S* is the similarity coefficient, n_{ab}, is the number of bands common to A and B cultivars, n_a and n_b are number of bands in A and B cultivar, respectively. The genetic similarity indices were used to compare the similarity of cultivars. A similarity matrix was used to construct a similarity dendogram by cluster analysis using the UPGMA algorism on NTSYS-pc, version 2.0 program (Rohlf, 2000). Another dendrogram was developed using Neighbor Joining method to determine how wheat cultivars from two gene pools are related. The genetic distances were calculated based on Nei's (1972) standard genetic distance:

$$Ds = -ln(Jxy/\sqrt{JxJy})$$

where $Jx = \Sigma\Sigma\ X_{ij}^2/r$, $Jy = \Sigma\Sigma\ Y_{ij}^2/r$, and $Jxy = \Sigma\Sigma\ X_{ij}Y_{ij}/r$ with X_{ij} and Y_{ij} being the frequencies of allele *i* at *j* locus of populations X and Y, respectively (Takezaki and Nei, 1996). Population genetics software, version 1.2.30 was used for genetic distance calculation (http://bioinformatics.org/~tryphon/populations/) and dendogram construction from the POPULATIONS program used the TreeView (Win32) program version 1.6.6 (http://taxonomy.zoology.gla.ac.uk/rod /treeview.html; Roderic D. M. Page, 2000). Dice similarity and Nei standard distance coefficients of each pairwise were correlated using PROC CORR (SAS, 2002)

RESULTS AND DISCUSSION

The genetic diversity of Turkish and U.S. Great Plains wheat cultivars were screened using 90 SSR markers. Fifty five SSR primers (61%) produced 159 polymorphic alleles with PIC values ranging from 0.022 to 0.917. The PIC value mean across 45 cultivars was 0.503 indicating that the markers were highly informative (PIC > 0.5; Botstein et al., 1980). In previous studies, PIC values of wheat reported by Powell et al. (1996) ranged from 0.29-0.79 and an average PIC value of 0.51 from 49 SSR primer pairs isolated from hexaploid wheat genome (Bryan et al., 1997). The genetic differentiation of 60 wheat cultivars selected for adaptation and end-use from Hungary, Austria, and German using 42 microsatellite showed an average PIC value of 0.57 (Stachel et al., 2000).

For each pairwise similarity estimation, Dice similarity and Nei standard distance coefficients were used for the dendrogram construction based on microsatellite data because the Nei standard distance was appropriate to estimate the branch length (Takezaki and Nei, 1996). In addition, Balestre et al. (2008) compared similarity and dissimilarity coefficients using SSR markers data in maize (*Zea mays* L.) and found that the coefficient with the smallest stress value was Dice similarity coefficients. The Dice similarity coefficients ranged from 0.3478 to 0.8489 where ‘Millennium’ and ‘NE06143’ (a line with Millennium as a parent) had the highest similarity value following by ‘Aytin-98’ and ‘Gerek-79’ (0.8421). The Nei standard distance coefficient ranged from 0.142-0.674. Similar to the Dice similarity coefficient, the smallest Nei standard distance coefficient from both pairwise comparisons were Millennium and NE06143, and Aytin-98 and Gerek-79 (both having a distance coefficient value of 0.142) indicating again the close relationship within each of these pairs of lines. The Nei standard distance coefficient of each pairwise agreed with Dice similarity coefficient because these two similarities/distances have high correlation ($r = -0.94^{**}$).

Cluster analysis using the UPGMA method based on Dice coefficients with a threshold value of 0.608 clustered forty-five wheat cultivars into five groups which generally agreed with pedigree information (Figure 1). Group I consisted of both Turkish and Great Plains wheat cultivars and was divided into two subgroups. Subgroup IA consisted of six Turkish wheat cultivars (‘Karasu-90’, ‘Yildirim’, ‘Alparslan’, ‘Sonmez-2001’, ‘Harmankaya’, and ‘Alpu-2001’, and Bezostaya-1). Most cultivars in this group had Bezostaya-1 as common ancestor. Bezostaya-1 was an ancestor of Sonmez-2001 while Yildirim and Alpu-2001 had Veery as parent and Veery had Bezostaya-1 as ancestor. A parent of Harmankaya was Lovrin-32 which was also derived from Bezostaya-1. The subgroup IB was the group that included the Turkish cultivar ‘Lancer’ and seven Great Plains wheat cultivars including three historic wheat cultivars (Turkey, Kharkof, and Cheyenne), four closely related Nebraska cultivars (‘Buckskin’, ‘Centurk-78’, ‘Centura’, and ‘Pronghorn’). Centura had Centurk-78 as a parent, and Centura was a parent of Pronghorn. Furthermore, the name Lancer was used for at least three wheat cultivars that were developed from breeding programs in U.S.A. (Nebraska), Turkey, and Canada. In this study, Lancer was distinct from the Nebraska developed Lancer and was sent to us from Turkey. We determined that there were differences among Lancer cultivars from Turkey, U.S., and Canada by identifying different gliadin protein patterns among these cultivars using high-performance capillary electrophoresis (Lookhart and

Bean 1995a, 1995b) (data not shown). Gliadin patterns are commonly used to identify different wheat cultivars except when the cultivars are closely related (Bietz et al., 1984).

Most modern Great Plains wheat cultivars were clustered into Group II which had three subgroups. Subgroup IIA included 'Dogu-88' (Turkish wheat) and 'Colt' (Great Plains wheat). Subgroup IIB containing eight Great Plains wheat cultivars ('Scout-66', 'Sage', 'Siouxland', 'Karl-92', 'Alliance', 'Bennett', and 'Nekota'). Most cultivars in this group agreed with their pedigree relationships. Scout 66 was selected from Scout, which, in turn, was a parent of Sage. Sage and Siouxland have Cheyenne as their common ancestor. Scout was also a parent of Bennett which was a parent of Nekota. Alliance and Karl-92 were clustered in this group and both have Kaw as a common ancestor. Subgroup IIC contained mainly modern Nebraska wheat cultivars released between 1986 and 2006 and were grouped based upon Brule as common ancestor. 'Redland', 'Arapahoe', 'Niobrara', Millennium, and NE06143 were in this cluster. Redland was a selection from Brule. Brule was a parent of Arapahoe and Niobrara. Arapahoe was a parent of Millennium and a sib line of Millennium was a parent of NE01643.

Three Turkish wheat varieties (Gerek-79, Aytin-98, and 'Kirgiz-95') were clustered in Group III. Gerek-79 was a parent of Aytin-98. 'Palandoken-97', 'Altay-2000', 'Kirac-66', and 'Suzen-97' were clustered in Group IV due to Norin-10 (the important source of semi-dwarfing genes) and Brevor as their co-ancestors. Kirac-66 was a parent of Suzen-97. In addition, two Great Plains wheat cultivars (Wichita and 'TAM-107') were surprisingly grouped into Group IV which illustrated that an ancestal Great Plains wheat (Wichita) was closely related to Turkish wheat cultivars as well as to a modern Great Plains cultivar. We were surprised at TAM-107 being grouped in this cluster. It is possible that TAM107 was clustered into this group due to Wichita and Palandoken-97. TAM 107 had Amigo that was a 1AL/1RS wheat-rye translocation line and derived from Wichita, as parent. Additionally, one of Palandoken-97 parent was Mexipak derived from Gabo (1D/1R translocation).

The last group (Group V) was a Turkish group consisting of 'Nenehatun', 'Sultan', 'Atay-85', and 'Yildiz-98'. Sultan and Atay-85 do not have a known common ancestor. From UPGMA dendrogram at 0.608 threshold level, 'Daphan', 'Cetinel', and Warrior which is an important line as the parent of Siouxland, Centura, and ancestor of several wheat cultivars were not clustered with any groups, indicating little relationship with the other 42 lines.

Based on the high correlation between Dice similarity and Nei standard distance estimate, there were little differences of each pairwise similarity for both coefficient estimations. In this study, wheat cultivars were derived from intensive selection in the breeding programs to improve agronomic and end-use quality performance. The DNA sequence variation as SSR alleles can be used to detect wheat genome difference among 45 wheat cultivars which were from different rate of selection. The UPGMA is the simplest clustering method and the NJ is based on minimum evolution rate assumption (Nei, 1991; Higgs and Attwood, 2005). Both UPGMA and Neighbor-joining (NJ) methods were used in this study for clustering to gain insight on how wheat cultivars from two counties related after intensive selection for favorable traits. Thus, to evaluate the sensitivity of the clustering results to clustering method, (NJ) clustering method also was used to construct a dendrogram following Kim (1993) advice that more than one method for dendrogram construction should be used to evaluate the robustness of the results.

From NJ clustering, the forty-five wheat cultivars were clustered into five groups which were similar to the results of UPGMA clustering (Figure 2). Group I from NJ cluster contained both Great Plains wheat and Turkish wheat cultivars. Turkish wheat cultivars in Group I were also clustered based on Bezostaya-1 similar to UPGMA clustering. Subgroup IA included four Turkish wheat cultivars (Alpaslan, Sonmez-2001, Karasu-90, and Yildirim) from the UPGMA small group plus they clustered with Dogu-88. Dogu-88 derived from Bezostaya-1 and wheat from Oklahoma (Danne) and Colorado (CO-725052), was clustered within the Turkish wheat group that was different from UPGMA clustering because it was grouped closer to the Great Plains wheat cultivars by UPGMA. The Group IB still contained ancestral Great Plains wheat cultivars similar to the UPGMA cluster except Warrior was clustered in this group as was Siouxland. The clustering of Warrior and Siouxland demonstrated the close pedigree relationship between Siouxland and Warrior (its parent). Finally, Subgroup IIB included Bezostaya-1 and its Turkish derivatives, Harmankaya and Alpu-2001.

Similar to UPGMA clustering, a small group (Group II; Buckskin, Centurk-78, Centura, and Pronghorn) which possibly could be considered part of Group I was separated from older Great Plains wheat cultivars by NJ clustering. However, this small NJ cluster highlights both the similarity and distinctness of these lines. In the large Group I UPGMA cluster, these four modern cultivars were more closely related to predominantly historic Great Plains and modern Turkish wheat cultivars. Our result was similar to Fufa et al. (2005) who used SSR markers to evaluate genetic diversity in predominantly upper Great Plains cultivars, and these four cultivars were clustered into same group and were related to Turkey wheat.

Group III consisted of Scout-66, Sage, Colt, and TAM 107 and was based on Scout as a parent, but the difference was that Lancer clustered with this group with the NJ-resulting dendrogram but not with the UPGMA. Lancer was clustered in the predominantly Great Plains group by both clustering methods because it related to U.S. wheat cultivars by its ancestors; Bezostaya-1, Norin-10, and Brevor. TAM 107 was closely related with Sage, Scout 66, Colt, and Wichita by the large Dice similarity and small Nei standard distance. Although both UPGMA and NJ clustering methods were distance or similarity coefficient based clustering, both methods used different criteria for cluster analysis. Cluster analysis using UPGMA method was started by the smallest similarity coefficient and then, all cultivars were clustered by average similarity. The NJ method was initiated by calculating the branch length using distance coefficient values and then, the dendrogram was constructed based on minimum of branch length (Saitou and Nei, 1987; Sneath and Sokal, 1973).

Many modern Great Plains wheat cultivars were clustered in group IV. Six modern Great Plains wheat cultivars including Karl-92, Alliance, Niobrara, Redland, Arapahoe, Millennium, and NE01643 (subgroup IV-A) were clustered with five additional wheat cultivars, Gerek-79, Aytin-98, Kirgiz-95, Nekota, and Bennett, as subgroup IV-B. Gerek-79, Aytin-98, and Kirgiz-95 were clustered into a group and agreed with UPGMA clustering. Although Kirgiz-95 was not related to both cultivars by pedigree information, our results were similar to Altinas et al. (2008) where Kirgiz-95 was closely related to Gerek-79. NJ clustering revealed that these Turkish wheat cultivars were related to modern Great Plains wheat cultivars, possibly because Newthatch was the ancestor of Gerek-79 and Bennett. In addition, Gerek-79 was a cultivar developed after 1970 for colder regions of Turkey. During its development, the National Wheat Project in Turkey introduced many new germplasm lines for the Turkish breeding programs (many were from the U.S.). Gerek-79 became a popular cultivar in colder areas of Turkey (Akar et al., 2007) which would be similar climatically to Nebraska. Three Turkish wheat cultivars based on Gerek-79 were clustered in the group with Bennett and Nekota. The exchange of germplasm for incorporating desirable alleles for adaptation of the two countries appears to have led to some modern winter wheat cultivars from Turkey being genetically similar to modern Great Plains wheat cultivars. The result is similar to the relationship between Canadian and U.S. bread wheat because of germplasm exchange (Trethowan et al., 2006).

Turkey wheat was the ancestor of many well known wheat cultivars including ‘Scout’, ‘Gaines’, Bezostaya-1, ‘8156 CR’, ‘Norin-10’ and ‘Centurk’ which were widely used as parental germplasm for breeding programs in the Great Plains and Bezostaya-1 was introduced to wheat breeding program in Turkey (Schmidt, 1974; Akar et al., 2007). Neighbor-joining clustered ten Turkish wheat cultivars in Group V with Wichita. Wichita was closely related with Turkish wheat cultivars that had Great Plains wheat cultivars as their common ancestors. Palandoken-97, Altay-200, and Suzen-97 had Norin-10 and Brevor in their pedigree. Kirac-66 was clustered in this group because it was a Suzen-97 parent.

An important goal in this research was to determine if the modern the Turkish and Great Plains wheat breeding programs diverged since the introduction of Turkey to the

Great Plains. Our results suggest that Turkish wheat cultivars have not diverged greatly from the older Great Plains wheat cultivars based upon the clustering with both UPGMA and NJ dendrograms. Bezostaya-1 and four of five historic Great Plains wheat cultivars (Turkey, Kharkof, Cheyenne, and Warrior) were clustered with modern Turkish wheat cultivars released between 1990 and 2002. Moreover, an older Great Plains wheat cultivar (Wichita) was grouped with another Turkish wheat group including Turkish wheat cultivars released between 1917 and 2002. The result was similar to Altintas et al. (2008) who studied genetic diversity among Turkish wheat cultivars and found that modern Turkish wheat cultivars were clustered with bread wheat landraces. In contrast, Great Plains wheat cultivars displayed greater genetic diversity. There were only four modern Great Plain wheat cultivars that were clustered with the historic Great Plain wheat cultivars. Before 1950, breeders in U.S. selected HRWW based on Turkey wheat type (Cox et al., 1986). Nevertheless, after 1970, genetic diversity of hard red winter wheat in U.S. was increased due to germplasm introduction (Prasad et al., 2009). Based on the UPGMA clustering, the group of Centurk-78 and its derivatives were clustered with the Turkish wheat but they formed a small group and were separated more from the historic wheat according to the NJ clustering . Other modern Great Plains wheat cultivars in Group III and Group IV clustered by the NJ method were obviously separated from all older Great Plains wheat cultivars and it was similar to the UPGMA cluster. Peterson and Pfeiffer (1989) indicated that the Great Plains and Ankara Turkey were similar in term of winter stress which may have led to similar winter selection for adaptation. Thus, while there were predominantly Great Plains and Turkish clusters or subclusters, there were lines from the other region in many of the larger clusters indicating that 130 years after the introduction of Turkey wheat to the Great Plains, a relationship still remains in the germplasm adapted to both regions. Perhaps this relationship is best seen in clusters I and II (Fig. 1) where some of the Turkish wheat cultivars are more closely related to Great Plains cultivars than to other Turkish cultivars and vice versa.

In conclusion, this genetic diversity study based on molecular markers, indicated that forty-five wheat cultivars from Turkey and the Great Plains were clustered into five groups largely according to their country of origin and pedigree. However this study suggested that Turkish and U.S. Great Plains wheat cultivars continue to be related, because wheat cultivars from the two regions were clustered together in many groups. Both older and some modern Turkish wheat cultivars were clustered with ancestral Great Plains wheat cultivars. A few modern Turkish wheat cultivars were clustered with modern Great Plains wheat groups. This result may due to germplasm exchange and selection for similar climatic environments (e.g. selecting for similarly important adaptation genes). Modern Great Plains wheat cultivars have diverged from Turkey wheat and other historic Great Plains wheat cultivars. This divergence most likely was caused by breeding for adaptation and cultivar improvement after the introduction of Turkey wheat and other related ancestral cultivars to the Great Plain breeding program. Also it may be due to the use of different parents introduced to the two gene pools. For Great Plains wheat improvement, it is possible to use those Turkish wheat cultivars that are related to Great Plains wheat cultivars as parents to possibly add new alleles without adding too much new genetic diversity, or the genetic diversity that is most closely related to previous/historical parents.

REFERENCES

Acquaah, G. 2007. Principles of plant genetics and breeding. Blackwell Publishing MA, USA. 569 p.

Akar,T., S. Yazar, E. Dönmez, M. Avcı, and F. Düşünceli. 2007. Current status of national winter wheat breeding in Turkey. J. Agric. Res. 45:1-9.

Akkaya, M.S., and E.B. Buyukunal-Bal. 2004. Assessment of genetic variation of bread wheat varieties using microsatellite markers. Euphytica. 135:179-185.

Ali, M.L., J. F. Rajewski, P. S. Baenziger, K. S. Gill, K. M. Eskridge, and I. Dweikat. 2008. Assessment of genetic diversity and relationship among a collection of US sweet sorghum germplasm by SSR markers. Mol Breeding. 21:497-509.

Altintas, S., F. Toklu, S. Kafkas, B. Kilian, A. Brandolini, and H. Ozkan. 2008. Estimating Genetic Diversity in Durum and Bread Wheat Cultivars from Turkey using AFLP and SAMPL Markers. Plant breeding. 127:9-14.

Anderson. J.A., G.A. Churchill, J.E. Autrique, S.D. Tanksley, and M.E. Sorrells. 1993. Optimization parental selection for genetic linkage maps. Genome 36:181-186.

Balestre, M., R.G. Von Pinho, J.C. Souza, and J.L. Lima. 2008. Comparision of maize similarity and dissimilarity genetic coefficients based on microsatellite markers. Genetic and Molecular Research. 7(3):695-705.

Bietz, J.A., T. Burnouf, L.A. Cobb, and J.S. Wall. 1984. Wheat varietal identification and genetic analysis by reverse-phase high-performance liquid chromatography. Cereal Chemistry. 61(2):129-135.

Botstein, D., R.L. White, M. Skolnick, and R.W. Davis. 1980. Construction of a Genetic Linkage Map in Man Using Restriction Fragment Length Polymorphisms. Am. J. Hum. Genet. 32:314-331.

Brown S.M., A.K. Szewc-McFadden, and S. Kresovich. 1996. Development and application of simple sequence repeat (SSR) loci for plant genome analysis, p. 147-159. *In* P.P. Jauhar (ed.) Methods of genome analysis in plant. U.S. Department of Agriculture, Agricultural Research Service, Northern Crop Science Laboratory State University Station Fargo, North Dakota.

Brown, W. 1983. Genetic Diversity and Genetic Vulnerability--An Appraisal. Economic Botany. 37(1):4-12.

Bryan, G.J., A. J. Collins, P. Stephenson, A. Orry, J. B. Smith, and M. D. Gale. 1997. Isolation and characterisation of microsatellites from hexaploid bread wheat. Theor Appl Genet. 94:557-563.

Casa, A.M., S.E. Mitchell, M.T. Hamblin, H. Sun, J.E. Bowers, A.H. Paterson, C.F. Aquadro, and S. Kresovich. 2005. Diversity and selection in sorghum: simultaneous analyses using simple sequence repeats. Ther Appl Genet. 111:23-30.

Chao, S., W. Zhang, J. Dubcovsky, and M. Sorrells. 2007**.** Evaluation of Genetic Diversity and Genome-wide Linkage Disequilibrium among U.S. Wheat (*Triticum aestivum* L.) Germplasm Representing Different Market Classes. Crop Sci. 47:1018-1030.

Cox T.S. and J. P. Shroyer. 1984. Pedigrees of Hard Red Winter Wheat Varieties. Cooperative Extension Service. Kansas State University. Manhattan. Kansas.

Cox, T.S., J.P. Murphy and M. Rodgers. 1986. Changes in genetic diversity in the red winter wheat regions of the United States. Proc. Natl. Acad. Sci. USA. 83:5583-5586.

Dice, L.R. 1945. Measures of the amount of ecologic association between species. Ecology. 26:297-302.

Dograr, N., S. Akin-Yalin, and M.S. Akkaya. 2000. Discriminating durum wheat cultivars using highly polymorphic simple sequence repeat DNA markers. Plant breeding. 119:360-362.

Eivazi A.R., M.R. Naghavi, M. Hajheidari, S.M. Pirseyedi, M.R. Ghaffari, S.A. Mohammadi, I. Majidi, G.H. Salekdeh, and M. Mardi. 2008. Assessing wheat (*Triticum aestivum* L.) genetic diversity using quality traits, amplified fragment length polymorphisms, simple sequence repeats and proteome analysis. Ann Appl Biol. 152:81-91.

Fu, Y.B., and D.J., Somers. 2009. Genome-wide reduction of genetic diversity in wheat breeding. Crop Science. 49:161-168.

Fufa, H,, P.S. Baenziger, B.S. Beecher, I. Dweikat, R.A. Graybosch, and K.M. Eskridge. 2005. Comparison of phenotypic and molecular marker-based classifications of hard red winter wheat cultivars. Euphytica. 145:133–146.

Higgs P.G., and T.K. Attwood. 2005. Bioinformatics and Molecular Evolution. Blackwell Science Ltd, MA USA. p 365

Johnson, R.A. and D.W. Wichern. 2007. Applied Multivariate Statistical Analysis. Pearson Education Inc. NJ. 773 p.

Kim, J. 1993. Improving the Accuracy of Phylogenetic Estimation by Combining Different Methods. Systematic Biology. 42 (3):331-340.

Kim, J., F.J. Rohlf, and R.R. Sokal. 1993. The accuracy of phylogenetic estimation using the Neighbor-Joining method. Evolution. 47(2):471-486.

Kuleung C., P.S. Baenzinger, and I. Dweikat. 2004. Transferability of SSR markers among wheat, rye, and triticale. Theor Appl Genet. 108:1147-1150.

Liu X.Z., and H. Y. Zhang. 2008. Advance of molecular marker application in the tobacco research. African Journal of Biotechnology. 7(25):4827-4831.

Lookhart, G. and Bean S. 1995a. A fast method for wheat cultivar differentiation using capillary zone electrophoresis. Creal Chem. 72:42-47.

Lookhart, G. and Bean S. 1995b. Separation and characterization of wheat protein fractions by high-performance capillary electrophoresis. Cereal Chem. 72:527-532.

Maccaferri, M., S. Stefanelli, F. Rotondo, R. Tuberosa, and M.C. Sanguineti. 2007. Relationships among durum wheat accessions I. Comparative analysis of SSR, AFLP, and phenotypic data. Genome. 50:373-384.

Mahmood, A. P.S. Baenziger, H. Budak, K.S. Gill and I. Dweikat. 2004. The use of microsatellite markers for the detection of genetic similarity among winter bread wheat lines for chromosome 3A. Theor Appl Genet. 109:1494-1503.

Manifesto, M.M., A. R. Schlatter, H. E. Hopp, E. Y. Suarez, and J. Dubcovsky. 2001. Quantitative evaluation of genetic diversity in wheat germplasm using molecular markers. Crop Sci. 41:682-690.

Mohammadi, S.A. and B.M. Prasanna. 2003. Analysis of genetic diversity in crop plant-salient statistical tools and considerations. Crop Science. 43:1235-1248.

Mohammadi, S.A., M. Khodarahmi, S. Jamalirad, and M.R. Jalal Kamali. 2009. Genetic diversity in a collection of old and new bread wheat cultivars from Iran as revealed by simple sequence repeat-based analysis. Annals of Applied Biology. 154 (1):67-76.

Nei, M. 1972. Genetic distance between populations. Am. Nat. 106:283-292.

Nei, M. 1991. Relative efficiencies of different tree-making methods for molecular data. p. 90-128. M.M. Miyamoto, and J. Cracraft (ed.) Phylogenetic analysis of DNA sequences. Oxford University Press, Inc.

Nei, M., F. Tajima, and Y. Tateno.1983. Accuracy of estimated phylogenetic trees from molecular d.ata. J Mol Evol. 19:153-170

Nei, M., and W.H. Li. 1979. Mathematical models for studying genetic variation in terms of restriction endonucleases. Proc. Natl. Acad. Sci. USA 76:5269-5273.

Ni, J., P.M. Colowit, and D.J. Mackill. 2002. Evaluation of genetic diversity in rice subspecies using microsatellite markers. Crop Science. 42:601-607.

Paulsen G.M., and J.P. Shroyer. 2008. The early history of wheat improvement in Great Plains. Agronomy Journal. 100:S70-S78.

Powell, W., G.C. Machray, and J. Provan. 1996. Polymorphism revealed by simple sequence repeats. Trend in plant science. 1 (7):215-222.

Peterson, C.J., and W. H. Pfeiffer. 1989. International winter wheat evaluation: relationships among test sites based on cultivar performance**.** Crop Sci. 29:276-282.

Prasad, B., M.A. Babar, X.Y. Xu, G.H. Bai, and A.R. Klatt. 2009. Genetic diversity in U.S. hard red winter wheat cultivars as revealed by microsatellite markers. Crop & Pasture Science. 60:16-24.

Quisenberry K.S. 1974. Let's talk Turkey. Transactions of the Kansas Academy of science. 77:135-144.

Quisenberry, K.S., and L.P. Reitz. 1974. Turkey wheat: the cornerstone of an empire. Agricultural History. 48:98-110.

Rao, R.V., and T. Hodgkin. 2002. Genetic diversity and conservation and utilization of plant genetic resources. Plant Cell, Tissue and Organ Culture. 68:1-19.

Reif, J.C., A. E. Melchinger, and M. Frisch. 2005. Genetical and Mathematical Properties of Similarity and Dissimilarity Coefficients Applied in Plant Breeding and Seed Bank Management. Crop Sci. 45:1-7.

Reif, J.C., P. Zhang, S. Dreisigacker, M. L. Warburton, M. van Ginkel, D. Hoisington, M. Bohn, and A. E. Melchinger. 2005. Wheat genetic diversity trends during domestication and breeding. Theor Appl Genet. 110:859-864.

Rohlf, F.J., 2000. NTSYS-pc Numerical Taxonomy and Multivariate Analysis System, v. 2.202k. Exeter Software, Setauket, New York.

Ross, J.G. 1969. With interest…Repaying a debt to Turkey. Farm & home research. Vol XX. No 2. South Dakota.

Roussel, V., J. Koenig, M. Beckert, and F. Balfourier. 2004. Molecular diversity in French bread wheat accessions related to temporal trends and breeding programmes. Theor Appl Genet. 108:920-930.

Saitou, N., and M. Nei. 1987. The Neighbor-joining method: A new method for reconstructing phylogenetic trees. Mol. Biol. Evol. 4(4):406-425.

Salem, K.F.M., A.M. El-Zanaty, and R.M. Esmail. 2008. Assessing wheat (Triticum aestivum L.) genetic diversity using morphological characters and microsatellite markers. World Journal of Agricultural Science. 4(5):538-544.

SAS Institute Inc. 2002. SAS/STAT User's Guide, Version 9.1. SAS Institute, Inc, Cary, NC, USA.

Schmidt, J.W. 1974. The role of Turkey wheat germplasm in wheat improvement. Transactions of the Kansas Academy of Science. 77(3):159-172.

Sneath, P.H.A., and R.R. Sokal. 1973. Numerical taxonomy; the principles and practice of numerical classification. W.H. Freeman, San Fancisco. 573 p.

Stachel M., T. Lelley, H. Grausgrube, and J. Vollmann. 2000. Application of micro-satellites in wheat (Triticum aestivumL.) for studying genetic differentiation caused by selection for adaptation and use. Theor Appl Genet. 100:242-248.

Takezaki, N., and M. Nei. 1996. Genetic distances and reconstruction of phylogenetic tree from microsatellite DNA. Genetics. 144:389-399.

Tanksley, S.D. 1983. Molecular marker in plant breeding. Plant molecular biology reporter. 1(1):3-8.

Trethowan, R.M., A. Morgunov, Z. He, R. De Pauw, J. Crossa, M. Warburton, A. Baytasov, C. Zhang, M. Mergoum, and G. Alvarado. 2006. The global adaptation of bread wheat at high latitudes. Euphytica. 152:303-316.

Weising, K., H. Nybom, K. Wolff, and G. Kahl. 2005. DNA Fingerprinting in Plants (Principles, Methods, and Applications). CRC press. New York, USA. 444 p.

Zhang, P., S. Dreisigacker, A.E. Melchinger, J.C. Reif, A. Mujeeb Kazi, M. Van Ginkel, D. Hoisington, and M.L. Warburton. 2005. Quantifying novel sequence variation and selective advantage in synthetic hexaploid wheats and their backcross-derived lines using SSR markers. Molecular Breeding 15:1-10.

Table 1 Pedigree, source and year of release of 22 wheat cultivars from Turkey and 23 wheat cultivars from the U.S. Great Plains.

No	Cutivar	Year	Source	Pedigree
1	Karasu-90	1990	Turkey	Lom-11/BL-2973//Mironovskaya-264;Ganso/Anhinga//Pelicano/3/Cocorit-71
2	Daphan	2002	Turkey	Jupateco-73/4/Collafen/3/II-14.53/Odin,Swe//Vogel-1(CI-14431)/WA-00477
3	Alpaslan	2001	Turkey	TX-69-A-509-2//Blueboy-II(BBY2)/Fox
4	Palandoken 97	1997	Turkey	Avrora//Yaktana-54*2/Norin-10-Brevor/3/II-8260/5/Ponca(PNC)/CM//NB-6977/3/CC/Linia//Bluebird/4/Mexipak/IKR/Funo
5	Nenehatun	2002	Turkey	Nord-Desprez(ND)/P-101/Blueboy[2899][2993];
6	Lancer	1982	Turkey	Bezostaya-1/5/II-50-72/3/Yaqui-54//Norin-10/Brevor/4/Nord-Desprez/IGA-Bordeaux;Bezostaya-1/4/II-50.72//Yaqui-54/N10B/3/Marne-Desprez(MD)/IGA-Bordeux
7	Dogu-88	1988	Turkey	Bezostaya-1/Danne//CO-725052
8	Yildirim	2002	Turkey	ID-800994.W/Veery
9	Altay 2000	2000	Turkey	ES14//YKT/Blueboy2, YE5470-0E-0E-0E-30E-0E
10	Sultan	1917	Turkey	Kings-white/Caliph; Marshalls-3/Kings-White//Kings-White[1451];Steinwedel/Indian-B//Indian-D
11	Harmankaya	1999	Turkey	Fundulea -29/2*Lovrin-32
12	Alpu-2001	2001	Turkey	ID-800994.W/Veery
13	Kirgiz 95	1995	Turkey	Domanic*2/Avrora; Domanic/Avrora
14	Atay 85	1985	Turkey	Hyslop/Siete-Cerros-66
15	Aytin 98	1998	Turkey	Gerek-79//93-044/NO-57
16	Sonmez- 2001	2001	Turkey	Bez//Bez/TVR/3/Kremena/Lov29/4/Katya1 TE4732-0T-0YC-0YC-5YC-0YC
17	Gerek-79	1979	Turkey	Mentana/Mayo-48//4-11/3/Yayla-305
18	Kirac-66	1966	Turkey	Florence(FNA)/Yayla-305
19	Suzen-97	1997	Turkey	C-126-15/Collafen/3/Norin-10-Brevor/P-14//P-101/4/(KRC)Kirac-66
20	Bezostaya-1	1959	Russia	Lutescens-17/Skorospelka-2
21	Yildiz 98	1998	Turkey	Sel.55-1744/P-101//Maya-74/3/Musala/(PRM)Primo// Maya-74/(SIB)Alondra
22	Cetinel	2000	Turkey	Malcolm(MLC)/4/VPM-1/MOS95//Hill/3/(SPN)Stephens
23	Turkey	1874	Kansas	Selection from collection in U.S.A.
24	Kharkof	1905	Kansas	Selection from Kharkov introduced from Russia
25	Cheyenne	1933	Nebraska	Selection from Crimean, believe to be related to Turkey
26	Wichita	1944	Kansas	Early Blackhull/Tenmarq
27	Warrior	1960	Nebraska	Pawnee/Cheyenne
28	Scout 66	1967	Nebraska	Selection from Scout (Scout's pedigree Nebred//Hope/Turkey/3/Cheyenne/Ponca)

Table 1 (cont.)

No	Cultivar	Year	Source	pedigree
29	Sage	1973	Kansas	Agent/4*Scout
30	Buckskin	1973	Nebraska	Scout/3/Quivira/Tenmarq//Marquillo/Oro
31	Bennett	1978	Nebraska	Scout/3/Quivira/Tenmarq//Marquillo/Oro/4/Homestead
32	Centurk 78	1978	Nebraska	Selection from Centurk (Centurk from Kenya 58//Newthatch /3/Hope/2*Turkey/4/Cheyenne/5/Parker
33	Centura	1983	Nebraska	Warrior*/Agent/NE68457/3/Centurk 78
34	Colt	1983	Nebraska	Agate sib (NE69441)//391-56-D8/Kaw (TX65A1503-1)
35	Siouxland	1984	Nebraska	(Warrior*5/Agent)*2/Kavkaz
36	TAM 107	1984	Texas	TAM 105*4/Amigo (TAM 105 from Short wheat/Scout
37	Redland	1986	Nebraska	Brule selection
38	Arapahoe	1988	Nebraska	Brule/3/Parker*4/Agent//Beloterkovskaja 198/Lancer
39	Karl 92	1992	Kasas	Karl selection (Karl from Plainsman V/3/Kaw/Atlas 50//Parker*5/Agent
40	Alliance	1993	Nebraska	Arkan/Colt//Chisholm sib
41	Nekota	1994	Nebraska	Bennett/TAM 107
42	Niobrara	1994	Nebraska	TAM 105*4/Amigo//Brule
43	Pronghorn	1996	Nebraska	Centura/Dawn//Colt sib
44	Millennium	2000	Nebraska	Arapahoe/Abilene/4/Colt/3/Warrior*5/Agent//Kavkaz
45	NE01643	2007	Nebraska	‘Millennium’ (PI 613099) sib/ND8974

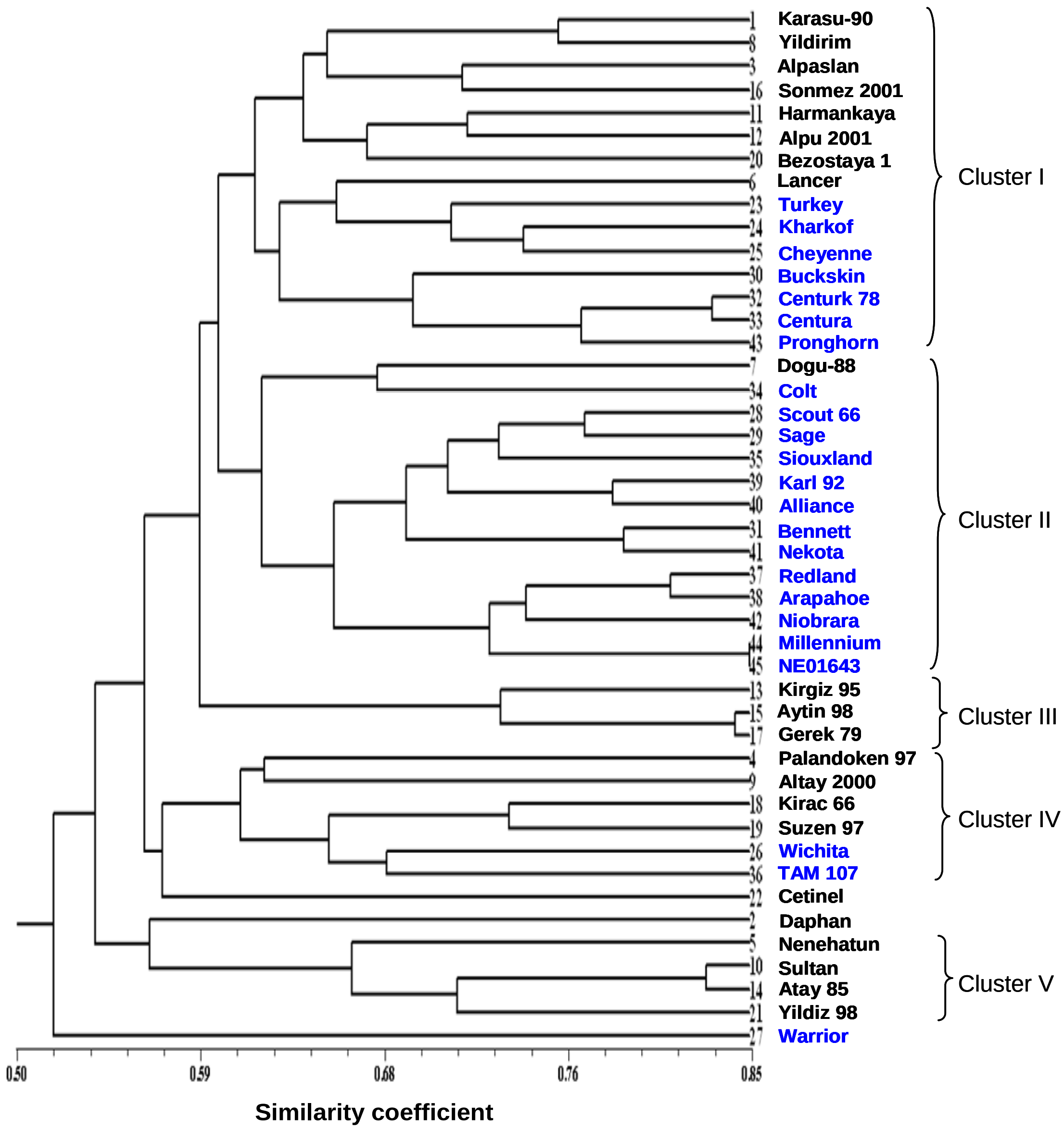


Figure 1 Dendrogram from UPGMA analysis based on Dice (Nei and Li 1979) similarity coefficient of 45 hard red winter wheat cultivars including Turkish wheat cultivars (No. 1-22) and Great Plains cultivars (No. 23-45) using 55 SSR markers.

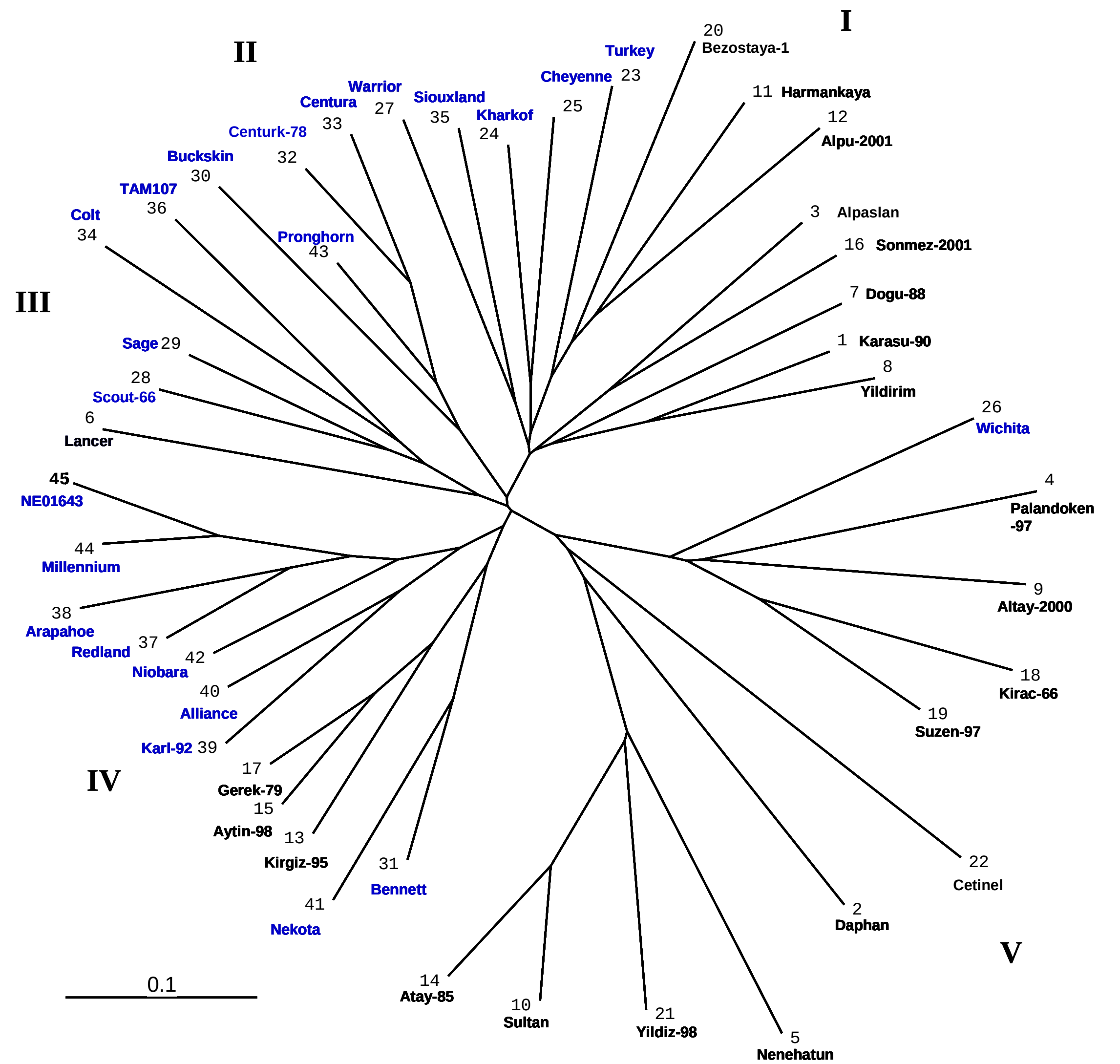


Figure 2 Dendrogram analysed by Neighbor Joining based on Nei (1972) standard distance of 45 hard red winter wheat cultivars including Turkish wheat cultivars (No. 1-22) and U.S. Great Plains wheat cultivars (No. 23-45) based on SSR data

APPENDICES

Appendix 1 Polymorphic information content

No	Primer Name	No of allele	PIC**
1	Xbarc1	1	0.249
2	Xbarc3	2	0.500
3	Xbarc4	4	0.694
4	Xbarc6	2	0.494
5	Xbarc11	1	0.170
6	Xbarc12	4	0.647
7	Xbarc14	4	0.344
8	Xbarc15	2	0.201
9	Xbarc17	4	0.540
10	Xbarc19	4	0.292
11	Xbarc20	3	0.509
12	Xbarc24	2	0.231
13	Xbarc26	1	0.917
14	Xbarc32	3	0.520
15	Xbarc44	2	0.133
16	Xbarc52	3	0.700
17	Xbarc56	2	0.458
18	Xbarc61	4	0.609
19	Xbarc67	2	0.488
20	Xbarc71	3	0.709
21	Xbarc84	3	0.558
22	Xbarc98	2	0.444
23	Xbarc108	4	0.602
24	Xbarc117	2	0.470
25	Xbarc123	2	0.086
26	Xbarc124	2	0.229
27	Xbarc125	1	0.857
28	Xbarc127	2	0.375
29	Xbarc134	2	0.761
30	Xbarc138	2	0.518
31	Xbarc145	2	0.022
32	Xbarc163	4	0.736
33	Xbarc175	2	0.124
34	Xbarc176	9	0.520
35	Xbarc183	1	0.129
36	Xbarc184	5	0.655
37	Xbarc195	1	0.494
38	Xbarc267	5	0.859
39	Xbarc321	5	0.736
40	Xbarc356	1	0.324
41	Xbarc1148	1	0.613
42	Xgwm5	1	0.802
43	Xgwm102	2	0.618
44	Xgwm155	6	0.519
45	Xgwm218	5	0.662
46	Xgwm291	3	0.914
47	Xgwm458	2	0.247
48	Xgwm539	5	0.891
49	Xgwm544	3	0.839
50	Xgwm566	6	0.647
51	Xgwm604	4	0.690
52	Xgwm674	2	0.180
53	WMC367	3	0.234
54	WMC553	2	0.487
55	WMC631	4	0.430
	Mean	3	0.503
	Total	159	

** PIC = Polymotphism information content

Appendix 2 Dice similarity coefficient

Cultivars	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
1 Karasu90	1.0000																						
2 Daphan	0.5873	1.0000																					
3 Alparslan	0.6260	0.4567	1.0000																				
4 Palandoken97	0.5397	0.5574	0.5354	1.0000																			
5 Nenehatun	0.5581	0.4640	0.5692	0.4800	1.0000																		
6 Lancer	0.5414	0.4806	0.5522	0.5116	0.4697	1.0000																	
7 Dogu88	0.6512	0.5760	0.6000	0.5600	0.5156	0.6212	1.0000																
8 Yildirim	0.7576	0.5469	0.6917	0.5625	0.5649	0.5481	0.6565	1.0000															
9 Altay2000	0.5984	0.5203	0.5469	0.6179	0.5556	0.4308	0.4921	0.5581	1.0000														
10 Sultan	0.6000	0.6032	0.4885	0.5238	0.6667	0.4662	0.4806	0.6212	0.6457	1.0000													
11 Harmankaya	0.5778	0.4885	0.6029	0.4885	0.5075	0.5942	0.5522	0.6569	0.5000	0.5185	1.0000												
12 Alpu	0.6815	0.4427	0.5882	0.5954	0.6119	0.5942	0.5672	0.7007	0.5909	0.6222	0.7143	1.0000											
13 Kirgiz95	0.5714	0.4348	0.5667	0.4696	0.4746	0.6066	0.5932	0.5289	0.5345	0.4034	0.4677	0.5161	1.0000										
14 Atay85	0.5781	0.5484	0.4186	0.5161	0.6299	0.5038	0.4724	0.5846	0.5760	0.8281	0.4962	0.5865	0.4615	1.0000									
15 Aytin98	0.6412	0.5354	0.6667	0.5197	0.6154	0.5672	0.5692	0.5414	0.5156	0.4733	0.5147	0.5882	0.7333	0.4651	1.0000								
16 Sonmez2001	0.6107	0.5039	0.7121	0.5197	0.5692	0.5672	0.6308	0.6617	0.6563	0.5191	0.6912	0.6618	0.6167	0.5426	0.5758	1.0000							
17 Gerek79	0.5606	0.5156	0.6767	0.5625	0.6718	0.5926	0.6107	0.5970	0.5271	0.4848	0.5985	0.5547	0.7273	0.4923	0.8421	0.6316	1.0000						
18 Kirac66	0.4154	0.5079	0.4885	0.6032	0.4651	0.6015	0.6047	0.4394	0.6299	0.4615	0.5333	0.5333	0.5378	0.5000	0.5802	0.5649	0.6061	1.0000					
19 Suzen	0.5000	0.5645	0.5581	0.6290	0.5197	0.5496	0.5512	0.5385	0.6560	0.5469	0.5865	0.5865	0.5470	0.5873	0.5581	0.5581	0.5846	0.7344	1.0000				
20 Bezostaya1	0.6154	0.5079	0.5954	0.5238	0.4806	0.5714	0.5736	0.5909	0.5669	0.4769	0.6519	0.6815	0.5378	0.4063	0.5954	0.6718	0.5606	0.6154	0.5000	1.0000			
21 Yildiz98	0.6043	0.6370	0.5571	0.5926	0.6812	0.4930	0.5072	0.6383	0.6471	0.7626	0.6250	0.6389	0.4063	0.6569	0.5857	0.5714	0.5816	0.6043	0.5839	0.6187	1.0000		
22 Cetinel	0.5532	0.5401	0.5352	0.4964	0.5143	0.5417	0.5286	0.5315	0.5507	0.5816	0.5205	0.4795	0.5077	0.5036	0.5634	0.4789	0.5874	0.6099	0.5899	0.5532	0.6133	1.0000	
23 Turkey	0.6815	0.5191	0.5588	0.4733	0.5224	0.6522	0.5970	0.5839	0.5455	0.5185	0.6143	0.6857	0.5806	0.5414	0.6765	0.6471	0.5985	0.5926	0.5714	0.6815	0.5417	0.6027	1.0000
24 Kharkof	0.6377	0.5672	0.6619	0.5075	0.5693	0.6950	0.7153	0.6286	0.4889	0.5072	0.6294	0.6294	0.5827	0.5588	0.6475	0.6475	0.6571	0.5797	0.6618	0.5507	0.5170	0.5638	0.6993
25 Cheyenne	0.6667	0.6260	0.6618	0.5344	0.5075	0.6087	0.6119	0.6423	0.5758	0.5630	0.6429	0.6286	0.5323	0.5564	0.6912	0.6176	0.6277	0.5481	0.6165	0.6222	0.6111	0.5479	0.7143
26 Wichita	0.5522	0.5538	0.5333	0.6462	0.4361	0.5985	0.5113	0.4853	0.5954	0.4776	0.5899	0.6187	0.5366	0.5000	0.5778	0.5481	0.5441	0.6716	0.6364	0.5970	0.5734	0.5241	0.6043
27 Warrior	0.5739	0.4505	0.5862	0.4144	0.3860	0.5763	0.6140	0.5470	0.4821	0.3478	0.5333	0.5000	0.5962	0.4248	0.5690	0.6207	0.5299	0.4696	0.4956	0.5913	0.3710	0.4603	0.6000
28 Scout66	0.6154	0.5612	0.5694	0.5036	0.4930	0.6849	0.6620	0.6207	0.5571	0.6154	0.6757	0.5811	0.5455	0.6099	0.5833	0.5833	0.6069	0.5874	0.5532	0.5734	0.6053	0.6234	0.6351
29 Sage	0.5926	0.5038	0.6618	0.5496	0.5224	0.6377	0.5970	0.6569	0.4848	0.5778	0.6000	0.5714	0.5806	0.5714	0.6029	0.6324	0.6569	0.5185	0.5564	0.5481	0.5833	0.5342	0.5714
30 Buckskin	0.6074	0.4733	0.6618	0.4733	0.4925	0.6522	0.5373	0.5985	0.4545	0.4741	0.5857	0.5857	0.5161	0.4211	0.5588	0.5147	0.5693	0.4741	0.5414	0.5333	0.5694	0.5890	0.5714
31 Bennett	0.6462	0.5238	0.6565	0.5238	0.5581	0.5414	0.6047	0.5455	0.4567	0.4769	0.5778	0.5481	0.6218	0.5000	0.6412	0.5802	0.6667	0.4462	0.4844	0.5077	0.5036	0.5106	0.5926
32 Centurk78	0.5926	0.5649	0.6029	0.5191	0.5672	0.5507	0.5821	0.5985	0.5455	0.4889	0.6714	0.6714	0.5484	0.4812	0.6324	0.6471	0.6277	0.5630	0.6165	0.5333	0.5972	0.5890	0.6286
33 Centura	0.6423	0.5714	0.6087	0.5414	0.4559	0.5857	0.6029	0.6475	0.5075	0.5109	0.6197	0.6620	0.4762	0.4444	0.5652	0.5507	0.5324	0.5255	0.5481	0.5401	0.5479	0.5811	0.6056
34 Colt	0.5758	0.5000	0.5564	0.4844	0.5191	0.5333	0.6718	0.5821	0.5116	0.5909	0.5401	0.5401	0.5289	0.5385	0.5263	0.5564	0.5522	0.5000	0.5385	0.4545	0.5248	0.5594	0.4818
35 Siouxland	0.6763	0.5185	0.6286	0.4889	0.4928	0.5493	0.6522	0.6525	0.5147	0.5899	0.6528	0.6528	0.5313	0.5839	0.6000	0.6286	0.5674	0.4748	0.5401	0.5612	0.5000	0.6000	0.6667
36 TAM107	0.5390	0.5109	0.5915	0.5693	0.5286	0.6528	0.5714	0.5874	0.5217	0.6241	0.6849	0.6301	0.5385	0.5899	0.5634	0.5634	0.6014	0.6241	0.6619	0.4823	0.6000	0.6447	0.5479
37 Redland	0.6222	0.5802	0.6176	0.6107	0.4478	0.5362	0.5970	0.5693	0.5455	0.5481	0.5857	0.5000	0.5000	0.5414	0.6029	0.5882	0.6131	0.5630	0.5414	0.5778	0.6250	0.6438	0.6000
38 Arapahoe	0.6087	0.5970	0.5755	0.6269	0.4672	0.5532	0.5255	0.5429	0.5630	0.5797	0.5734	0.5594	0.5512	0.5882	0.6043	0.5612	0.6286	0.5362	0.5441	0.5362	0.5850	0.5906	0.5594
39 Karl92	0.7194	0.5481	0.6143	0.5333	0.4928	0.5634	0.6667	0.6099	0.5735	0.5755	0.6250	0.5278	0.5938	0.5255	0.6571	0.6429	0.6667	0.5468	0.5401	0.6043	0.5541	0.6267	0.6111
40 Alliance	0.6187	0.5333	0.6714	0.5037	0.5507	0.6056	0.6667	0.6241	0.5735	0.5612	0.6250	0.5139	0.5938	0.5255	0.6143	0.6286	0.6525	0.5899	0.5693	0.6331	0.5811	0.6533	0.6111
41 Nekota	0.5915	0.5072	0.6154	0.4638	0.5957	0.6483	0.5957	0.5694	0.4748	0.5211	0.5986	0.5578	0.6412	0.5429	0.6573	0.5594	0.6944	0.5070	0.5143	0.4789	0.5563	0.6013	0.6122
42 Niobrara	0.6142	0.5691	0.6094	0.5691	0.5079	0.5692	0.6190	0.5891	0.5161	0.5512	0.5909	0.5303	0.5862	0.5760	0.6250	0.6094	0.6357	0.5669	0.5760	0.5984	0.6176	0.5652	0.5303
43 Pronghorn	0.6875	0.5484	0.6202	0.4677	0.5197	0.5649	0.6772	0.6615	0.5280	0.5156	0.6316	0.6015	0.5812	0.5397	0.5891	0.6357	0.6000	0.5156	0.5714	0.5469	0.5255	0.5612	0.5865
44 Millennium	0.6015	0.5891	0.5821	0.5891	0.4091	0.5147	0.6667	0.5926	0.5846	0.5113	0.5797	0.5797	0.5082	0.4733	0.5224	0.5522	0.5185	0.6165	0.6107	0.6015	0.6197	0.6111	0.6087
45 NE01643	0.5735	0.5606	0.5839	0.5303	0.4593	0.5036	0.6370	0.5797	0.5414	0.5294	0.6099	0.5106	0.4960	0.4776	0.4964	0.5401	0.5652	0.5735	0.5821	0.5441	0.6621	0.6667	0.5390

Appendix 2 Dice similarity coefficient (continue)

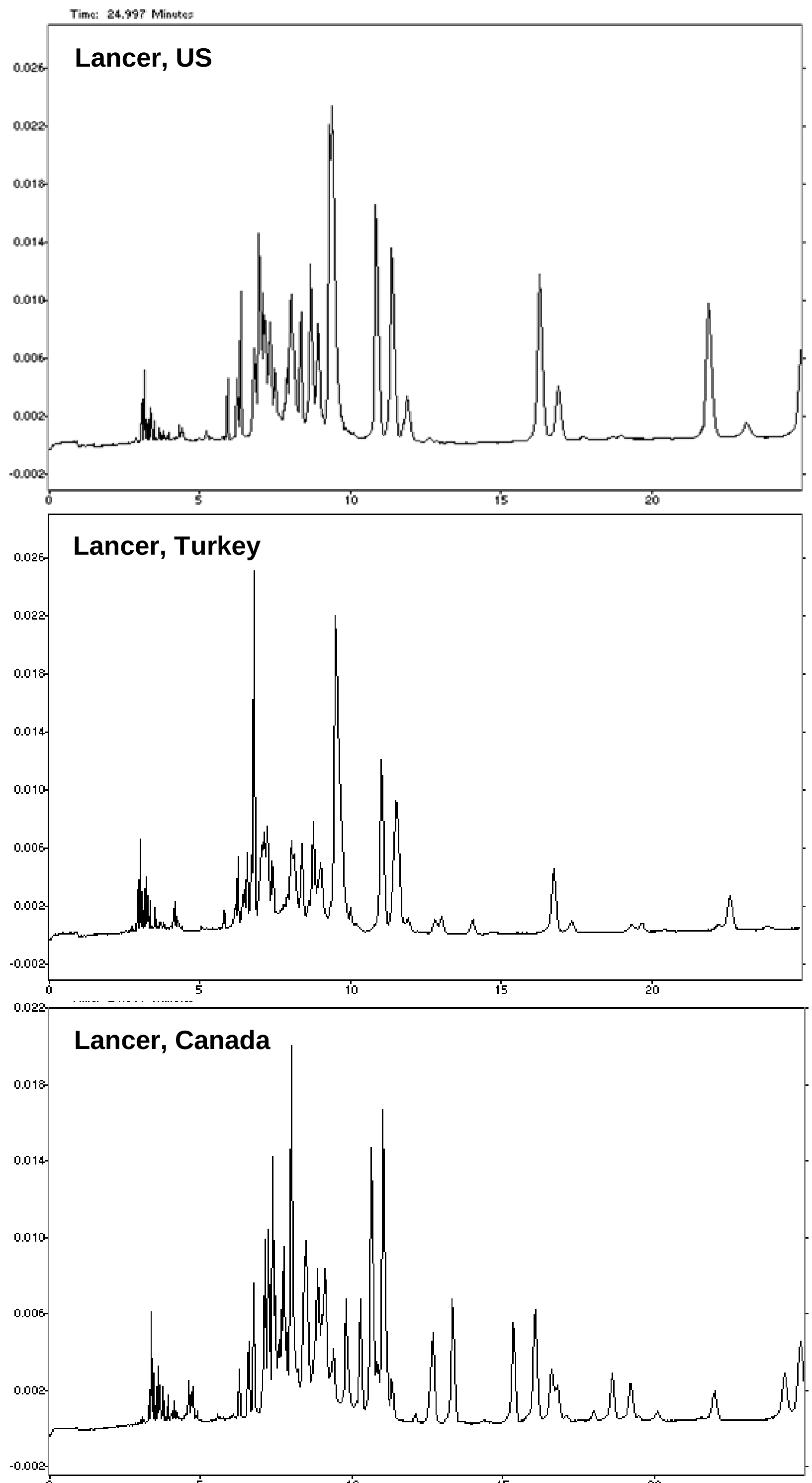
Cultivars	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45
24 Kharkof	1.0000																					
25 Cheyenne	0.7413	1.0000																				
26 Wichita	0.5775	0.5036	1.0000																			
27 Warrior	0.6016	0.6500	0.4202	1.0000																		
28 Scout66	0.6623	0.6757	0.5714	0.5625	1.0000																	
29 Sage	0.6573	0.5857	0.6187	0.4833	0.7703	1.0000																
30 Buckskin	0.6434	0.6000	0.6331	0.5000	0.6216	0.6286	1.0000															
31 Bennett	0.6522	0.5926	0.5672	0.5739	0.6713	0.6963	0.6370	1.0000														
32 Centurk78	0.6993	0.6429	0.6187	0.5333	0.5946	0.5286	0.6571	0.5333	1.0000													
33 Centura	0.7310	0.6338	0.6241	0.5082	0.6533	0.6479	0.7324	0.6131	0.8310	1.0000												
34 Colt	0.5714	0.5255	0.5441	0.4786	0.6897	0.6423	0.5109	0.5909	0.5255	0.5468	1.0000											
35 Siouxland	0.6939	0.6806	0.5315	0.6613	0.7368	0.7222	0.5972	0.6906	0.6944	0.7397	0.6383	1.0000										
36 TAM107	0.6174	0.5616	0.6759	0.4444	0.7143	0.7123	0.6849	0.5674	0.6438	0.6351	0.6713	0.6400	1.0000									
37 Redland	0.5734	0.6429	0.6187	0.5333	0.6351	0.6857	0.5857	0.6963	0.5571	0.6056	0.5985	0.6667	0.6438	1.0000								
38 Arapahoe	0.5616	0.5594	0.6620	0.4390	0.6490	0.6993	0.5874	0.7101	0.5874	0.6345	0.5429	0.7211	0.6309	0.8112	1.0000							
39 Karl92	0.6122	0.6111	0.5315	0.5645	0.6974	0.6944	0.5694	0.6619	0.5833	0.6164	0.6241	0.7297	0.6267	0.7222	0.6531	1.0000						
40 Alliance	0.6531	0.6250	0.5175	0.5968	0.7105	0.7222	0.6389	0.6763	0.5833	0.6164	0.6525	0.6757	0.6133	0.7778	0.6395	0.7838	1.0000					
41 Nekota	0.6400	0.5578	0.5890	0.4724	0.6968	0.7347	0.6939	0.7887	0.5170	0.5772	0.6250	0.6490	0.7059	0.6531	0.6400	0.6887	0.6887	1.0000				
42 Niobrara	0.6370	0.6061	0.6107	0.5536	0.6143	0.6667	0.5606	0.6614	0.5303	0.5522	0.5426	0.6176	0.6377	0.8030	0.6815	0.7059	0.7353	0.6475	1.0000			
43 Pronghorn	0.6912	0.6165	0.6061	0.5664	0.6241	0.6617	0.6767	0.5938	0.7669	0.7704	0.6154	0.7299	0.6619	0.6617	0.5735	0.6277	0.6861	0.6143	0.6560	1.0000		
44 Millennium	0.5532	0.5942	0.6861	0.4576	0.5616	0.6232	0.6087	0.6015	0.5507	0.6286	0.5630	0.6056	0.5694	0.7391	0.6809	0.6056	0.6479	0.6069	0.6769	0.6260	1.0000	
45 NE01643	0.5417	0.5674	0.6286	0.4298	0.6174	0.6099	0.5816	0.6029	0.5390	0.5734	0.5942	0.5655	0.6122	0.8227	0.7083	0.6207	0.6759	0.6351	0.7218	0.5970	0.8489	1.0000

Appendix 3 Nei (1972) standard distance coefficient

Cultivars	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
1 Karasu90	0																						
2 Daphan	0.396	0																					
3 Alparslan	0.368	0.569	0																				
4 Palandoken97	0.454	0.415	0.464	0																			
5 Nenehatun	0.444	0.547	0.434	0.526	0																		
6 Lancer	0.484	0.547	0.474	0.505	0.58	0																	
7 Dogu88	0.333	0.405	0.396	0.425	0.494	0.378	0																
8 Yildirim	0.225	0.454	0.298	0.434	0.444	0.484	0.333	0															
9 Altay2000	0.387	0.464	0.454	0.35	0.434	0.626	0.515	0.444	0														
10 Sultan	0.396	0.378	0.547	0.474	0.315	0.592	0.547	0.378	0.333	0													
11 Harmankaya	0.444	0.547	0.415	0.547	0.536	0.434	0.474	0.350	0.536	0.526	0												
12 Alpu	0.315	0.615	0.434	0.405	0.396	0.434	0.454	0.298	0.415	0.387	0.29	0											
13 Kirgiz95	0.387	0.526	0.396	0.484	0.494	0.359	0.359	0.444	0.415	0.592	0.536	0.474	0										
14 Atay85	0.415	0.434	0.638	0.474	0.35	0.526	0.547	0.415	0.405	0.149	0.547	0.425	0.505	0									
15 Aytin98	0.350	0.464	0.324	0.484	0.378	0.454	0.434	0.484	0.494	0.569	0.536	0.434	0.225	0.569	0								
16 Sonmez2001	0.387	0.505	0.273	0.484	0.434	0.454	0.359	0.333	0.324	0.505	0.307	0.342	0.342	0.464	0.434	0							
17 Gerek79	0.454	0.494	0.315	0.434	0.315	0.425	0.387	0.415	0.484	0.558	0.425	0.484	0.233	0.536	0.142	0.368	0						
18 Kirac66	0.650	0.494	0.547	0.378	0.569	0.405	0.387	0.626	0.35	0.58	0.505	0.505	0.425	0.515	0.425	0.444	0.396	0					
19 Suzen	0.515	0.415	0.444	0.342	0.484	0.464	0.444	0.474	0.315	0.454	0.425	0.425	0.405	0.396	0.444	0.444	0.415	0.241	0				
20 Bezostaya1	0.378	0.494	0.405	0.474	0.547	0.444	0.425	0.415	0.425	0.558	0.35	0.315	0.425	0.65	0.405	0.315	0.454	0.378	0.515	0			
21 Yildiz98	0.425	0.368	0.494	0.425	0.324	0.603	0.558	0.387	0.359	0.233	0.415	0.396	0.65	0.35	0.454	0.474	0.464	0.425	0.444	0.405	0		
22 Cetinel	0.505	0.505	0.536	0.569	0.558	0.536	0.536	0.547	0.494	0.464	0.58	0.65	0.515	0.569	0.494	0.626	0.464	0.425	0.444	0.505	0.454	0	
23 Turkey	0.315	0.505	0.474	0.569	0.515	0.359	0.415	0.444	0.474	0.526	0.415	0.324	0.396	0.484	0.324	0.359	0.425	0.425	0.444	0.315	0.536	0.454	0
24 Kharkof	0.378	0.454	0.35	0.536	0.464	0.315	0.281	0.396	0.569	0.558	0.405	0.405	0.405	0.474	0.368	0.368	0.359	0.454	0.342	0.494	0.592	0.526	0.315
25 Cheyenne	0.333	0.368	0.342	0.484	0.536	0.415	0.396	0.368	0.434	0.464	0.378	0.396	0.454	0.464	0.307	0.396	0.387	0.484	0.387	0.387	0.434	0.536	0.29
26 Wichita	0.474	0.454	0.505	0.342	0.638	0.425	0.526	0.580	0.405	0.58	0.444	0.405	0.444	0.536	0.444	0.484	0.494	0.324	0.359	0.415	0.484	0.569	0.425
27 Warrior	0.368	0.484	0.359	0.526	0.58	0.378	0.324	0.405	0.454	0.638	0.434	0.474	0.307	0.526	0.378	0.324	0.425	0.484	0.444	0.350	0.674	0.558	0.359
28 Scout66	0.425	0.484	0.494	0.569	0.603	0.342	0.359	0.425	0.494	0.425	0.359	0.494	0.474	0.425	0.474	0.474	0.444	0.464	0.505	0.484	0.474	0.454	0.415
29 Sage	0.425	0.526	0.342	0.464	0.515	0.378	0.415	0.350	0.558	0.444	0.434	0.474	0.396	0.444	0.415	0.378	0.35	0.526	0.464	0.484	0.474	0.558	0.474
30 Buckskin	0.405	0.569	0.342	0.569	0.558	0.359	0.494	0.425	0.603	0.592	0.454	0.454	0.474	0.662	0.474	0.536	0.464	0.592	0.484	0.505	0.494	0.474	0.474
31 Bennett	0.342	0.474	0.333	0.474	0.444	0.484	0.387	0.474	0.569	0.558	0.444	0.484	0.333	0.515	0.35	0.425	0.324	0.603	0.536	0.515	0.569	0.569	0.425
32 Centurk78	0.425	0.444	0.415	0.505	0.454	0.494	0.434	0.425	0.474	0.569	0.342	0.342	0.434	0.569	0.378	0.359	0.387	0.464	0.387	0.505	0.454	0.474	0.396
33 Centura	0.368	0.444	0.415	0.484	0.626	0.454	0.415	0.368	0.536	0.547	0.415	0.359	0.536	0.638	0.474	0.494	0.526	0.526	0.484	0.505	0.536	0.494	0.434
34 Colt	0.434	0.515	0.464	0.536	0.505	0.505	0.315	0.434	0.505	0.415	0.505	0.505	0.444	0.474	0.505	0.464	0.474	0.536	0.474	0.603	0.547	0.505	0.592
35 Siouxland	0.333	0.526	0.396	0.569	0.58	0.515	0.359	0.368	0.536	0.444	0.378	0.378	0.474	0.444	0.434	0.396	0.484	0.615	0.505	0.484	0.626	0.474	0.359
36 TAM107	0.526	0.547	0.454	0.464	0.536	0.378	0.474	0.464	0.536	0.405	0.342	0.415	0.474	0.444	0.494	0.494	0.444	0.405	0.35	0.615	0.474	0.415	0.536
37 Redland	0.387	0.425	0.396	0.387	0.626	0.515	0.415	0.464	0.474	0.484	0.454	0.58	0.494	0.484	0.415	0.434	0.405	0.464	0.484	0.444	0.415	0.396	0.434
38 Arapahoe	0.415	0.415	0.464	0.378	0.615	0.505	0.526	0.515	0.464	0.454	0.484	0.505	0.444	0.434	0.425	0.484	0.396	0.515	0.494	0.515	0.484	0.484	0.505
39 Karl92	0.281	0.484	0.415	0.505	0.58	0.494	0.342	0.425	0.454	0.464	0.415	0.558	0.396	0.526	0.359	0.378	0.35	0.505	0.505	0.425	0.536	0.434	0.434
40 Alliance	0.405	0.505	0.342	0.547	0.494	0.434	0.342	0.405	0.454	0.484	0.415	0.58	0.396	0.526	0.415	0.396	0.368	0.444	0.464	0.387	0.494	0.396	0.434
41 Nekota	0.454	0.558	0.425	0.626	0.444	0.387	0.444	0.494	0.615	0.558	0.464	0.526	0.35	0.515	0.368	0.505	0.324	0.58	0.558	0.626	0.547	0.484	0.444
42 Niobrara	0.368	0.405	0.378	0.405	0.494	0.434	0.359	0.405	0.474	0.444	0.415	0.494	0.359	0.405	0.359	0.378	0.35	0.425	0.405	0.387	0.396	0.474	0.494
43 Pronghorn	0.29	0.434	0.368	0.536	0.484	0.444	0.298	0.324	0.464	0.494	0.368	0.405	0.368	0.454	0.405	0.35	0.396	0.494	0.415	0.454	0.526	0.484	0.425
44 Millennium	0.405	0.405	0.434	0.405	0.674	0.536	0.324	0.425	0.415	0.526	0.454	0.454	0.474	0.569	0.515	0.474	0.526	0.387	0.387	0.405	0.415	0.434	0.415
45 NE01643	0.454	0.454	0.444	0.494	0.615	0.569	0.368	0.454	0.484	0.515	0.425	0.569	0.505	0.58	0.569	0.505	0.474	0.454	0.434	0.494	0.368	0.368	0.526

Appendix 3 Nei (1972) standard distance coefficient (continue)

Cultivars	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45
24 Kharkof	0																					
25 Cheyenne	0.265	0																				
26 Wichita	0.474	0.569	0																			
27 Warrior	0.368	0.307	0.569	0																		
28 Scout66	0.387	0.359	0.505	0.434	0																	
29 Sage	0.368	0.454	0.405	0.494	0.241	0																
30 Buckskin	0.387	0.434	0.387	0.474	0.434	0.396	0															
31 Bennett	0.359	0.425	0.454	0.368	0.35	0.298	0.368	0														
32 Centurk78	0.315	0.378	0.405	0.434	0.474	0.536	0.359	0.505	0													
33 Centura	0.281	0.396	0.405	0.474	0.396	0.378	0.273	0.405	0.164	0												
34 Colt	0.474	0.526	0.494	0.484	0.333	0.368	0.547	0.415	0.526	0.505	0											
35 Siouxland	0.333	0.342	0.547	0.307	0.29	0.29	0.454	0.315	0.324	0.273	0.387	0										
36 TAM107	0.444	0.515	0.35	0.58	0.324	0.307	0.342	0.484	0.396	0.415	0.35	0.415	0									
37 Redland	0.484	0.378	0.405	0.434	0.415	0.324	0.454	0.298	0.494	0.434	0.425	0.359	0.396	0								
38 Arapahoe	0.515	0.505	0.359	0.569	0.405	0.315	0.464	0.29	0.464	0.405	0.515	0.298	0.425	0.186	0							
39 Karl92	0.444	0.434	0.547	0.415	0.342	0.324	0.494	0.35	0.474	0.434	0.405	0.29	0.434	0.29	0.387	0						
40 Alliance	0.387	0.415	0.569	0.378	0.324	0.29	0.396	0.333	0.474	0.434	0.368	0.359	0.454	0.225	0.405	0.225	0					
41 Nekota	0.415	0.526	0.474	0.547	0.35	0.281	0.333	0.209	0.592	0.505	0.415	0.405	0.333	0.387	0.415	0.35	0.35	0				
42 Niobrara	0.368	0.396	0.387	0.378	0.415	0.324	0.454	0.315	0.494	0.474	0.464	0.396	0.378	0.179	0.315	0.29	0.257	0.368	0			
43 Pronghorn	0.307	0.387	0.396	0.368	0.405	0.333	0.315	0.396	0.217	0.217	0.378	0.265	0.35	0.333	0.454	0.387	0.315	0.415	0.315	0		
44 Millennium	0.505	0.434	0.315	0.515	0.515	0.396	0.415	0.405	0.494	0.396	0.464	0.434	0.494	0.257	0.333	0.434	0.378	0.444	0.307	0.368	0	
45 NE01643	0.536	0.484	0.396	0.569	0.444	0.425	0.464	0.415	0.526	0.484	0.434	0.505	0.444	0.171	0.307	0.425	0.35	0.415	0.265	0.415	0.142	0



Appendix 4 Gliadin protein pattern of Lancer wheat from U.S., Turkey, and Canada

Appendix 5 the groups of wheat cultivars clustered by UPGMA and NJ methods

Group	UPGMA	Group	NJ
I	Karasu-90	I	Karasu-90
	Yildirim		Yildirim
	Alpaslan		Alpaslan
	Sonmez- 2001		Sonmez- 2001
	Harmankaya		Harmankaya
	Alpu-2001		Alpu-2001
	Bezostaya-1		Bezostaya-1
	Lancer		Dogu-88
	Turkey		Turkey
	Kharkof		Kharkof
	Cheyenne		Cheyenne
	Buckskin		Warrior
	Centurk78		Siouxland
	Centura		
	Pronghorn	II	Buckskin
			Centurk78
			Centura
			Pronghorn
II	Dogu-88	III	Lancer
	Colt		TAM107
	Scout66		Scout66
	Sage		Sage
	Siouxland		Colt
	Karl92		
	Alliance	IV	Karl92
	Bennett		Alliance
	Nekota		Bennett
	Redland		Nekota
	Arapahoe		Redland
	Niobrara		Arapahoe
	Millennium		Niobrara
	NE01643		Millennium
			NE01643
III	Kirgiz 95		Kirgiz 95
	Aytin 98		Aytin 98
	Gerek-79		Gerek-79
IV	Palandoken 97	V	Palandoken 97
	Altay 2000		Altay 2000
	Kirac-66		Kirac-66
	Suzen-97		Suzen-97
	Wichita		Wichita
	TAM107		Nenehatun
			Sultan
V	Nenehatun		Atay 85
	Sultan		Yildiz 98
	Atay 85		Daphan
	Yildiz 98		Cetinel
out group	Daphan		
	Cetinel		
	Warrior		

CHAPTER 2

Genetic Diversity Assessment of Turkish and Great Plains Wheat Based on Agronomic and End-use Quality Traits and the Comparison of Genetic Diversity Based on Morphology Characters and SSR Markers

ABSTRACT

Hard red winter wheat (*Triticum aestivum* L.) breeding programs in the Great Plains were established after 'Turkey' wheat (originating from Turkey) was introduced. We hypothesized that modern wheat cultivars in Turkey and the Great Plains were selected for adaptation in two countries which were similar in climate and the modern Turkish wheat cultivars may have novel and useful genes of use to Great Plains breeding programs. Agronomic and end-use quality traits were used to investigate genetic diversity between 22 Turkish and 23 Great Plains wheat cultivars. The field experiments were conducted at Lincoln (2007 and 2009), Mead (2008 and 2009), and North Platte (2008 and 2009), Nebraska. An incomplete block design with nine incomplete blocks of five plots each was used for all six locations. From nine agronomic and four end-use quality traits, the cultivars (C) and cultivar by environment interactions (CxE) were significant with the similar ranking of cultivars across all environments. Most Turkish wheat cultivars were lower for winter survival and grain yield than Great Plains wheat cultivars. The selection of wheat breeding programs in both counties improved wheats for high grain yield, mixograph mixing time and mixing tolerance but reduced protein content. The genetic diversity estimates based on agronomic traits showed modern Great Plains wheat cultivars diverged from Turkish wheat cultivars by breeding for adaptation.

However, both Turkish and Great Plains breeding programs had similar selections for end-use quality. In the cluster analysis based on both agronomic and end-use quality traits, Benzostaya-1 (a popular Russian wheat in Turkey) was not clustered with either Turkish or Great Plains wheat groups. Most Turkish wheat and Great Plains wheat cultivars were clustered separately. Historic Great Plains wheat cultivars (Turkey, Kharkof, Cheyenne, and Warrior) were clustered with two Turkish wheat cultivars (Karasu-90 and Lancer). From cluster analysis based on SSR markers, agronomic traits, end-use quality traits and the combination of agronomic and end-use quality trait data, we found that Turkey wheat had a relationship with some Turkish wheat and Great Plains wheat cultivars. The original wheat cultivars (Turkey and Kharkof) were clustered separately from modern Great Plains wheat cultivars which indicated that (i) wheat cultivars from both countries were initially related; (ii) breeding programs in the Great Plains progressed by using diverse germplasm; and (iii) wheat cultivars were selected for specific environment adaptation. The Turkish wheat cultivars (Karasu-90, Alpaslan, Lancer, Dogu-88, Harmankaya, and Yildirim) were adapted to the Nebraska environments and could be used as parents.

INTRODUCTION

The first hard red winter wheat (*Triticum aestivum* L.) cultivar in the Great Plains, Turkey wheat originated from Turkey and was introduced by the Mennonites to Kansas in the early 1870's (Quisenberry and Reiz, 1974). Turkey wheat was grown and ranked in the top five cultivars based on planted area between 1919 and 1944. It continued to be grown on measurable hectarages until 1954 (Dalrymple, 1988). From 1949 to 1984, breeding programs in the Great Plains increased wheat grain yields over Turkey wheat by releasing widely grown cultivars such as 'Triumph', 'Scout' (including 'Scout-66' and other selections), 'Wichita', 'Pawnee', 'Centurk', and 'TAM 101' and high-yielding semidwarf winter wheat lines first apperaing in 1974 (Dalrymple, 1988; Schmidt, 1984). Many of these well-known cultivars have Turkey wheat in their parentage. Moreover, Turkey wheat germplasm was widely distributed in breeding programs in the Great Plains and throughout the world. For example, Turkey wheat is a parent of 'Norin-10' which was from Japan and is an important source of semidwarf genes (Schmidt, 1974; Paulsen, 2003).

Breeders have made continuous progress in improving Great Plains wheat. Hard red winter wheat cultivars in the Great Plains released between 1966 and 1973 averaged 143% higher yielding than wheat cultivars released in 1921-1940 (Schmidt 1974). Great Plains wheat cultivars released between 1943 and 1995 were improved for high grain yield, kernel number m^{-1}, kernels $spike^{-1}$, and lodging and leaf rust (incited by *Puccinia triticina*, Roberge ex Desmaz. f. sp. *tritici*.) resistance (Domez et al., 2001). Selection often based on environmental stress tolerance for hard red winter wheat cultivars released between 1874 and 2000 in Great Plains, increased grain yield, grain weight per spike, and spikes per square meter and decreased plant height and days to flowering (Fufa et al., 2005). These results agreed with Cox et al., (1988) who studied wheat cultivars released between 1874 and 1987.

In Turkey, the winter wheat breeding program was initiated in 1926 and there were three main periods. The first period was from 1960 to 1970 and cultivars such as 'Kose', 'Surak', 'Yayla', and 'Kunduru-149' were released, followed by 'Gerek-79', 'Haymara-79', 'Kyrkpynar-79', and 'Cakma-79'. During the second period (1971-1989), 'Bezostaya-1' (a widely grown cultivar from the former Soviet Union) and 'Hawk' were introduced. After 1990, many new cultivars were released with high yield, good quality, and yellow rust (incited by *P. striiformis* Westend. f.sp. *tritici)* resistance (Akar et al., 2007). The objective of wheat breeding programs was the selection of lines for the diverse wheat producing regions in Turkey. As the part of the breeding effort wheat germplasm from around the world was introduced into the Turkey to develop wheat cultivars for specific areas (Altintas et al., 2008). For example, eastern Anatolia in Turkey has low rainfall, severely cold winters, and hot summers. Winter wheat cultivars such as 'Dogu-88', 'Karasu-90', 'Lancer', and 'Palandoken-97' were released for eastern Anatolia area (Olgun et al., 2005).

While grain yield is a primary trait for selection, end-use quality traits are also extremely important for making bread in both the U.S. and Turkey. Breeders select high protein content, mixograph mixing time and mixing tolerance as indicator for good bread loaf volume and bread dough properties (Baenziger et al., 2001). Although grain yield and end-use quality are influenced by genetics, the environment also affects them (Baenziger et al., 2001; Peterson et al., 1992; 1998; Ozturk and Aydin, 2004; Groos et al., 2003). Winter wheat grain yield and related agronomic and end-use quality traits also exhibit environment (E) and cultivar (C) by environment (CxE) interaction in Nebraska (Mishra et al., 2006; Fufa et al., 2005; Budak et al., 2003). Hence, CxE is an important consideration for breeding programs. One form of CxE, known as crossover interaction, indicates changies in rank among cultivars across environments and is the most important (Russell et al., 2003). Therefore, plant breeders should try to identify which cultivars have good performance and adaptation in wide range of environments or identify target environments where the crossover interaction is minimal. To understand phenotypic stability various methods based upon regression or cluster analyses have been suggested (Finlay and Wilkinson, 1963; Eberhart and Russell, 1966; Lin et al., 1986; Weber and Wricke, 1990)

Modern hard red winter wheat cultivars bred in the U.S. and Turkey were selected specifically for adaptation with high yield and good end-use quality. Peterson and Pfeiffer (1989) using cultivar performance, identified five Great Plains locations (Hutchinson Kansas, Stillwater Oklahoma, Akron and Fort Collin Colorado, and Lincoln Nebraska) that were clustered with Ankara Turkey for winter wheat adaptation. All locations were associated with a relatively severe winter growing season. Based upon the similar climate between the Great Plains and Turkey, we hypothesized that wheat cultivars from Turkey and the U.S. Great Plains may have similar adaptation needs. Therefore, we were interested in genetic diversity in Turkish and Great Plains wheat cultivars to investigate how the two gene pools have evolved since the introduction of Turkey wheat to the U.S. for the important agronomic traits. We were also interested in identifying new germplasm resources for improving the U.S. breeding lines. Genetic diversity based on simple sequence repeat (SSR) markers (Chapter 1) clustered Turkish and Great Plains wheat cultivars into the groups that could be explained largely by pedigree and country of origin. Wheat cultivars from both countries continued to be related as cultivars from both countries were clustered together in the some groups. Though modern Great Plains, historic Great Plains, and most Turkish wheat cultivars were clustered separately, a few modern Turkish wheat cultivars were clustered in the modern Great Plains wheat group due to germplasm exchange and selection for performance in similar climates. Historic Great Plains wheat cultivars were clustered with both old and modern Turkish wheat cultivars.

In addition to molecular marker estimates of genetic diversity, phenotypic data are often used for estimating genetic diversity as phenotypic diversity is derived from genes controlling the traits (Cui et al., 2001). For example, eight morphologic characters were used to estimate genetic diversity of wheat landrace populations from different altitudes of three regions in Turkey (Southeast Anatolia, Central Anatolia, and North Transition). Cluster analysis identified four clusters: (i) bread wheat accessions from 0 to 399 m above sea level (ASL), (ii) from 1600 m ASL and above, (iii) North Transitional zone, and (iv). Central Anatolia (Karagoz and Zencirci, 2005).

An obvious question when considering methods to estimate genetic diversity is how do the various methods compare? Tsombalova et al. (2008) estimated genetic diversity in spring wheat from Estonia using SSR and morphological data and found the morphological clustering disagreed with SSR clustering. Maric et al. (2004) also found no correlation between clusters based on RAPD markers and morphological traits in hexaploid Croatian wheat which was similar to the results of Moghaddam et al. (2005)

who found no correlation between amplified fragment length polymorphism (AFLP) and agronomic trait clustering of wheat cultivars from Mexico and Iran. However, Viera et al. (2007) found the correlation of genetic distance from AFLP and morphology in wheat. In barley (*Hordeum vulgare* L.) from Tunisia, genetic similarity coefficients estimated based on SSR markers were correlated with genetic similarity coefficients based on morphological traits (Hamza et al., 2004). Fufa et al. (2005) also found correlation of clustering based on SSR markers and morphology of the thirty U.S. wheat cultivars.

The objectives of this study were (i) to determine agronomic and end-use quality trait variation among cultivars from Turkey and the Great Plains due to the environment, cultivar, and CxE interaction, (ii) to assess genetic diversity of wheat cultivars from the U.S. Great Plains and Turkey based on agronomic and end-use quality performance, (iii) to compare the diversity previously estimated from molecular markers to those estimated by agronomics and end-use quality traits, and (iv) to identify new sources of germplasm for wheat improvement in Nebraska.

MATERIALS AND METHODS

Forty-five wheat cultivars including 22 Turkish wheat and 23 Great Plains hard red winter wheat cultivars were used in this study. Great Plains hard red wheat cultivars were released between 1874 and 2006 and are Turkey, 'Kharkof', 'Cheyenne', 'Wichita', Warrior, Scout-66, 'Sage', 'Buckskin', 'Bennett', 'Centurk-78', 'Centura', 'Colt', 'Siouxland', 'TAM107', 'Redland', 'Arapahoe', 'Karl-92', 'Alliance', 'Nekota', 'Niobrara', 'Pronghorn', 'Millennium' and 'NE01643' (sold as Husker Genetics Brand Overland). Turkish wheat cultivars were Karasu-90, 'Daphan', 'Alpaslan', Palandoken-97, 'Nenehatun', Lancer, Dogu-88, 'Yildirim', 'Altay-2000', 'Sultan', 'Harmankaya', 'Alpu-2001', 'Kirgiz-95', 'Atay-85', 'Aytin-98', 'Sonmez-2001', Gerek-79, 'Kirac-66', 'Suzen-97', Bezostaya-1, 'Yildiz-98', and 'Cetinel' (see Chapter1 for full description of these lines).

Agronomic Trails

The wheat cultivars were planted under rainfed conditions at six environments (Lincoln in 2006/07, 2008/09, North Platte and Mead in 2007/08 and 2008/09). The experimental design for agronomic trait evaluation was an incomplete block design with nine incomplete blocks of five entries nested in three replications at Lincoln 2006/07 and North Platte 2007/08, 2008/09, Mead 2008/09 and two replications at Mead 2007/08 and Lincoln 2008/2009 (the latter two lost a replication due to field variation). A plot was planted at a seeding rate of 54 kg of seed ha^{-1} and consisted of four rows 2.4 m long with 0.30 m between rows.

Five agronomic traits (winter survival, days to 50% flowering, plant height, grain yield and grain volume weight) and four components of yield (spikes per square meter, thousand kernel weight, kernel weight per spike, and kernel number per spike) were measured at all six environments. Winter survival was evaluated during the last week of April through the first week of May in each environment as percentage of plants surviving the winter. Days to flowering were recorded when 50% spikes in a plot has extruded anthers (noted as days from January 1^{st}). Plant height was measured at maturity as the average height in cm from ground to the tip of spike (awns excluded). Grain yield was measured using a combine harvest of all four rows of each plot. Grain volume weight was measured on a 200 ml sample. Ten spikes were randomly harvested from each plot and threshed. Their kernels were counted by using an Agriculex ESC-1 seed counter (Agriculex Inc., Guelph, Ontario) and weighted to determine the mean grain weight per spike, the number of kernels per spike, and to estimate thousand kernel weights. Then, plot size, plot grain yield and grain weight per spike were used for estimating the number of spikes per square meter.

End-use Quality Analysis

The quality analyses were performed in the Seed Quality Laboratory of the Department of Agronomy and Horticulture in the University of Nebraska-Lincoln using a 50 g grain sample per plot from two replications. Historically, quality traits are measured with the high level of repeatability so two replications are sufficient. Each grain sample was tempered to 152 g H_2O kg^{-1} before milling on a Brabender Quadrumate senior mill (C.W. Brabender Instruments, South Hackensack, NJ). Flour yield was measured after using Standard shaker (Standard shaker Co. Minneapolis, MN) at 225 rpm for 90 seconds. Flour protein content was determined using Near-infrared reflectance (NIR) spectroscopy of flour samples from each plot and corrected following combustion techniques of a few samples (Method 46-30; AACC, 1995; LECO Manufacturing Equipment, St Joseph, MI). A 10 g flour sample was evaluated for flour mixing characters with constant water absorption of 620 g H_2O kg^{-1} of flour using a Mixograph (National Manufacturing Co., Lincoln NE) following the Approved Method 54-40 (AACC, 1995). Mixing time was recorded as the time (in minutes) to reach maximum curve height. Mixing tolerance was evaluated after comparison to standard curves using a scale from low (0) to very high tolerance (7) with higher scores indicating greater tolerance of dough to over-mixing using Approved Methods 54-40 (AACC, 1995). Wheat lines with mixing time of >3 min (preferably higher than 4) and a mixing tolerance scores of >3 (preferably higher than 4) are considered as being an acceptable (Baenziger et al., 2001).

Statistical Analysis of Agronomic and End-use Quality Trail

Agronomic and quality data from individual environments were analyzed for each trait using PROC MIXED considering the environments and cultivars as fixed effects, replications and incomplete blocks within environments as random effects using SAS version 9.1 (SAS 2002). Homogeneity variances were tested using F_{max} and considered homogeneous if the value was less than 5 (Tabachnick and Fidell, 2001). If variances from six environments of each trait were homogeneous, a trait was analyzed over environments in a combined ANOVA. Yield stability was determined by regression method (Eberhart and Russell, 1966) to estimate regression coefficient between cultivar mean and environmental mean. Regression coefficients that were less than 1 were considered as being stable for grain yield (Finlay and Wilkinson, 1963). To determine the relationship among variables and correlations of genetic similarity/distance from SSR, agronomic, end-use quality, and agronomic and end-use quality combination, simple (Pearson) correlations were determined using PROC CORR. Principal component analysis using a correlation matrix from least square means (LSMEAN) averaged over six environments was done using PROC PRINCOMP to determine the traits that account for most variation between lines. To illustrate the relationship among cultivars, scatter plots were developed using PROC PLOT. Because of the large difference in the unit of each trait, agronomic and end-use quality data were standardized using the standard deviation of mean average over six environment by PROC STANDARD and then were used for clustering using PLOC CLUSTER using “Average Linkage Cluster Analysis” based on Euclidean distance (Flury and Riedwyl, 1986). Average Linkage algorithms were used for cluster analysis and then, dendograms constructed using PROC TREE (SAS, 2002).

RESULTS AND DISCUSSION

Agronomic traits

The variances of each trait from all environments were evaluated for homogeneity and the F_{max} value was less than 5.0. Hence, a combined ANOVA was performed across six environments for all traits. The combined analysis of variance showed highly significant differences ($P<0.0001$) for cultivars and CxE interaction for all agronomic traits (Table 1). The mean squares of cultivars were larger (5.0 to 17.6 times larger) than CxE interaction mean square; therefore, the ranking of cultivars was considered to be similar across environments as suggested by Gomez and Gomez (1984) who stated that if there is small treatment x environment interaction effect compared with effect of treatments, the ranking of treatments across environments were expected to be similar. Hence, we considered the cultivars in this study to have similar performance in different environments. This result was somewhat surprising because North Platte is generally considered as being environmentally different from Mead and Lincoln (Peterson, 1992).

Great Plains wheat cultivars had higher grain yield, spikes per square meter, grain volume weight, and winter survival than most Turkish wheat cultivars (Appendix 2, 3). All Great Plains wheat and three Turkish wheat cultivars (Alparslan, Lancer, and Dogu-88) had 100% winter survival in all environments. The remaining Turkish wheat cultivars were injured by the winter e.g. Daphan, Altay-2000, Sultan, Alpu 2001, Atay-85, Aytin-98, Sonmez-2001, Kirac-66, Suzen, Yildiz-98, and Cetinel that had winter survival values of less than 80%. As mentioned previously, Turkey has four major wheat producing region, one of which is Central Anatolia. It is possible that the winter-injured Turkish lines came from one of the other three regions where the need for winter survival is lower than that needed for the Great Plains or Central Anatolia.

For Great Plains wheat cultivars, historics cultivars had lower grain yield than modern wheat cultivars, as expected. The highest grain yielding cultivars were the modern and broadly adapted Nebraska wheat cultivars NE01643, Alliance, Arapahoe, Millennium, and Redland with grain yield 5231, 5067, 4893, 4822, and 4738 kg ha^{-1}, respectively. NE06143, Redland, Karl-92, and Nekota were high yielding cultivars that were also stable across environments using Eberhart and Russell (1966) method with b value less than 1.0 indicated they were high yielding in all environments. Among the Turkish wheat cultivars, the highest grain yielding cultivars were Dogu-88, Harmankaya, Alpaslan, Yildirim, Alpu-2001, Yoldiz-98, and Nenehatun with grain yields of 4027, 3800, 3738, 3731, 3662, 3512, and 3470 kg ha^{-1}. However, only three Turkish wheat cultivars (Alpaslan, Dogu-88, and Harmakaya) had good winter survival, and high yield were stable (Appendix 2). Great Plains wheat cultivars compared to Turkish wheat cultivars had greater spikes per square meter (> 400 spike per m^2). There were only 4 cultivars (Karasu-90, Alpaslan, Dogu-88, and Gerek-79) that had the number of spikes per square meter greater than 400. Additionally, all Great Plains wheat cultivars had high grain volume weight (> 74 kg hL^{-1}). On the other hand, Turkish wheat cultivars had lower grain volume weight and only 7 Turkish wheat cultivars (Karasu-90, Alpaslan, Dogu-88, Yildirim, Altay-2000, Alpu-2001, and Bezostaya-1) had grain volume weight higher than 74 kg hL^{-1}. Alpaslan was the earliest flowering Turkish wheat cultivars (145 Julian days) and was similar to two early Great Plains wheat cultivars (TAM 107 and Karl 92). Both Turkish and Great Plains wheat cultivars flowered from 145 to 152 days indicating similar growth and development pattern. Five Great Plains wheat cultivars (Turkey, Kharkof, Cheyenne, Warrior, and Buckskin) and 4 Turkish wheat cultivars (Karasu-90, Palandoken-97, Lancer, and Kirac-66) were tall (≥ 100 cm.) and most likely conventional height cultivars (i.e. not semi-dwaft). There were 8 short wheat cultivars (81-85 cm.) including 5 Turkish wheat cultivars (Daphan, Alpaslan, Nenehatun, Alpu-2001, and Yildiz-98) and 3 Great Plains wheat cultivars (TAM 107, Karl 92, and Nekota).

To determine the relationship among the measured traits, simple correlation coefficients based on genotype LSMEAN were estimated. There was a highly significant positive correlation between winter survival and grain yield ($r = 0.64^{**}$) (Appendix 4). In general, high winter survival of the Great Plains wheat cultivars led to high grain yields except for the historic Great Plains (Turkey, Kharkof, Cheyenne) and a Turkish wheat cultivar (Lancer) that had 100% winter survival but were low yielding as expected by their year of release. The flowering date was negatively correlated with grain yield and winter survival ($r = -0.56^{**}$ and -0.45^{**}, respectively). Hence, this result could mean that breeders have selected wheat with earlier flowering dates, better winter survival, and higher grain yield. The average flowering date of historic cultivars (except Wichita) was 151 Julian days which was later than modern Great Plains cultivars (averaging 147 Julian days). Also, cultivars with winter injury often have more tillers per plant and these secondary tillers flower later than the primary tillers hence delay flowering. Breeding programs in the Great Plains improved grain yield an average 15.9 kg ha^{-1} and reduced plant height 0.19 cm per year based on regressing grain yield and plant height on year of released ($r=0.84^{**}$ and $r=0.71^{**}$, respectively) (Appendix 5). This result agreed with Fufa

(2004) who found flowering date went from 152 days in historic cultivars to 143-145 days and increased of grain yield in 10.4 kg ha^{-1} per year in modern cultivars. Cox et al. (1988) estimated the progress of grain yield and plant height in Kansas from wheat cultivars released between 1919 and 1987 that were 16.6 kg ha^{-1} and -0.5 cm per year, respectively. Similar results were reported by Domez et al. (2001) who also found that Great Plains wheat cultivars increased grain yield and decreased plant height and heading date over time.

Grain yield was positively correlated with grain volume weight and spikes per square meter ($r = 0.75^{**}$ and 0.85^{**}, respectively). The latter correlation was expected due to the derivation of spikes per square meter. Grain volume weight is an important trait in both Turkey and the U.S. since most cultivars in this study had grain volume weight higher than 70 kg hL^{-1} (only four Turkish wheat cultivars grain volume weight between 66 and 69.1 kg hL^{-1}). However, the significant correlation between grain volume weight and winter survival ($r = 0.74^{**}$) indicated the effect of winter in Nebraska on Turkish wheat cultivars. Although kernel number and kernel weight per spike were not significantly correlated with grain yield, they had a highly significant negative correlation with spikes per square meter (again expected due to its derivation), grain volume weight, and winter survival. The correlation coefficient between kernel number per spike and these three traits were -0.62^{**}, -0.56^{**}, and -0.67^{**}, respectively. The correlation coefficient between kernel weight per spike and these three traits were -0.67^{**}, -0.38^{**}, and -0.63^{**}, respectively. These results may be explained by the plants that were injured by the winter having fewer spikes per square meter which led to lower grain yield. The remaining spikes have more kernels per spike and kernel weight per spike.

When principle component analysis based on the correlation matrix of agronomic traits was analyzed, the first two principle components explained 76% of total variability among cultivars. The first principle component explained 51% by contrasting grain yield, winter survival, grain volume weight, and spikes per square meter with kernel number and kernel weight per spike (Appendix 11). The second principle component explained 25% and was based on flowering date, wheat height contrasting kernel weight per spike, and thousand kernel weights. The first two principle component scores were plotted and discriminated Turkish and Great Plains wheat cultivars into three main groups (Figure 1).

The first group included all modern, a historic Great Plains wheat cultivar (Wichita) and two Turkish wheat cultivars (Alpaslan and Dogu-88). Wheat cultivars in group 1 had 100% winter survival, high grain yield (> 3545 kg ha^{-1}), high grain volume weight, and high spikes per square meter. The second group included four historic Great Plains wheat cultivars (Turkey, Kharkof, Cheyenne, and Warrior), and two Turkish wheat cultivars (Karasu-90 and Lancer) that had high winter survival and low grain yield. The third group was a small group consisting of Atay-85, Cetinel, and Sultan having low yield and winter survival. Eighteen Turkish wheat cultivars were not clustered and were distant from the three groups.

Principle component analysis based on agronomic traits revealed most Turkish and Great Plains wheat cultivars were largely in different clusters, but four Turkish wheat cultivars were grouped with Great Plains wheat cultivar group and had good adaptation in Nebraska. Two Turkish wheat cultivars (Dogu-88 and Alpaslan) were included with modern Great Plains cultivars due to higher for grain yield and 100% winter survival compared with other Turkish wheat cultivars. From our study, five other ungrouped

Turkish wheat cultivars (Harmankaya, Yidirim, Alpu-2001, Nenehatun, and Yildiz-98) also had high grain yield but lower winter survival. The high yielding cultivars, Nenehatun and Yildiz-98 with yield 3470 and 3512 kg ha^{-1}, respectively were not as valuable for parents in the Nebraska environment because Yildiz-98 suffered winter injury (71% winter survival) and Nenehatun was stem rust (incited by *Puccinia graminis* Pers.:Pers. f. sp. *tritici* Eriks. E. Henn.) susceptible. We decided not to spray this experiment with fungicides because we were interested in evaluating the lines in realistic Nebraska conditions where disease pressure will vary from year to year and location to location.

Euclidean distances were estimated between all lines using least square means of the lines for agronomic traits. The wheat cultivars were clustered using average linkage method and the results generally agree with principal component analysis. Using 0.80 for the average distance between clusters, the 45 wheat cultivars were clustered into 5 clusters and most Turkish and Great Plains wheat cultivars were separately clustered (Figure 2). Cluster I, II and III were Turkish wheat cultivar groups. Four historic Great Plains wheat cultivars (Turkey, Kharkof, Cheyenne, and Warrior), and two Turkish wheat cultivars (Karasu-90 and Lancer) were clustered together (Cluster V). Eighteen modern Great Plains wheat, historic wheat (Wichita), and two high yield Turkish wheat cultivars (Alpaslan and Dogu-88) were clustered in cluster IV that could be separated into four subclusters. Subclusters IVA and IVB were the cluster of Great Plains wheat cultivars. In subcluster IVC, Dogu-88 was clustered with Niobrara and Siouxland which were joined together with Nebraska wheat cultivars (NE01643, Alliance, Centura, Millennium, Arapahoe, Redland, and Centurk-78). Alpaslan was closely related with TAM107 in subcluster IVD most likely due to their shorter height and early flowering. Furthermore, Bezostaya-1 a Russian wheat cultivar widely grown in Turkey was not clustered into any Turkish and Great Plains wheat groups.

The results of cluster analysis based on SSR markers using UPGMA method (Chapter 1) were similar to those of agronomic traits using average linkage clustering method. First, most Turkish wheat and Great Plains wheat cultivars were clustered into largely separate groups. Secondly, three historic Great Plains wheat cultivars (Turkey, Cheyenne, and Kharkof) and a Turkish wheat cultivar (Lancer) were clustered in the same group. Third, Dogu-88 (Turkish wheat cultivar) was clustered in the group of modern Great Plains wheat by both methods. Fourth, Turkish wheat cultivars (Kirgiz-95, Aytin-98, and Gerek-79) were clustered in the same group by cluster analysis based on both SSR and agronomic data clustered which was same as the group of Sultan, Atay-85, and Yildiz-98. Lastly, 13 modern Great Plains wheat cultivars were also clustered in the same group based on both traits.

End-use quality traits

The homogeneity variance of each trait was evaluated and the F_{max} value was less than 5.0, so a combined over environment ANOVA was run. The end-use quality traits from six environments, flour yield, protein content, mixing time, and mixing tolerance indicated that there were significant differences among the cultivars and the CxE interaction was significant (Table 2). Similar to the results of agronomic traits, mean squares of cultivar for all end-use quality traits were larger than CxE interaction mean squares from 6.0 to 22.5 times; therefore, the cultivars were assumed to have similar rankings across environment for all quality traits (Gonmez and Gonmez, 1984). Turkish and Great Plains wheat cultivars had flour yields higher than 30 g flour from 50 g of grain. Protein contents from all cultivars were between 109 and 138 g protein per kg flour and there was no significant difference for protein content between both the Great Plains wheat (123 g protein per kg flour) and Turkish wheat (123 g protein per kg flour) cultivars by single degree of freedom contrast (P-value = 0.5623). Historic Great Plains wheat cultivars were higher in protein content (such as Kharkof, Turkey, and Wichita having 138, 134, and 129 g protein per kg flour, respectively) than modern cultivars (such as Alliance, Millennium and NE01643 which had 111, 118 and 120 g protein per kg flour protein content, respectively; Appendix 7, 8). This result agreed with Cox et al (1989) who reported that the mean flour protein content of cultivars released between 1976 and 1988 were lower than the previously released cultivars which most likely related to modern cultivars having much higher grain yields. Mixing time of Turkish wheat cultivars ranged from 1.74 to 4.15 min and the average from 22 cultivars was 2.97 min. Great Plain wheat cultivars had mixing time ranged from 2.10 to 4.67 min and the average of mixing time of 23 Great Plains wheat cultivars (3.34 min) was significantly higher than Turkish wheat cultivars. This result was similar to the average mixing tolerance score as Great Plains wheat cultivars averaged a mixing tolerance score of 3.92 that was significantly higher than Turkish wheat mixing tolerance score (2.85).

The correlations of all end-use quality traits showed no correlation between flour yield and protein content and mixing time but there was significant correlation of flour yield with mixing tolerance ($r=0.55^{**}$; Appendix 9). However, protein content was negatively correlated with mixing time ($r=-0.38^{**}$). Mixing tolerance showed a highly significant positive correlation with mixing time ($r = 0.79^{**}$) which was similar to

Peterson et al. (1992) and Dong et al. (1992). Our current objectives for end-use quality are lines with mixograph mixing time and mixing tolerances greater than 3 (preferably greater than 4) and whole grain protein greater than 120 g protein for 1000 g of flour (Baenziger et al, 2001). Sixteen Turkish wheat and 16 Great Plains wheat cultivars had protein content higher than 120 g protein for 1000 g of flour. Great Plains wheat cultivars, fifteen cultivars had mixing time higher than 3.0 and 21 cultivars had mixing tolerance higher than 3. Ten Turkish wheat cultivars had mixing time higher than 3.0 min and another ten wheat cultivars had mixing tolerance score greater than 3. Eight Turkish wheats (36% of the tested lines) and 15 Great Plains wheat cultivars (65 % of the tested lines) had both mixing time and mixing tolerance higher than 3. Historic Great Plain wheat cultivars (Turkey and Wichita) had lower mixing tolerance and mixing time score. It appears that both breeding programs had similar criteria for improving end-use quality traits and both selected for longer mixing time and tolerance.

Principle component analysis using a correlation matrix based on end-use quality traits showed that the first two principle components explained 82 % of total variability among cultivars (Figure 3; Appendix 11). The first principle component explained 53% which was associated with mixing tolerance and mixing time. The second principle component explained 29% of the total variation and was explained by flour protein content and flour yield. From the principle component score plot, there were three main groups. Group I included seven Turkish wheat and eleven Great Plains wheat cultivars. Group II included seven Great Plains wheat cultivars and Bezostaya-1. The last group included five Turkish wheat cultivars and Wichita. Nine Turkish wheat cultivars and two Great Plain wheat cultivars were not clustered in any group. Five ungrouped Turkish wheat cultivars (Kirac-66, Gerek-79, Palandoken-97, Kirgiz-95, and Cetinel) were separated from other cultivars due to very low mixing tolerance (<2). Historic Great Plains wheat cultivars (Turkey and Wichita) were separated from other Great Plains wheat cultivars due to high protein content and low mixing time whereas Karl 92 and Pronghorn were split from main group and other modern Great Plains wheat cultivars because they had high flour yield (35.4, 35.9 g from 50 g of grain), average protein content (129, 126 g per 1000 g of flour), and long mixing time (4.67 and 4.12 min, respectively), and high mixing tolerance (5.36 and 4.99, respectively) scores. Twenty-three Great Plains wheat cultivars in this study were included in Fufa et al (2004) and their results were similar because principle component analysis based on end-use quality traits clustered the cultivars as Turkey, Wichita, and Karl 92 far from other U.S. wheat cultivars.

Genetic diversity based on end-use quality data at 0.70 average distance between clusters clustered the 45 wheat cultivars into 7 clusters (Figure 4). Cetinel and Kirgiz-95 were clustered in Cluster I because of low mixing characteristics and flour yield. Turkey and Wichita clustered together in cluster II with nine Turkish wheat cultivars. Cluster III and cluster IV were the clusters of Turkish wheat cultivars. As in the principal component analysis, Karl 92 and Pronghorn were clustered in the same cluster (Cluster V) and separated from other modern Great Plains wheat cultivars. Cluster VI and Cluster VII contained both Turkish and U.S. Great Plains wheat cultivars. Cluster VI included seven Great Plains wheat cultivars and Bezostaya-1 that was the same Group II of the principal component analysis. Cluster VII is the cluster of eleven Great Plains wheat and three Turkish wheat (Yildiz-98, Karasu-90, and Dogu-88) cultivars. Siouxland had

Kavkaz (1BL.1RS translocation) in its pedigree and TAM107, Nekota, and Niobrara that had Amigo (1AL.1RS translocation) as an ancestor, were clustered in this group. Both Kavkaz and Amigo were most frequently used as parents in breeding programs to improve grain yield, yield stability, and grain protein content but the rye (*Secale cereale* L.) chromatin and loss of wheat chromatin decreased wheat quality (Graybosch, 2001, Kumlay et al., 2003). However, our experiment showed that all wheat cultivars derived from the 1BL.1RS and 1AL.1RS translocation had mixing tolerance score and mixing time over 3 with protein content between 116 and 120 g per 1000 g of flour. End-use quality of wheat cultivar derived from the translocation was investigated by Moreno-Sevilla et al. (1995) who indicated that the generally deleterious effect of 1BL.1RS on end-use quality could be overcome.

When agronomic and end-use quality traits dendrogram were compared, most Turkish wheat cultivars were clustered separately from Great Plains wheat cultivars in both dendrograms. The main exceptions were Turkish wheat cultivars, Karasu-90, Alpaslan, Lancer, and Dogu-88 which clustered with Great Plains wheat cultivar group by both agronomic and end-use quality data. Lancer was clustered with the group of historic Great Plains by both clustering procedures. Karasu-90 was clustered with the historic Great Plains wheat cluster by its good winter survival but low grain yield; however, it was clustered with modern Great Plains wheat due to its end-use quality traits. Alpaslan, the cultivar from Turkey that had high yield and winter survival was clustered with modern Great Plains wheat by agronomic traits but clustered with old Great Plains wheat cultivars by end-use quality traits. The highest yielding of Turkish wheat cultivar (Dogu-88) was clustered with modern Great Plains wheat cultivars by its agronomic performance and quality traits. When Dogu-88 and Alpaslan were compared with other Turkish wheat cultivars, they had superior agronomic performance in our testing environments, especially for winter survival and grain yield stability. In addition, Dogu-88 had good mixing characters (mixing time was 3.42 minutes and mixing tolerance was 3.69, respectively; Appendix 7). The wheat cultivars clustered with the Great Plains wheat cluster such as Dogu-88, Karasu-90, and Lancer were most likely developed for the eastern Anatolia region where the winter is cold and summer is hot (Olgun et al., 2005) which is similar to our testing sites. Although Karasu-90, Alpaslan, Lancer, and Dogu-88 produced lower yield than modern Great Plains wheat cultivars, they were able to survive during winter in Nebraska and were acceptable in their mixing characteristics. The other two Turkish wheat cultivars (Harmankaya and Yildirim) that were clustered separately from Great Plains wheat cultivars, and they had good yield and also had acceptable mixing characters

Comparison of genetic diversity based on SSR marker, agronomic and end-use quality traits

The correlations between agronomic and end-use quality traits were analyzed to study the effect of selection in Turkey and Great Plains. Wheat breeders selected wheat for high grain yield, mixing time, and mixing tolerance and reduced protein content (reflecting the inverse relationship between grain yield and flour protein content). There were significant correlations between grain yield and flour yield, protein content, mixing time, and mixing tolerance ($r = 0.65^{**}$, -0.35^{*}, 0.48^{**}, and 0.60^{**}, respectively; Appendix 10). There were significant positive correlations between winter survival and two end-use quality traits, flour yield ($r=0.71^{**}$) and mixing tolerance ($r=0.43^{**}$) which represented high winter survival cultivars also had high flour yield and mixing tolerance. This correlation was similar to the correlation between grain volume weight and these two traits. The correlation between winter survival and mixing tolerance indicated that Turkish wheat cultivars selected for high grain yield with lighter winter tolerance in Turkey. In addition, it is possible some Turkish wheat cultivars (eg. Gerek-79 and Kirac-66) were not selected for end-use quality which could explain these results (Bilgin and Korkut, 2005).

From the principle component analysis based on the combined agronomic and quality traits, the first two principle components explained 65% of total variability (Figure 5). This result was similar to the principle component analysis based on agronomic traits alone because the modern Great Plains wheat and two Turkish wheat cultivars (Alpaslan and Dogu-88) were grouped together and four historic wheat cultivars were in the same group. However, the differences from agronomic trait clusters were Wichita grouped with Turkey, Cheyenne, and Warrior but Kharkof was outgrouped. Most Turkish cultivars were unable to be grouped except Aytin-98, Palandoken-97, Kirgiz-98, and Gerek-79 were grouped together in a small group. Cetinel was separated from any groups due to its low agronomic performance and end-use quality.

Cluster analysis reflects the traits that are used to form the cluster. In making clusters, we used all the traits (nine agronomic and flour end-use quality traits) measured to gain a fuller picture of relationship among Turkish and Great Plains wheat cultivars. At a threshold of 0.80 using average distance between clusters, wheat cultivars were grouped into five groups and two cultivars (Bezostaya-1 and Cetinel) were grouped elsewhere (Figure 6). These results are most similar to those based on agronomic clustering.

Comparing agronomic and the combination of agronomic and end-used quality trait dendrograms, most Turkish wheat and Great Plains wheat cultivars were clustered separately. Secondly, wheat cultivars in cluster IV and V of both clustering procedures were the same cultivars. Moreover, Turkish wheat cultivars in cluster I, II, and III from the two dendrograms included the same cultivars in 75%, 75%, and 83% of the time respectively. Because the combined trait cluster analysis was similar to the agronomic trait cluster results, this analysis supported our hypothesis that wheat cultivars were selected for different agronomic traits for specific environments in each country but also for similar end-use quality traits.

In our studies of the diversity of wheat, we used SSR markers (Chapter 1), agronomic, end-use quality, and a combination of agronomic and end-use quality traits. To compare these similarity/distance estimates, we correlated the pairwise similarity value among the different methods that were based upon Dice similarity of SSR markers, and Euclidean distance of agronomic, end-used quality, and the combination of agronomic and end-use quality traits. Both agronomic and end-use quality were related ($r=0.34^{**}$; Appendix 12). The correlation of the similarity/distance estimates between SSR markers (Dice similarity) and the agronomic, end-use quality or the combination of agronomic and end-use quality traits (Euclidean distance) were significant ($r = -0.34^{**}$, -0.22^{**}, and -0.36^{**}, respectively; note that the negative correlation is because we are correlating genetic similarity with genetic distance) which was similar to the correlation between morphologic and SSR markers in barley ($r=0.25^{**}$; Hamza et al., 2004), durum wheat (*T. durum* L.; $r = 0.32^{**}$; Annicchiarico et al., 2009) and in winter wheat ($r = 0.21^{**}$; Fufa et al., 2005). Hence, all similarity/distance measures were somewhat similar.

According to cluster analysis based on SSR markers, agronomic, end-use quality, and the combined agronomic and end-use quality, few Turkish wheat cultivars were clustered with the Great Plains wheat group. However, the historic Great Plains wheat cultivars were often clustered with Turkish wheat groups indicating their common origin. Two Turkish wheat cultivars including Sultan released in 1917 and Atay-85 released in 1985 were highly related by all four clustering method despite considerable differences in the years of release. Dogu-88 was the only Turkish wheat cultivar that was clustered with modern Great Plains wheat cultivars by all clustering methods. Turkey and Kharkof were separated from modern Great Plains wheat cultivars indicating considerable breeding progress which used diverse germplasm. When the dendrogram from SSR markers was compared with combined agronomic and end-use quality trait dendrogram, a Turkish wheat cultivar (Cetinel) can not be grouped into any cluster most likely due to poor adaptation performance in Nebraska environment and its pedigree. Modern Great Plains wheat cultivars were grouped together and diverged from Turkish wheat groups and historic Great Plains wheat cultivars by agronomic and end-use quality combination clustering indicating diverse breeding objectives. In contrast, clustering based on SSR markers identified a closer relationship between Turkish wheat and Great Plains wheat cultivars. In our study, the Turkish wheat cultivars had greater diversity in their genetic background when compared to the Great Plains wheat cultivars. Turkey wheat was related to some Turkish wheat cultivars, as well as some Great Plains wheat cultivars. Thus, this result indicated that Turkish wheat and Great Plains wheat cultivars were initially related but they diverged due to selection for specific environmental adaptation using different parents in each country.

In conclusion, 22 historical and modern Turkish wheat cultivars and 23 U.S. Great Plains wheat cultivars were used to study genetic diversity to see how breeding programs from the countries were related, based on the knowledge that the original hard red winter wheat in the U.S. was introduced from Turkey. Highly significant differences among 45 cultivars and CxE interaction were found for all agronomic and end-use quality traits. Most Turkish wheat cultivars were injured during winter in Nebraska which caused lower grain yields presumably because we sampled the diverse 4 regions of Turkish wheat production and not all regions require high levels of winterhardiness. Highly significant correlations between agronomic traits indicated that grain yield, grain volume weight, and earlier flowering dates were important criteria for the Great Plains breeding programs. Breeding programs in Turkey improved wheat cultivars for specific Turkish environment adaptation which was the reason why some Turkish wheat cultivars were injured by the winter in Nebraska. Principle component analysis and cluster analysis were used to assess genetic diversity based on phenotypic traits. Both analysis methods showed similar results in the agronomic, end-use quality, and agronomic and end-use quality combination data. Generally, most Turkish and Great Plains wheat cultivars were clustered separately. Cluster analysis using agronomic traits revealed that modern Great Plains wheat cultivars diverged from Turkish wheat cultivars through breeding and adaptation. Breeding for wheat end-use quality traits had similar results in both Turkish and U.S. breeding programs. Genetic similarities/distances were estimated by all of the measured traits and all methods were related. The original Great Plains wheat cultivars (Turkey and Kharkof) were clustered apart from modern Great Plains wheat cultivars by both SSR markers and phenotypic clustering. Wheat cultivars from two the countries were obviously separately by the combination of agronomic and end-use quality trait clustering; however, SSR clustering showed a relationship among the wheat cultivars from both countries. Our results suggested that breeding programs in Turkey and U.S. selected wheat cultivars for specific environmental adaptation as would be measured by the agronomic data but genetic background of two wheat groups has been maintained in many lines as was identified by SSR data. Turkish wheat cultivars, Karasu-90, Alparslan, Lancer, Dogu 88, Harmankaya, and Yildirim had good agronomic and end-use quality performance and good adaptation to Nebraska environments. These results suggest that they would be useful as parents for crossing with Great Plains wheat cultivars.

REFERENCES

Akar, T., S. Yazar, E. Dönmez, M. Avcı, and F. Düşünceli. 2007. Current status of national winter wheat breeding in Turkey. J. Agric. Res. 45(1):1-8.

Altintas, S., F. Toklu, S. Kafkas, B. Kilian, A. Brandolini, and H. Ozkan. 2008. Estimating genetic diversity in durum and bread wheat cultivars from Turkey using AFLP and SAMPL markers. Plant breeding. 127:9-14.

Annicciarico, P., C. Royo, F. Bellah, and M. Moragues. 2009. Relationships among adaptation patterns, morphophysiological traits and molecular markers in durum wheat. Plant Breeding. 128:164-171.

Baenziger, P.S., D.R. Shelton, M.J. Shipman, and R.A. Graybosch. 2001. Breeding for end-use quality: Reflections on the Nebraska experience. Euphytica. 119:95-100.

Bilgin, O.; K.Z. Korkut. 2005. Determination of Some Bread Quality and Grain Yield Characters in Bread Wheat (*Triticum aestivum* L.). International Journal of Agriculture-and Biology. 7(1): 125-128.

Budak, H., P. S. Baenziger, R. A. Graybosch, B. S. Beecher, K. M. Eskridge, and M. J. Shipman. 2003. Genetic and environmental effects on dough mixing characteristics and agronomic performance of diverse hard red winter wheat genotypes. Cereal Chemistry. 80(5):518-523.

Cox, T.S., J. P. Shroyer, Liu Ben-Hui, R. G. Sears, and T. J. Martin. 1988. Genetic improvement in agronomic traits of hard red winter wheat cultivars from 1919 to 1987. Crop Sci. 28:756-76.

Cox, T.S., M. D. Shogren, R. G. Sears, T. J. Martin and L. C. Bolte. 1989. Genetic Improvement in Milling and Baking Quality of Hard Red Winter Wheat Cultivars, 1919 to 1988. Crop Sci 29:626-631

Cui. Z., T.E. Carter, Jr., J.W. Burton, and R. Wells. 2001. Phenotypic diversity of modern Chinese and north American soybean cultivars. Crop Sci. 41:1954-1967.

Dalrymple, D.G. 1988. Changes in wheat varieties and yields in the United States, 1919-1984. Agriculture History. 62(4):20-36.

Dong, H. RG, Sears, TS Cox, RC Hoseney. G.L. Lookhart and M.D. Shogren. 1992. Relationships between protein composition and mixograph and loaf characteristics in wheat. Cereal Chem. 69 (2): 132-136

Donmez, E., R. G. Sears, J. P. Shroyer, and G. M. Paulsen. 2001. Genetic gain in yield attributes of winter wheat in the Great Plains. Crop Sci. 41:1412-1419.

Eberhart, S.A., and W.A. Russell. 1966. Stability parameters for comparing varieties. Crop Sci. 6:36-40.

Finlay, K.W. and G.N. Wilkinson. 1963. The analysis of adaptation in a plant-breeding programme. Australian Journal of Agricultural Research 14(6) 742 – 754

Flury, B and H. Riedwyl. 1986. Standard distance in univariate and multivariate analysis. The American Statistician. 40:249-251.

Fufa, H. 2004. Improvement trends, phenotypic and molecular diversity among hard red winter wheat cultivars in Nebraska. University of Nebraska-Lincoln dissertation. NE.

Fufa, H., P. S. Baenziger, B. S. Beecher, R. A. Graybosch, K. M. Eskridge, and L. A. Nelson. 2005. Genetic improvement trends in agronomic performances and end-use quality characteristics among hard red winter wheat cultivars in Nebraska. Euphytica. 144:187-198.

Fufa, H., P.S. Baenziger, B.S. Beecher, I. Dweikat, R.A. Graybosch, and K.M. Eskridge. 2005. Comparison of phenotypic and molecular marker-based classifications of hard red winter wheat cultivars. Euphytica. 145:133-146.

Gomez, A.K., and A.A. Gomez. 1984. Statistic procedures for agriculture research. Wiley, New York. 332 p.

Graybosh, R.A. 2001. Uneasy Unions: Quality Effects of Rye Chromatin Transfers to Wheat. Journal of Cereal Science 33: 3-16

Groos, C., N. Robert, E. Bervas, and G. Charmet. 2003. Genetic analysis of grain protein-content, grain yield and thousand-kernel weight in bread wheat. Theor Appl Genet. 106:1032-1040.

Hamza, S., W. B. Hamida, Ahmed Rebaï and Moncef Harrabi. 2004. SSR-based genetic diversity assessment among Tunisian winter barley and relationship with morphological traits. Euphytica 135: 107-118

Karagoz, A., and N. Zencirci. 2005. Variation in wheat (*Triticum* spp.) landraces from different altitudes of three regions of Turkey. Genetic Resources and Crop Evolution. 52:775-785.

Kumlay, A. M., P. S. Baenziger, K. S. Gill, D. R. Shelton, R. A. Graybosch, A. J. Lukaszewski, and D. M. Wesenberg. 2003. Understanding the effect of rye chromatin in bread wheat. Crop Science 43: 1643-1651.

Lin, C.S., M. R. Binns and L. P. Lefkovitch. 1986. Stability Analysis: Where Do We Stand?. Crop Sci 26:894-900.

Maric, S., S. Bolaric, J. Martincic, I. Pejic, and V. Kozumplik. 2004. Genetic diversity of hexaploid wheat cultivars estimated by RAPD markers, morphological traits and coefficients of parentage. Plant breeding. 123:366-369.

Mishra, R., P. S. Baenziger, W. K. Russell, R. A. Graybosch, D. D. Baltensperger, and K. M. Eskridge. 2006. Crossover Interactions for Grain Yield in Multienvironmental Trials of Winter Wheat. Crop Sci.46:1291-1298

Moghaddam, M.E., R.M. Trethowan, H.M. William, A. Rezai, A. Arzani, and A.F. Mirlohi. 2005. Assessment of genetic diversity in bread wheat genotypes for tolerance to drought using AFLPs and agronomic traits. Euphytica. 141:147-156.

Moreno-Sevilla, B., P. S. Baenziger, D. R. Shelton, R. A. Graybosch, and C. J. Peterson. 1995. Agronomic performance and end-use quality of 1B vs. 1BL/1RS genotypes derived from winter wheat 'Rawhide'. Crop Sci 35:1607-1612.

Olgun, M., T. Yildirim and M. Turan. 2005. Adaptation of wheat genotypes (*Triticum aestivum* L.) to cold climate. Acta Agriculturae Scandinavica Section B-Soil and Plant. 55:9-15.

Ozturk, A., and F. Aydin. 2004. Effect of water stress at various growth stages on some quality characteristics of winter wheat. J. Agronomy and Crop Science. 109:93-99.

Paulsen, G.M. 2003. A history of wheat improvement at Kansas State University. Keeping up with research. Kansas state university agricultural experiment station and cooperative extension service.

Peterson, C.J. 1992. Similarities among Test Sites Based on Cultivar Performance in the Hard Red Winter Wheat Region. Crop Sci 32:907-912.

Peterson, C.J., and W. H. Pfeiffer. 1989. International winter wheat evaluation: relationships among test sites based on cultivar performance**.** Crop Sci. 29:276-282.

Peterson, C.J., R. A. Graybosch, P. S. Baenziger, and A. W. Grombacher. 1992. Genotype and environment effects on quality characteristics of hard red winter wheat. Crop Sci. 32:98-103.

Peterson, C.J., R.A. Graybosch, D.R. Shelton, and P.S. Baenziger. 1998. Baking quality of hard winter wheat: Response of cultivars to environment in the Great Plains. Euphytica. 100:157-162.

Peterson, C.J., V.A. Johnson, J.W. Schmidt, and R.F. Mumm. 1989. Genetic improvement and the variability in wheat yields in the Great Plains. p. 175-184. *In* J.R. Anderson, and P.B.R. Hazell (ed.) Variability in grain yields implications for agricultural research and policy in developing countries.

Quisenberry, K.S., and L.P. Reitz. 1974. Turkey wheat: the cornerstone of an empire. Agricultural History. 48:98-110.

Russell, W.K., K. M. Eskridge, D. A. Travnicek, and F. R. Guillen-Portal. 2003. Clustering environments to minimize change in rank of cultivars. Crop Sci. 43:858-864.

Schmidt, J.W. 1974. The role of Turkey wheat germplasm in wheat improvement. Transactions of the Kansas Academy of Science. 77(3):159-172.

Schmidt, J.W. 1984. Genetic contribution to yield gains in wheat. p 89-101. *In* W.R. Fehr (ed.) Genetic Contribution to Yield Gains of Five Major Crop Plants. ASA-CSSA Madison, Wisconsin.

Tabachnick, B.G., and L.S. Fidell. 2001. Using multivariate statistics. Allyn & Bacon, Inc. MA. p 80.

Tsõmbalova; J., M. Haljak, A. Ingver, and K.Järve. 2008. Acta Agriculturae Scandinavica, Section B - Plant Soil Science. 58:97-104.

Vieira, E.A., F. I. Félix de Carvalho, I.Bertan, M. M. Kopp, P. D. Zimmer, G. Benin, J. A. Gonzalez da Silva2, I. Hartwig, G. Malone and A. Costa de Oliveira. 2007. Association between genetic distances in wheat (Triticum aestivum L.) as estimated by AFLP and morphological markers. Genetics and Molecular Biology. 30 (2): 392-399

Weber W.E, and G. Wricke. 1990. Genotype x environment interaction and its implications in plant breeding. p. 1-19. *In* M.S. Kang (ed.) Genetic-by-Environment interaction and plant breeding. Louisiana State University. Baton Rouge, Louisiana.

Table 1 Analysis of variance for nine agronomic traits from six environments

		Mean Squares								
Source of variance	df	Grain Yield (kg/ha)	Number of spike per m^2	Grain Volume Weight (kg /hL)	Winter Survival (%)	Days of Flowering (day)	Plant Height (cm)	Kernel number per spike	Thousand Kernel weight (g)	Kernel weight per spike (g)
Environment	5	181431094	2158478	4510	1598.27	3873.1	8677.22	2977.9	3071.719	9.839
Iblock (Env)	138	389455	8009	3.586	74.07	1.33	21.577	13.235	5.397	0.0235
Cultivar	44	4836914 **	129553 **	107.52 **	1897.52 **	32.50 **	655.21 **	221.89 **	75.21 **	0.3502 **
C x E	220	559874 **	9950 **	16.44 **	208.91 **	1.84 **	37.20 **	22.32 **	14.83 **	0.0567 **
MSE	305	128902	4140	1.494	37.429	0.509	11.41	10.81	3.4	0.0168
Mean	-	3748	437	74.62	90	148	92	33	33.5	1.11
C.V. (%)	-	9.58	14.72	1.64	6.79	0.48	3.66	10.03	5.51	11.73

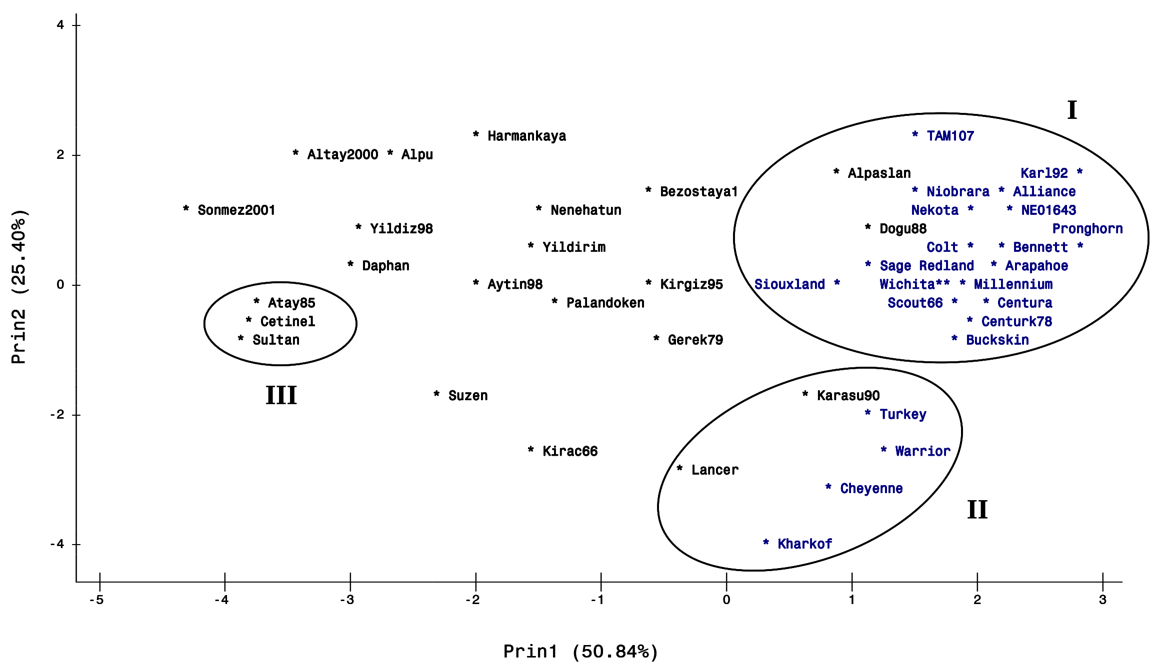


Figure 1 Principle component analysis plot using nine agronomic variables

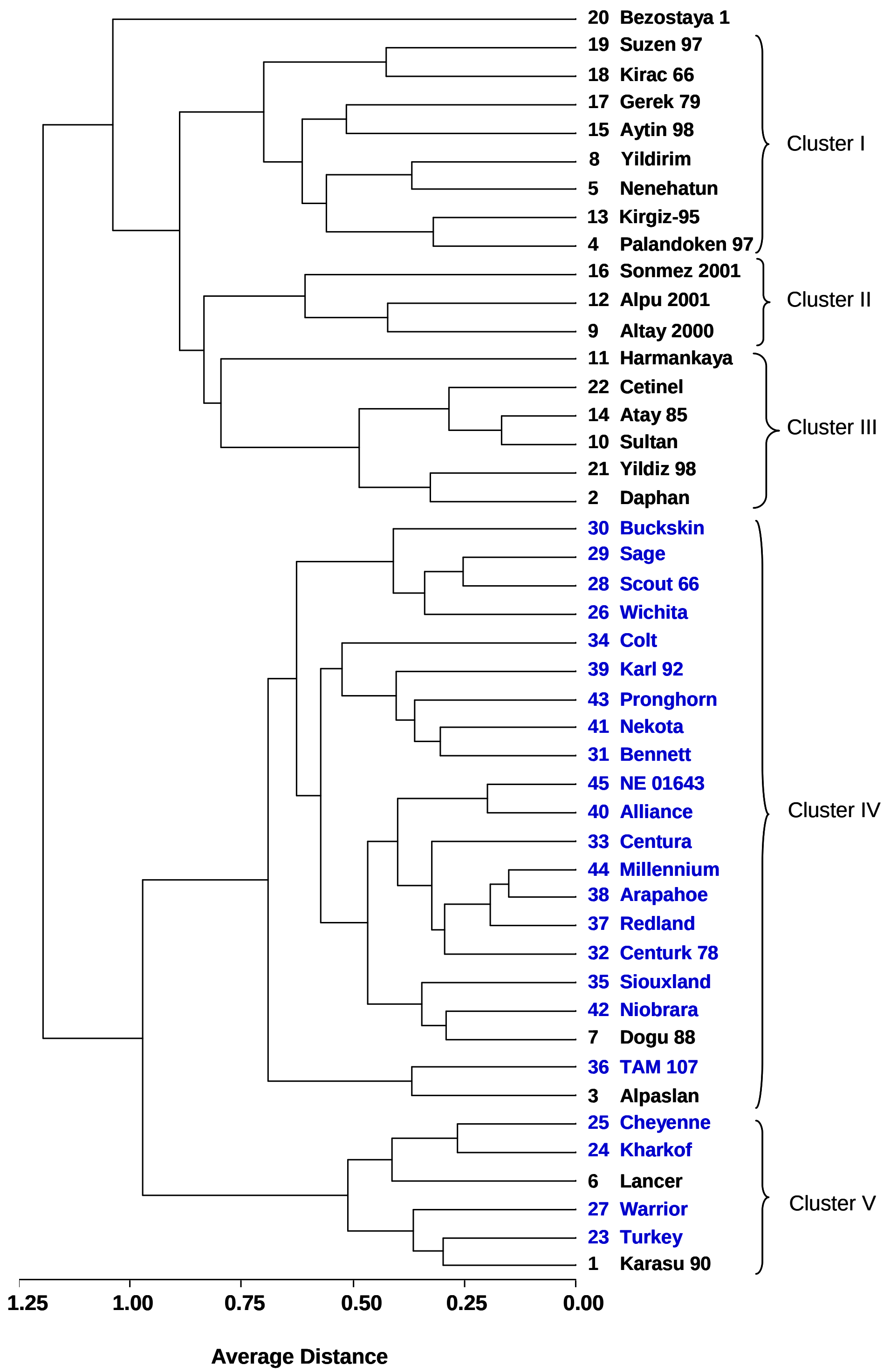


Figure 2 Dendrogram of 45 wheat cultivars based on nine agronomic traits using the average linkage clustering method

Table 2 Analysis of variance for four quality traits from six environments

		Mean Squares			
Source of variance	df	Flour Yield[a] (g)	Protein content[b] (g)	Mixing Time (min)	Mixing Tolerance (0-7)
Environment	5	431.36	9345.14	2.9222	6.3963
Iblock (Env)	44	2.2608	70.9034	0.124	0.3033
Cultivar	102	17.7301**	329.3**	4.8862**	9.0130**
C x E	220	2.02096*	54.2144**	0.2509**	0.4003**
MSE	168	1.4729	15.5898	0.1150	0.1389
Mean	-	34.44	123.01	3.16	3.40
C.V. (%)	-	3.52	3.21	10.74	10.97

*, ** highly significant at 5% and 1%, respectively; df = degree of freedom

[a] Flour yield from 50 g of grain; [b] flour protein from 1000 g of flour

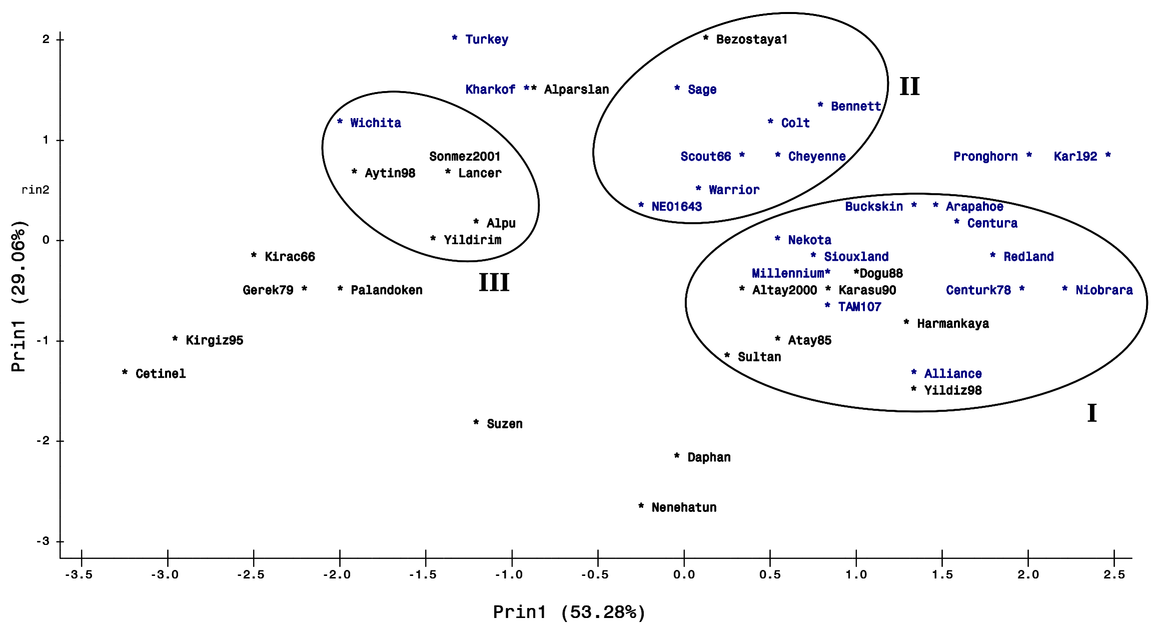


Figure 3 Principle component analysis plot using four quality variables

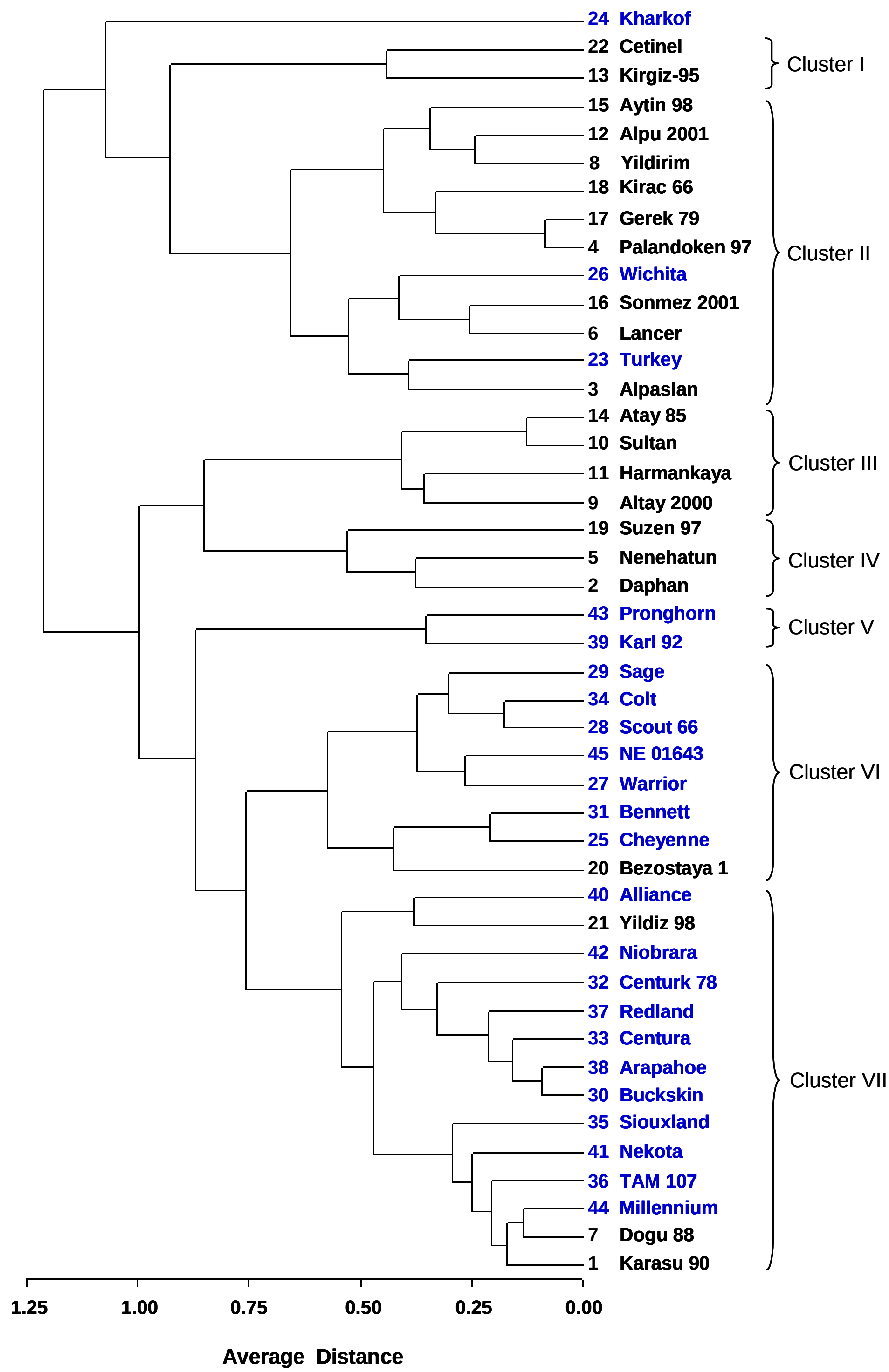


Figure 4 Dendrogram of 45 wheat cultivars based on end-use quality traits using average linkage clustering method

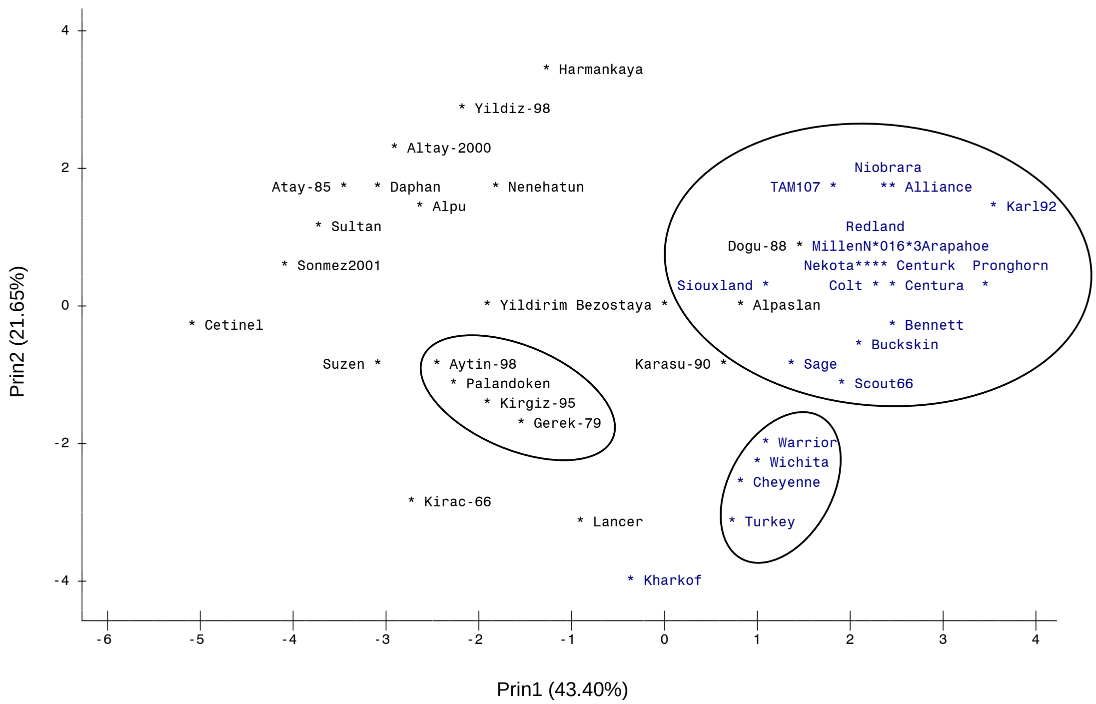


Figure 5 Principle component analysis plot using agronomic and end-use quality variables

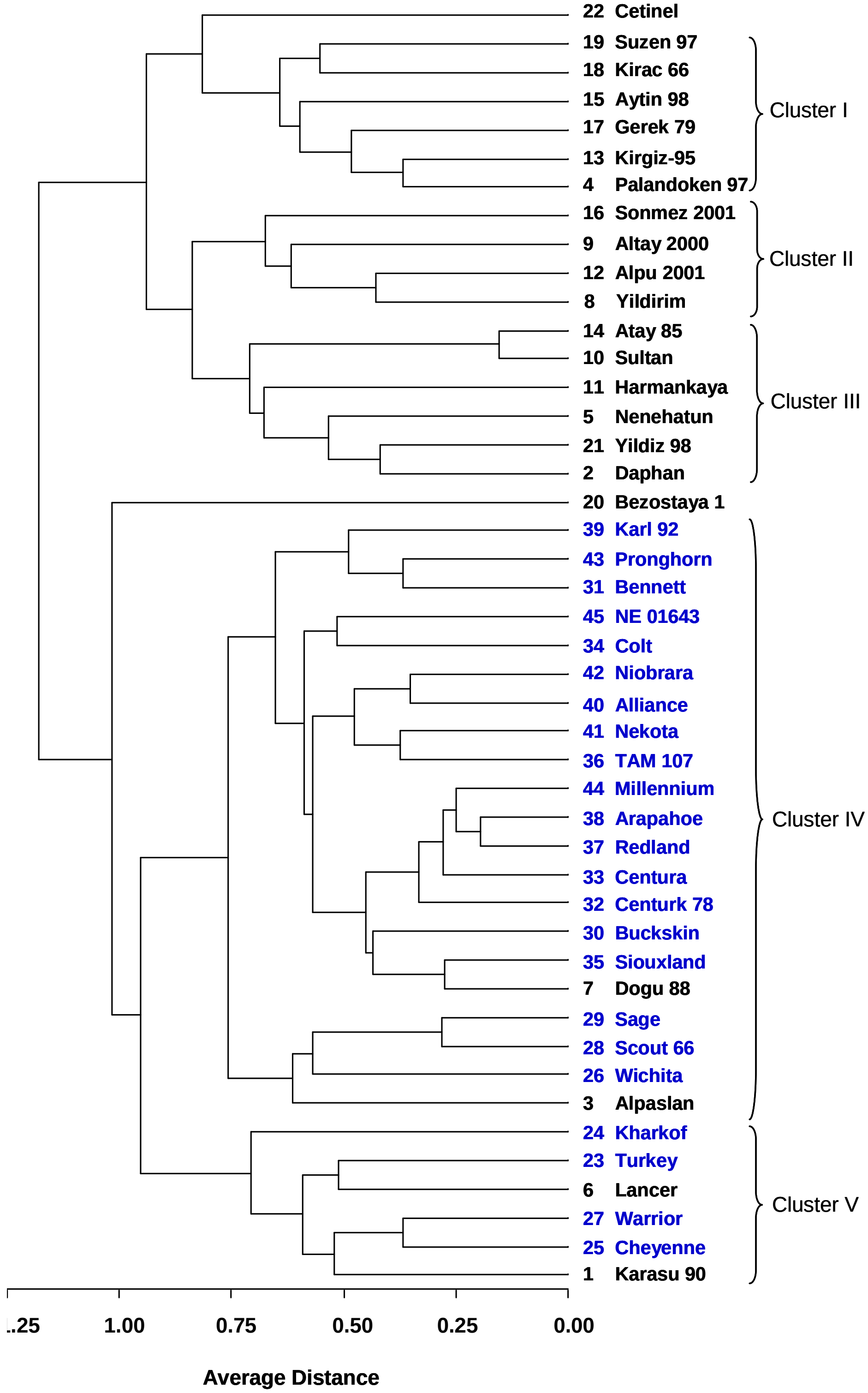


Figure 6 Dendrogram of 45 wheat cultivars based on agronomic and end-use quality traits using average linkage clustering method

APPENDICES

Appendix 1 Analysis of variance of nine agronomic traits from each environment

		Mean Squares								
Source of variance	df	Grain Yield	Number of spike per m^2	Test Weight (kg /hL)	Winter Survival (%)	Days of Flowering	Plant Height (cm)	Kernel number per spike	Thousand Kernel weight (g)	Kernel weight per spike (g)
Lincoln 2007										
Rep	2	6387356	55917	11.41	414.63	12.41	31.25	0.38	13.37	0.0229
Block (rep)	24	261483	11462	24.72	125.66	1.139	21.88	23.77	6.66	0.02617
Cultivar	44	2283276	41409	40.84	1126.86	13.358	158.92	75.19	33.29	0.0816
MSE	64	100604	5648.98	1.1	58.41	0.9366	8.98	19.271	6.65	0.0214
P-Value	-	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
C.V. (%)	-	9.47	17.76	1.35	9.75	0.6859	3.86	13.25	8.29	14.84
Lincoln 2009										
Rep	1	321951	18918	4.377	87.6	20.556	39.86	30.003	0.369	0.0629
Block (rep)	16	346187	5783.9	1.213	128.59	1.242	41.41	11.7	3.756	0.0200
Cultivar	44	801982	19353	4.39	261.68	4.809	121.046	56.0756	20.526	0.162
MSE	23	203949	5030.96	0.93	29.44	0.7006	19.819	15.471	2.603	0.0233
P-Value	-	0.0004	0.0005	<.0001	<.0001	<.0001	<.0001	0.0008	<.0001	<.0001
C.V. (%)	-	9.588	17.19	1.2008	6.17	0.581	5.23	10.31	4.165	10.266
Mead 2008										
Rep	1	10570	1339	0.0017	71.11	0.044	90.00	68.57	16.73	0.0007
Block (rep)	16	52896	1262	8.23	41.05	0.227	22.27	3.63	3.043	0.0059
Cultivar	44	500736	12156	83.86	216.43	4.61	66.25	39.018	29.79	0.0288
MSE	28	37229	2338.71	3.25	23.11	0.225	17.31	7.52	3.58	0.005
P-Value	-	<.0001	<.0001	<.0001	<.0001	<.0001	0.0002	<.0001	<.0001	<.0001
C.V. (%)	-	12.71	18.43	2.97	5.19	0.307	4.61	8.72	8.33	10.04
Mead 2009										
Rep	2	490286	22638	62.989	155.18	0.8714	90.67	17.192	20.846	0.0794
Block (rep)	24	221683	2738	2.349	88.3	1.2623	11.22	18.565	7.517	0.0414
Cultivar	44	2337797	23846	39.473	1065.07	10.3855	168.706	58.45	29.292	0.1593
MSE	61	183564	2469	2.055	25.195	0.2956	10.248	10.4285	2.438	0.0219
P-Value	-	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
C.V. (%)	-	11.59	14.44	1.905	5.9	0.371	3.617	8.679	4.233	10.757
North Platte 2008										
Rep	2	187184	13628	1.743	133.89	2.49	14.21	8.49	1.55	0.0224
Block (rep)	24	406768	6836	1.062	67.02	0.69	12.86	5.73	2.45	0.0108
Cultivar	44	1651475	58942	13.346	492.57	5.27	192.53	101.84	20.78	0.17781
MSE	64	149959	4241	1.697	57.92	0.48	11.65	6.42	2.51	0.0096
P-Value	-	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
C.V. (%)	-	7.17	11.02	1.7	8.2	1.97	3.26	7.66	4.4	8.18
North Platte 2009										
Rep	2	1523715	33554	5.78	11.851	1.029	111.0296	7.4868	27.668	0.0492
Block (rep)	24	353165	9198.98	1.39	22.49	0.443	8.61	4.097	3.851	0.00997
Cultivar	44	988818	51578	5.46	209.548	7.506	253.41	37.753	24.231	0.0877
MSE	64	97176	4612.84	0.67	22.185	0.207	9.093	4.311	2.311	0.007
P-Value	-	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
C.V. (%)	-	8.062	11.276	1.05	4.996	0.306	2.99	8.547	4.467	10.067

Appendix 2 Least square mean of nine agronomic traits and slopes of grain yield response to different Nebraska environments based on Eberhart and Russell (1966)

Cultivars	Days of Flowering (day)	Plant Height (cm)	Kernel number per spike	Number of spike per m^2	Grain Volume Weight (kg /hL)	Thousand Kernel weight (g)	Kernel weight per spike (g)	Grain Yield (kg/ha)	Winter Survival (%)	Slope (b)* of Grain Yield
Karasu-90	148	100	29	433	73.7	31.07	0.90	3236	93	0.97
Daphan	150	84	38	301	71.9	33.03	1.25	3085	66	1.03
Alparslan	145	85	33	417	78.0	34.89	1.16	3738	97	0.82
Palandoken-97	148	101	32	300	70.7	36.76	1.17	2977	87	1.10
Nenehatun	148	85	35	331	73.0	35.21	1.24	3470	81	1.02
Lancer	151	101	29	387	71.5	31.10	0.89	2707	98	0.81
Dogu-88	147	90	33	483	77.9	33.45	1.09	4027	97	0.97
Yildirim	150	91	37	358	74.0	34.69	1.28	3731	83	1.01
Altay-2000	149	93	43	245	74.7	36.83	1.59	3263	70	1.08
Sultan	152	87	42	307	67.3	30.40	1.27	3241	70	1.04
Harmankaya	148	76	42	341	72.6	34.24	1.44	3800	92	0.98
Alpu-2001	150	84	40	304	74.2	37.25	1.51	3662	78	1.00
Kirgiz-95	148	96	31	370	72.6	35.46	1.12	3380	87	1.02
Atay-85	151	88	42	306	67.6	31.09	1.32	3310	70	1.13
Aytin-98	149	88	31	345	72.5	34.48	1.12	2989	60	0.83
Sonmez-2001	149	91	39	206	71.4	37.22	1.46	2432	56	0.89
Gerek-79	148	91	29	404	71.0	32.67	0.96	3167	80	1.02
Kirac-66	150	100	31	322	70.9	29.97	0.95	2552	78	0.92
Suzen	151	98	34	318	69.1	32.75	1.12	2877	79	1.10
Bezostaya-1	148	96	32	312	75.4	40.23	1.32	3358	99	1.00
Yildiz-98	149	82	41	325	70.1	31.96	1.30	3512	71	1.18
Cetinel	151	86	40	257	66.0	31.59	1.29	2994	79	1.31
Turkey	149	105	29	464	75.9	31.55	0.93	3406	100	0.97
Kharkof	152	109	27	416	74.0	30.05	0.83	2805	99	0.90
Cheyenne	152	106	28	485	74.9	30.44	0.85	3346	99	1.02
Wichita	146	99	27	465	77.4	35.59	0.97	3545	99	0.88
Warrior	150	102	29	526	74.0	29.90	0.85	3730	100	1.17
Scout66	148	99	27	499	78.3	35.86	0.97	3873	98	0.91
Sage	148	97	30	467	77.3	35.53	1.10	3971	98	0.94
Buckskin	148	105	30	530	76.6	33.66	0.99	4219	100	1.30
Bennett	146	91	27	521	77.9	35.12	0.97	3969	100	0.89
Centurk78	148	95	34	593	77.4	29.05	0.98	4510	100	1.13
Centura	148	93	30	568	78.1	32.38	0.97	4317	99	1.08
Colt	147	79	30	568	77.4	31.28	0.94	4224	99	0.85
Siouxland	148	97	34	480	76.1	32.87	1.13	4200	98	1.05
TAM107	145	84	30	479	77.4	37.60	1.15	4240	99	0.92
Redland	148	92	33	573	75.9	30.54	1.01	4738	99	0.83
Arapahoe	148	91	32	601	77.6	31.71	1.03	4893	100	1.04
Karl92	145	81	27	592	78.2	34.89	0.96	4537	100	0.89
Alliance	147	89	32	596	77.9	33.90	1.10	5067	99	1.08
Nekota	147	84	29	547	78.0	35.21	1.02	4286	100	0.73
Niobrara	147	90	32	521	76.9	35.16	1.13	4613	100	1.11
Pronghorn	146	95	28	597	78.4	34.32	0.97	4598	100	1.20
Millennium	149	91	33	592	77.5	31.34	1.02	4822	100	1.02
NE01643	148	88	33	619	78.7	32.83	1.09	5231	100	0.86
Mean	148	92	33	437	74.62	33.5	1	3748	90	-
LSD	1.21	5.71	5.55	109	2.1	3.11	0.22	606	10	-

* Slope of grain yield response to different Nebraska environments

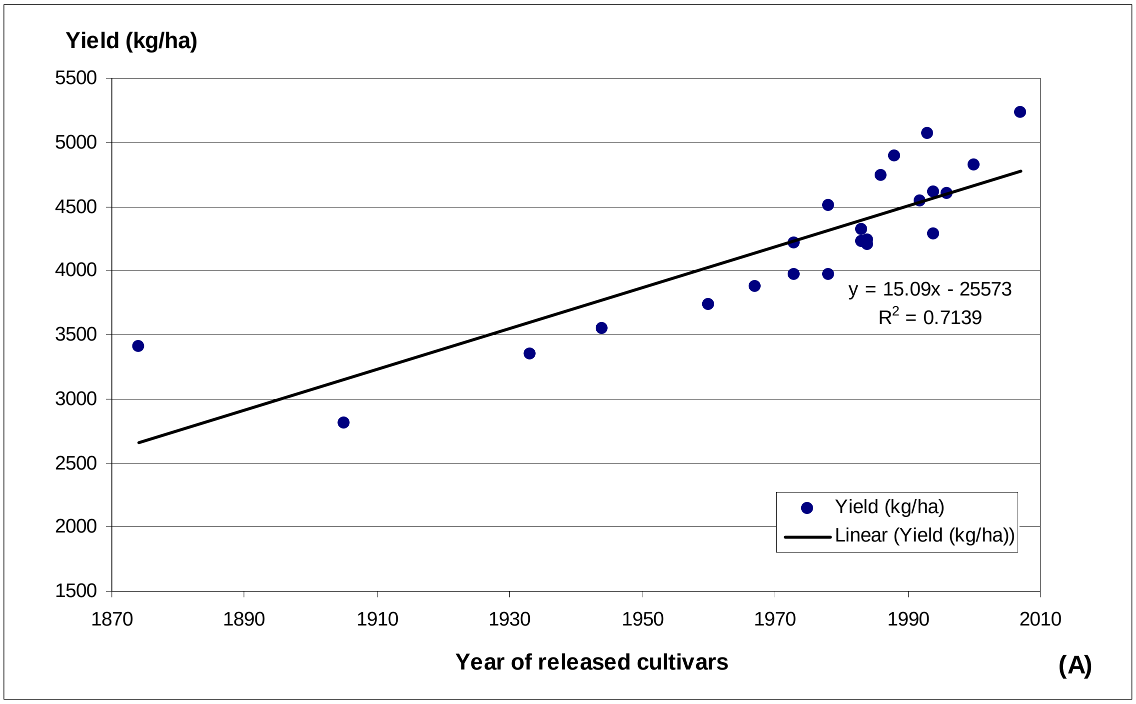
Appendix 3 Single degree of freedom contrast analysis of means for agronomic traits

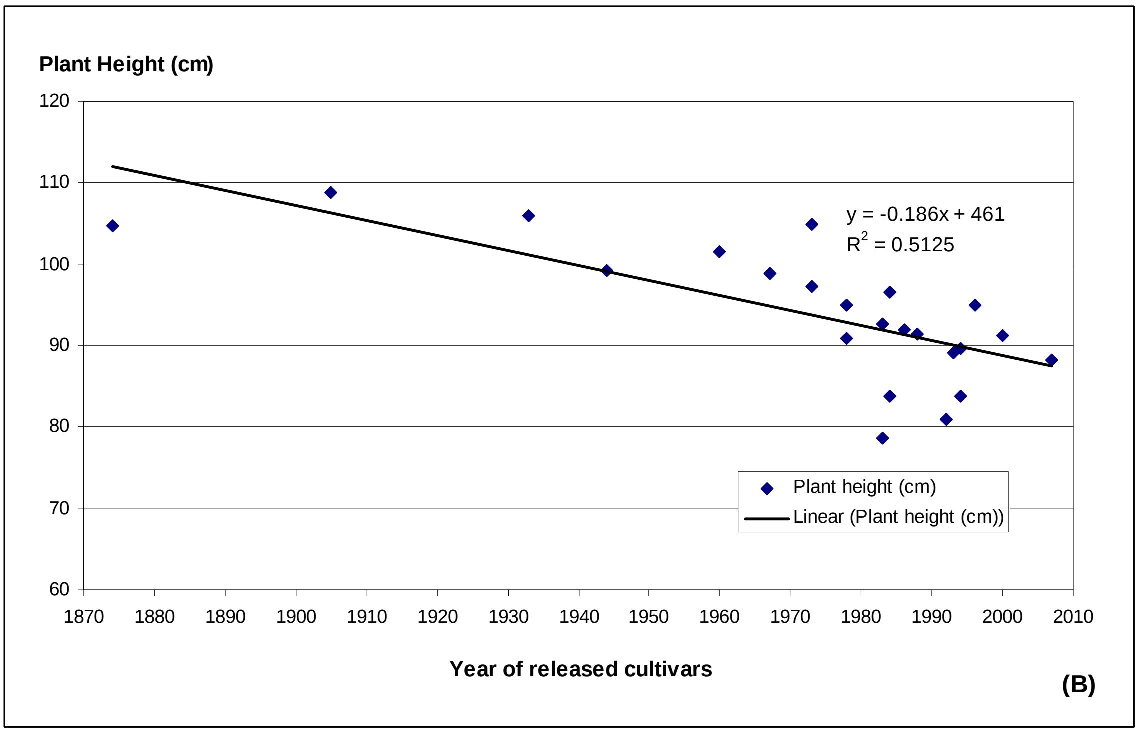
Mean	Grain Yield (kg/ha)	Number of spike per m^2	Grain Volume Weight (kg /hL)	Winter Survival (%)	Days of Flowering (day)	Plant Height (cm)	Kernel number per spike	Thousand Kernel weight (g)	Kernel weight per spike (g)
Turkish wheat	3250	335	72.09	80	149	91	36	33.9	1.22
Great Plains wheat	4223	535	77.03	100	148	94	30	33.1	1.00
P-value contrast	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001

Appendix 4 Simple correlation coefficient among nine agronomic traits of 45 wheat cultivar means averaged over six environments

	Days of Flowering (day)	Plant Height (cm)	Kernel number per spike	Number of spike per m^2	Grain Volume Weight (kg /hL)	Thousand Kernel weight (g)	Kernel weight per spike (g)	Grain Yield (kg/ha)	Winter Survival (%)
Days of Flowering (day)	1.0000	0.3277 *	0.3827 **	-0.4968 **	-0.6952 **	-0.4729 **	0.1183 ns	-0.5639 **	-0.4504 **
Plant Height (cm)		1.0000	-0.4919 **	0.0682 ns	0.0277 ns	-0.2237 ns	-0.5150 **	-0.2742 ns	0.2785 ns
Kernel number per spike			1.0000	-0.6204 **	-0.5652 **	0.0392 ns	0.8700 **	-0.2104 ns	-0.6723 **
Number of spike per m^2				1.0000	0.8026 **	-0.2600 ns	-0.6755 **	0.8532 **	0.8106 **
Grain Volume Weight (kg /hL)					1.0000	0.2193 ns	-0.3834 **	0.7517 **	0.7421 **
Thousand Kernel weight (g)						1.0000	0.5175 **	-0.0138 ns	-0.0915 ns
Kernel weight per spike (g)							1.0000	-0.2120 ns	-0.6365 **
Grain Yield (kg/ha)								1.0000	0.6409 **
Winter Survival (%)									1.000

**highly significant at 1%; * significant at 5%





Appendix 5 Relationship between years of released cultivars and grain yield (A) and plant height (B) from the Great Plains

Appendix 6 Analysis of variance of four end-use quality traits using grain harvested from each of six environments

Mean Squres					
Source of variance	df	Flour yield[a] (g)	Protein content[b] (g)	Mixing tolerance (0-7)	Mixing Time (min)
Lincoln 2007					
Rep	1	9.9610	33.678	5.7209	0.2725
Block (rep)	16	3.1021	36.543	0.3750	0.0934
Cultivar	44	4.2262	87.458	2.1250	1.0297
MSE	28	2.3338	26.283	0.2693	0.0869
P-Value	-	0.051	0.0007	<.0001	<.0001
C.V. (%)	-	4.351	4.61	16.33	9.64
Lincoln 2009					
Rep	1	15.3099	717.9737	1.3444	0.0071
Block (rep)	16	3.0235	80.3324	0.2824	0.1406
Cultivar	44	4.4199	108.9147	2.2665	1.3637
MSE	28	2.1416	24.0066	0.1142	0.1927
P-Value	-	0.022	<.0001	<.0001	<.0001
C.V. (%)	-	4.068	3.95	9.38	14.27
Mead 2008					
Rep	1	1.7109	0.9384	0.1361	0.3459
Block (rep)	16	2.3329	34.2840	0.2180	0.1341
Cultivar	44	8.7129	106.3043	1.8363	0.9745
MSE	28	2.1457	6.3692	0.1830	0.0908
P-Value	-	0.0001	<.0001	<.0001	<.0001
C.V. (%)	-	4.889	1.846	12.52	9.60
Mead 2009					
Rep	1	0.6829	0.0401	0.2250	0.0098
Block (rep)	16	1.0518	21.4141	0.2031	0.0919
Cultivar	44	5.1305	87.5049	1.8383	0.7794
MSE	28	0.6279	5.7881	0.1057	0.0854
P-Value	-	<.0001	<.0001	<.0001	<.0001
C.V. (%)	-	2.262	1.812	8.63	9.28
North Platte 2008					
Rep	1	2.6001	0.2624	0.1000	0.0418
Block (rep)	16	0.7488	20.762	0.1430	0.0466
Cultivar	44	2.4389	149.8714	1.6627	0.9067
MSE	28	0.4509	10.0007	0.0664	0.0554
P-Value	-	<.0001	<.0001	<.0001	<.0001
C.V. (%)	-	1.932	2.63	7.59	7.78
North Platte 2009					
Rep	1	13.6344	2878.6777	1.4062	1.0956
Block (rep)	16	0.5519	32.1726	0.1423	0.1709
Cultivar	44	1.8629	85.9255	2.0122	1.3654
MSE	28	0.4666	21.4724	0.0994	0.1775
P-Value	-	0.0001	<.0001	<.0001	<.0001
C.V. (%)	-	1.91	4.10	10.34	12.00

[a] Flour yield from 50 g of grain; [b] flour protein from 1000 g of flour

Appendix 7 Least square mean of four end-use quality traits from six Nebraska environments

Cultivars	Flour Yield[a] (g)	Protein content[b] (g)	Mixing Time (min)	Mixing Tolerance (0-7)
Karasu-90	34.98	117.5	3.58	3.60
Daphan	32.05	114.4	3.58	3.22
Alparslan	35.08	130.3	2.22	3.44
Palandoken-97	32.81	124.1	2.40	1.92
Nenehatun	32.22	109.0	3.24	2.90
Lancer	35.04	126.0	2.36	2.22
Dogu-88	35.39	118.3	3.42	3.69
Yildirim	33.48	126.9	2.73	2.27
Altay-2000	33.43	123.2	3.60	3.85
Sultan	31.86	123.8	4.01	3.81
Harmankaya	33.52	121.2	4.15	4.46
Alpu-2001	34.32	126.4	2.94	1.97
Kirgiz-95	32.25	120.6	1.74	1.21
Atay-85	32.26	123.3	4.10	4.00
Aytin-98	33.74	130.4	2.36	2.12
Sonmez-2001	34.52	125.7	2.10	2.77
Gerek-79	32.77	124.3	2.27	1.77
Kirac-66	32.04	128.8	2.42	1.75
Suzen	31.88	117.7	3.22	2.06
Bezostaya-1	35.54	134.2	2.95	4.17
Yildiz-98	33.98	113.6	3.87	4.21
Cetinel	30.59	123.3	2.04	1.23
Turkey	35.69	134.2	2.27	2.60
Kharkof	32.93	138.0	2.85	3.98
Cheyenne	35.11	127.9	3.34	4.11
Wichita	35.31	128.6	2.10	1.51
Warrior	35.38	122.9	2.90	3.45
Scout66	36.18	122.4	2.59	3.93
Sage	35.94	128.0	2.53	3.89
Buckskin	35.65	122.1	3.72	4.26
Bennett	35.98	128.2	3.40	4.06
Centurk78	34.86	119.3	4.23	4.70
Centura	35.50	121.0	3.76	4.58
Colt	36.31	124.5	2.84	3.94
Siouxland	35.57	120.0	3.62	3.31
TAM107	35.01	115.4	3.25	3.87
Redland	35.73	119.1	4.02	4.34
Arapahoe	35.79	122.3	3.88	4.18
Karl92	35.36	128.9	4.67	5.36
Alliance	35.24	111.0	3.60	3.84
Nekota	35.64	118.5	3.05	3.62
Niobrara	36.17	115.7	4.26	4.30
Pronghorn	35.85	126.2	4.12	4.99
Millennium	35.28	117.9	3.36	4.05
NE01643	35.44	120.5	2.44	3.36
Mean	34.44	123.01	3.16	3.40
LSD	2.05	6.7	0.57	0.63

[a] Flour yield from 50 g of grain; [b] flour protein from 1000 g of flour

Appendix 8 Single degree of freedom contrast analysis of means for four end-use quality traits

Mean	Flour Yield[a] (g)	Protein content[b] (g)	Mixing Time (min)	Mixing Tolerance (0-7)
Turkish wheat	33.35	122.87	2.97	2.85
Great Plains wheat	35.47	123.15	3.34	3.92
P-value contrast	<.0001	0.5623	<.0001	<.0001

[a] Flour yield from 50 g of grain; [b] flour protein from 1000 g of flour

Appendix 9 Simple correlation coefficients among four end-use quality traits of 45 wheat cultivar means averaged over six environments

	Flour Yield[a] (g)	Protein Content[b] (g)	Mixing Time (min)	Mixing Tolerance (0-7)
Flour Yield[a] (g)	1.0000	0.0755 ns	0.1959 ns	0.5474 **
Protein Content[b] (g)		1.0000	-0.3829 **	-0.1258 ns
Mixing Time (min)			1.0000	0.7914 **
Mixing Tolerance (0-7)				1.0000

** highly significant at 1%; df = degree of freedom

[a] Flour yield from 50 g of grain; [b] flour protein from 1000 g of flour

Appendix 10 Simple correlation coefficients among nine agronomic and four end-use quality traits of 45 wheat cultivar means averaged over six environments

	Flour Yield[a] (g)	Protein Content[b] (g)	Mixing Time (%)	Mixing Tolerance (0-7)
Days of Flowering (day)	-0.5629 **	0.1557 ns	-0.1243 ns	-0.3019 *
Plant Height (cm)	0.1074 ns	0.3872 **	-0.2672 ns	-0.1606 ns
Kernel number per spike	-0.5367 **	-0.2830 ns	0.2014 ns	-0.0813 ns
Number of spike per m^2	0.7458 **	-0.1316 ns	0.3374 *	0.5491 **
Grain Volume Weight (kg /hL)	0.8561 **	0.0116 ns	0.1810 ns	0.5161 **
Thousand Kernel weight (g)	0.1357 ns	0.0543 ns	-0.2023 ns	-0.0952 ns
Kernel weight per spike (g)	-0.4049 **	-0.1756 ns	0.0467 ns	-0.1399 ns
Grain Yield (kg/ha)	0.6472 **	-0.3533 *	0.4830 **	0.5953 **
Winter Survival (%)	0.7063 **	0.0687 ns	0.1623 ns	0.4287 **

** highly significant at 1%; * significant at 5%

[a] Flour yield from 50 g of grain; [b] flour protein from 1000 g of flour

Appendix 11 Eigenvalues and eigenvectors of nine agronomic and four end-use quality traits from six environments

Estimate/Agronomic traits	PC1	PC2	PC3	PC4
Eigenvalues				
Eigenvalues	4.5757	2.2856	1.1596	0.5035
Proportion	0.5084	0.2540	0.1289	0.056
Cumulative	0.5084	0.7624	0.8912	0.9472
Eigenvector				
Days of Flowering	-0.2847	-0.4199	0.2259	0.4138
Plant Height	0.0938	-0.5090	-0.3895	0.5396
Kernel per Spike	-0.3672	0.2385	0.3788	0.3519
Spike per m^2	0.4417	0.0116	0.2740	0.0312
Grain volume weight	0.4073	0.2163	-0.0965	0.2393
Thousand kernel weight	-0.0408	0.4510	-0.6439	0.1760
Weight per spike	-0.3407	0.4124	-0.0023	0.3898
Grain yield	0.3461	0.2918	0.3933	0.2941
Winter survival	0.4206	-0.0465	-0.0118	0.2933

Estimate/Quality traits	PC1	PC2	PC3	PC4
Eigenvalues				
Eigenvalues	2.1313	1.1626	0.6003	0.1059
Proportion	0.5328	0.2906	0.1501	0.0265
Cumulative	0.5328	0.8235	0.9735	1.0000
Eigenvector				
Flour Yield	0.3995	0.5896	-0.6415	0.2850
Protein Content	-0.2491	0.7486	0.5972	0.1447
Mixing Time	0.6036	-0.2555	0.4199	0.6277
Mixing Tolerance	0.6434	0.1634	0.2356	-0.7098

Estimate/Agronomic-Quality traits	PC1	PC2	PC3	PC4
Eigenvalues				
Eigenvalues	5.6423	2.8144	1.8380	0.9436
Proportion	0.4340	0.2165	0.1414	0.0726
Cumulative	0.4340	0.6505	0.7919	0.8645
Eigenvector				
Days of Flowering	-0.2678	-0.1850	0.4037	0.1868
Plant Height	0.0396	-0.4790	0.1054	0.2195
Kernel per Spike	-0.2822	0.3765	0.1184	0.1264
Spike per m^2	0.3994	-0.0133	0.1357	-0.1669
Grain volume weight	0.3803	0.0402	-0.2134	0.0628
Thousand kernel weight	-0.0200	0.1731	-0.6473	0.1752
Weight per spike	-0.2591	0.3899	-0.2217	0.2107
Grain yield	0.3420	0.2561	0.0525	-0.1543
Winter survival	0.3673	-0.1307	0.0065	-0.0067
Flour Yield	0.3629	0.0008	-0.1470	0.2038
Protein Content	-0.0232	-0.3577	-0.1906	0.6299
Mixing Time	0.1456	0.3633	0.4005	0.3060
Mixing Tolerance	0.2648	0.2612	0.2423	0.4882

Appendix 12 Correlation of similarity/distance coefficient from SSR (Dice), agronomic, and end-use quality

	SSR	Agronomic	End-use Quality	Agronomic and End-use Quality
SSR	1.0000	-0.33732 **	-0.22469 **	-0.35727 **
Agronomic		1.0000	0.34202 **	0.92671 **
End-use Quality			1.0000	0.66119 **
Agronomic and End-use Quality				1.0000

** highly significant at 1%

Appendix 13 Euclidean distance based on agronomic traits

Cultivars	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
1 Karasu90	0.00																						
2 Daphan	4.45	0.00																					
3 Alparslan	3.72	4.51	0.00																				
4 Palandoken97	3.19	3.63	3.87	0.00																			
5 Nenehatun	3.67	2.07	2.72	2.56	0.00																		
6 Lancer	2.00	4.53	5.13	3.46	4.29	0.00																	
7 Dogu88	2.78	4.29	1.61	3.74	2.82	4.17	0.00																
8 Yildirim	3.67	2.13	3.49	2.75	1.55	3.95	2.93	0.00															
9 Altay2000	5.93	3.08	4.93	3.95	3.14	6.20	5.05	2.80	0.00														
10 Sultan	5.22	2.28	6.12	4.72	3.80	4.76	5.58	3.32	4.24	0.00													
11 Harmankaya	5.39	3.09	3.63	4.50	2.41	5.86	3.89	2.76	3.39	4.00	0.00												
12 Alpu	5.60	2.64	4.33	3.89	2.35	5.80	4.38	2.06	1.79	3.95	2.38	0.00											
13 Kirgiz95	2.39	3.25	2.93	1.34	1.88	3.13	2.56	2.15	4.10	4.55	4.00	3.68	0.00										
14 Atay85	5.07	1.95	5.71	4.33	3.37	4.81	5.27	2.96	3.70	0.70	3.59	3.51	4.19	0.00									
15 Aytin98	3.69	2.02	4.17	3.00	2.21	4.07	3.97	2.70	4.03	3.84	4.32	3.64	2.48	3.55	0.00								
16 Sonmez2001	5.97	2.72	5.59	3.76	3.34	6.03	5.81	3.54	2.23	4.09	4.37	2.93	4.15	3.62	3.17	0.00							
17 Gerek79	1.93	3.22	3.57	2.71	2.57	2.73	3.07	3.08	5.23	4.34	4.57	4.71	1.84	4.13	2.17	4.81	0.00						
18 Kirac66	2.38	3.51	5.17	3.32	3.85	1.92	4.45	3.70	5.49	3.86	5.57	5.41	3.08	3.85	3.04	4.96	2.28	0.00					
19 Suzen	3.16	2.62	5.04	2.52	3.02	2.49	4.38	2.58	4.29	2.80	4.58	4.08	2.54	2.71	2.67	3.88	2.54	1.83	0.00				
20 Bezostaya1	4.57	4.66	3.45	2.48	3.04	5.00	3.68	3.16	3.92	6.08	4.35	3.49	2.60	5.67	4.28	4.51	4.32	5.32	4.41	0.00			
21 Yildiz98	4.74	1.36	4.48	4.08	2.29	5.03	4.31	2.45	3.29	2.11	2.41	2.83	3.65	1.63	2.98	3.40	3.61	4.10	3.21	5.07	0.00		
22 Cetinel	5.00	2.26	5.72	4.08	3.34	4.52	5.40	3.18	4.06	1.26	3.60	3.71	4.09	1.17	3.67	3.75	3.99	3.74	2.52	5.47	2.07	0.00	
23 Turkey	1.27	5.06	4.07	3.55	4.23	2.16	2.88	3.86	6.13	5.74	5.81	5.81	2.84	5.61	4.41	6.46	2.97	3.07	3.62	4.51	5.40	5.60	0.00
24 Kharkof	2.71	5.68	6.03	4.52	5.50	1.58	4.88	4.93	7.11	5.84	7.08	6.83	4.19	5.93	5.13	7.09	3.93	2.86	3.64	5.84	6.24	5.80	2.24
25 Cheyenne	2.49	5.49	5.58	4.54	5.19	1.85	4.25	4.52	6.92	5.71	6.67	6.48	3.96	5.78	4.98	7.10	3.75	3.16	3.71	5.61	5.96	5.76	1.83
26 Wichita	2.53	5.40	2.59	3.33	3.81	4.01	2.24	4.11	5.98	6.79	5.54	5.57	2.53	6.47	4.36	6.29	3.18	4.52	4.73	3.43	5.72	6.41	2.53
27 Warrior	1.72	5.25	4.73	4.34	4.68	2.16	3.36	4.24	6.77	5.56	6.05	6.26	3.52	5.55	4.74	7.05	3.14	3.20	3.78	5.44	5.47	5.57	1.37
28 Scout66	2.66	5.28	3.08	3.55	3.86	3.79	2.18	3.78	5.92	6.57	5.56	5.33	2.61	6.32	4.31	6.36	3.33	4.52	4.56	3.45	5.69	6.34	2.27
29 Sage	2.64	4.60	2.47	3.06	3.07	3.75	1.52	2.92	5.05	5.86	4.59	4.44	2.05	5.56	3.96	5.71	3.11	4.32	4.08	2.83	4.88	5.60	2.37
30 Buckskin	2.33	5.39	3.56	3.72	4.17	3.57	2.30	3.79	5.99	6.25	5.61	5.58	2.86	6.00	4.73	6.64	3.49	4.30	4.38	4.09	5.57	6.13	1.69
31 Bennett	3.00	5.43	2.13	4.07	3.77	4.51	1.72	4.16	6.23	6.84	5.19	5.52	2.98	6.54	4.53	6.67	3.35	5.04	5.17	3.87	5.60	6.52	3.09
32 Centurk78	2.99	5.36	3.80	5.21	4.57	4.25	2.38	4.21	6.53	5.90	5.26	5.96	4.10	5.76	5.25	7.34	3.97	4.68	5.00	5.69	5.19	6.04	2.84
33 Centura	2.62	5.12	2.94	4.46	3.92	3.96	1.48	3.76	6.18	6.12	5.06	5.44	3.25	5.93	4.60	6.85	3.38	4.58	4.75	4.59	5.21	6.08	2.42
34 Colt	3.55	5.15	2.82	5.30	4.00	4.82	2.13	4.36	6.68	6.25	4.71	5.70	4.03	6.08	4.79	7.17	3.62	5.19	5.42	5.40	5.05	6.14	3.89
35 Siouxland	2.46	4.25	2.64	3.39	3.01	3.64	1.28	2.61	4.87	5.13	4.07	4.34	2.37	4.84	4.08	5.74	3.09	4.03	3.81	3.67	4.22	5.01	2.30
36 TAM107	4.39	5.32	1.56	4.26	3.37	5.74	2.28	4.08	5.58	6.92	4.32	4.75	3.35	6.52	4.71	6.21	4.13	6.02	5.71	3.36	5.32	6.50	4.61
37 Redland	2.97	5.01	3.38	4.81	4.02	4.22	1.97	3.76	6.18	5.64	4.74	5.45	3.64	5.46	4.86	6.97	3.60	4.67	4.74	5.19	4.79	5.69	2.95
38 Arapahoe	3.40	5.33	3.27	5.04	4.20	4.66	1.88	3.94	6.31	6.14	4.91	5.49	3.83	5.94	5.08	7.18	3.97	5.19	5.19	5.07	5.19	6.19	3.23
39 Karl92	4.33	6.10	2.58	5.43	4.47	5.84	2.55	5.05	7.04	7.51	5.37	6.10	4.26	7.22	5.36	7.55	4.33	6.26	6.34	5.03	6.06	7.25	4.57
40 Alliance	3.96	5.44	2.78	4.97	4.01	5.32	1.80	3.95	6.06	6.51	4.66	5.19	3.79	6.21	5.13	7.01	4.24	5.76	5.56	4.61	5.28	6.45	3.87
41 Nekota	3.58	5.14	2.11	4.49	3.53	4.85	1.57	3.86	6.04	6.51	4.57	5.04	3.29	6.25	4.53	6.64	3.61	5.38	5.27	4.03	5.22	6.27	3.68
42 Niobrara	3.50	4.85	2.05	4.00	3.19	4.78	1.23	3.25	5.32	6.06	4.09	4.48	2.89	5.72	4.49	6.21	3.65	5.23	4.89	3.55	4.78	5.84	3.47
43 Pronghorn	3.37	5.99	2.87	4.74	4.46	4.96	2.03	4.57	6.67	7.19	5.67	6.01	3.64	6.90	5.20	7.33	4.00	5.52	5.66	4.59	6.03	7.03	3.23
44 Millennium	3.36	5.14	3.57	5.04	4.18	4.40	2.07	3.75	6.22	5.81	4.85	5.37	3.85	5.67	5.01	7.10	3.96	4.98	4.94	5.15	5.03	5.93	3.12
45 NE01643	4.20	5.58	3.36	5.45	4.38	5.40	2.19	4.12	6.32	6.48	4.84	5.40	4.25	6.25	5.42	7.34	4.57	5.90	5.72	5.14	5.40	6.54	4.01

Appendix 13 Euclidean distance based on agronomic traits (continue)

Cultivars	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45
24 Kharkof	0.00																					
25 Cheyenne	1.11	0.00																				
26 Wichita	4.51	4.14	0.00																			
27 Warrior	2.20	1.44	3.48	0.00																		
28 Scout66	4.11	3.53	1.27	3.05	0.00																	
29 Sage	4.30	3.71	1.60	3.14	1.09	0.00																
30 Buckskin	3.73	3.05	2.03	2.31	1.55	1.56	0.00															
31 Bennett	5.10	4.52	1.32	3.65	1.58	1.73	2.37	0.00														
32 Centurk78	4.51	3.67	3.68	2.51	3.38	3.11	2.52	3.25	0.00													
33 Centura	4.34	3.50	2.43	2.51	1.93	1.84	1.75	1.81	1.65	0.00												
34 Colt	5.54	4.81	3.50	3.74	3.40	3.22	3.61	2.42	2.54	1.98	0.00											
35 Siouxland	4.24	3.58	2.54	2.73	2.26	1.45	1.64	2.47	2.09	1.65	2.96	0.00										
36 TAM107	6.59	6.03	2.67	5.19	2.97	2.55	3.70	1.93	4.37	3.16	3.14	3.17	0.00									
37 Redland	4.70	3.84	3.42	2.65	3.07	2.68	2.36	2.82	0.96	1.34	2.14	1.72	3.74	0.00								
38 Arapahoe	5.05	4.14	3.31	3.07	2.83	2.51	2.35	2.55	1.40	1.10	2.06	1.88	3.41	0.80	0.00							
39 Karl92	6.50	5.81	3.02	4.77	3.16	3.16	3.74	1.75	3.71	2.60	2.02	3.51	1.98	3.17	2.76	0.00						
40 Alliance	5.84	4.98	3.17	3.97	2.81	2.38	2.67	2.25	2.44	1.69	2.31	2.13	2.54	1.77	1.17	2.19	0.00					
41 Nekota	5.54	4.83	2.46	3.95	2.24	2.04	2.91	1.28	3.14	1.76	1.79	2.49	1.75	2.54	2.11	1.39	1.65	0.00				
42 Niobrara	5.46	4.73	2.49	3.83	2.25	1.57	2.37	1.77	2.83	1.77	2.51	1.64	1.84	2.13	1.79	2.27	1.10	1.34	0.00			
43 Pronghorn	5.32	4.58	2.04	3.58	1.92	2.09	2.02	1.29	2.71	1.51	2.61	2.41	2.57	2.34	1.91	1.94	1.64	1.73	1.73	0.00		
44 Millennium	4.76	3.81	3.59	2.83	2.98	2.63	2.45	2.92	1.30	1.27	2.25	1.89	3.80	0.83	0.63	3.24	1.65	2.43	2.12	2.41	0.00	
45 NE01643	5.82	4.88	3.76	3.92	3.22	2.83	2.95	2.86	2.18	1.78	2.35	2.37	3.27	1.61	0.92	2.72	0.84	2.13	1.76	2.19	1.21	0.00

Appendix 14 Euclidean distance based on end-use quality traits

Cultivars	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
1 Karasu90	0.00																						
2 Daphan	2.04	0.00																					
3 Alparslan	2.81	3.79	0.00																				
4 Palandoken97	2.89	2.63	2.33	0.00																			
5 Nenehatun	2.44	1.05	4.26	2.92	0.00																		
6 Lancer	2.53	3.35	1.37	1.54	3.63	0.00																	
7 Dogu88	0.38	2.36	2.58	2.93	2.72	2.38	0.00																
8 Yildirim	2.51	2.70	1.77	0.85	3.20	1.16	2.51	0.00															
9 Altay2000	1.41	1.82	2.49	2.49	2.68	2.56	1.55	2.00	0.00														
10 Sultan	2.39	1.75	3.42	2.89	2.80	3.44	2.63	2.56	1.18	0.00													
11 Harmankaya	1.61	2.04	3.33	3.45	2.92	3.47	1.81	2.99	1.00	1.34	0.00												
12 Alpu	2.34	2.88	1.89	1.29	3.33	0.96	2.32	0.69	2.15	2.82	3.05	0.00											
13 Kirgiz95	3.86	3.31	3.31	1.31	3.22	2.42	3.90	2.13	3.67	3.99	4.57	2.44	0.00										
14 Atay85	2.19	1.79	3.40	3.06	2.83	3.47	2.43	2.67	1.04	0.35	1.00	2.88	4.18	0.00									
15 Aytin98	3.15	3.47	1.55	1.22	3.93	1.13	3.08	0.80	2.64	3.21	3.63	1.11	2.24	3.33	0.00								
16 Sonmez2001	2.56	3.22	1.07	1.47	3.51	0.72	2.41	1.21	2.42	3.30	3.36	1.38	2.32	3.33	1.17	0.00							
17 Gerek79	3.09	2.82	2.41	0.23	3.06	1.59	3.12	1.01	2.72	3.11	3.68	1.42	1.14	3.28	1.24	1.53	0.00						
18 Kirac66	3.58	3.17	2.60	0.94	3.62	2.09	3.63	1.20	2.87	3.03	3.83	1.72	1.72	3.26	1.21	2.02	0.91	0.00					
19 Suzen	2.57	1.33	3.51	1.66	1.66	2.76	2.81	1.98	2.24	2.22	2.88	2.19	2.23	2.39	2.69	2.75	1.81	2.15	0.00				
20 Bezostaya1	2.96	4.19	1.40	3.34	4.87	2.45	2.74	2.58	2.47	3.32	3.02	2.58	4.51	3.22	2.50	2.35	3.47	3.46	4.17	0.00			
21 Yildiz98	1.16	1.64	3.69	3.51	2.05	3.53	1.44	3.27	1.70	2.23	1.37	3.26	4.37	2.00	3.98	3.43	3.72	4.16	2.71	3.76	0.00		
22 Cetinel	4.33	3.32	3.82	1.68	3.45	3.15	4.44	2.42	3.77	3.72	4.63	2.88	1.25	3.99	2.57	3.01	1.57	1.50	2.18	4.82	4.66	0.00	
23 Turkey	3.44	4.47	1.10	2.62	4.94	1.47	3.23	2.02	3.19	4.03	4.04	1.92	3.53	4.04	1.52	1.63	2.65	2.71	3.96	1.76	4.46	4.05	0.00
24 Kharkof	3.79	4.12	2.15	3.08	4.94	3.02	3.73	2.48	2.67	2.91	3.34	2.86	4.20	2.99	2.33	2.75	3.18	2.73	3.91	1.85	4.32	4.04	2.46
25 Cheyenne	1.81	3.14	1.69	2.94	3.84	2.25	1.65	2.22	1.42	2.44	1.91	2.18	4.16	2.28	2.52	2.17	3.13	3.28	3.35	1.20	2.58	4.48	2.32
26 Wichita	3.37	4.10	1.87	1.89	4.33	0.89	3.22	1.67	3.38	4.16	4.30	1.43	2.48	4.21	1.28	1.39	1.85	2.22	3.31	2.93	4.38	3.25	1.43
27 Warrior	1.32	2.78	1.54	2.34	3.18	1.49	1.06	1.82	1.64	2.79	2.32	1.68	3.38	2.68	2.20	1.46	2.51	2.98	2.83	1.99	2.34	3.98	2.21
28 Scout66	1.78	3.38	1.64	2.96	3.67	1.91	1.43	2.50	2.28	3.45	2.81	2.38	3.85	3.31	2.72	1.78	3.09	3.60	3.55	2.06	2.70	4.56	2.38
29 Sage	2.34	3.75	0.91	2.87	4.20	1.74	2.04	2.26	2.34	3.43	2.99	2.20	3.88	3.32	2.27	1.58	2.99	3.29	3.74	1.23	3.27	4.46	1.64
30 Buckskin	1.09	2.88	2.59	3.43	3.45	2.78	0.94	2.84	1.53	2.58	1.54	2.67	4.55	2.32	3.32	2.78	3.63	3.96	3.40	2.25	1.79	4.97	3.21
31 Bennett	1.95	3.56	1.84	3.29	4.18	2.36	1.72	2.55	1.91	2.95	2.28	2.37	4.48	2.76	2.78	2.39	3.46	3.66	3.75	1.20	2.82	4.90	2.30
32 Centurk78	1.40	2.62	3.49	3.95	3.27	3.63	1.51	3.45	1.64	2.30	0.98	3.36	5.04	1.97	4.04	3.59	4.17	4.45	3.48	3.08	1.30	5.30	4.17
33 Centura	1.17	2.85	2.82	3.64	3.42	3.07	1.06	3.08	1.59	2.58	1.42	2.96	4.73	2.29	3.58	3.01	3.84	4.18	3.51	2.47	1.63	5.12	3.52
34 Colt	1.79	3.49	1.58	3.06	3.89	1.96	1.44	2.49	2.17	3.34	2.66	2.31	4.07	3.18	2.69	1.92	3.21	3.62	3.64	1.70	2.76	4.70	2.22
35 Siouxland	0.63	2.51	2.57	2.88	2.94	2.26	0.54	2.37	1.59	2.63	1.90	2.07	3.91	2.44	2.93	2.42	3.07	3.52	2.79	2.64	1.75	4.43	3.05
36 TAM107	0.62	2.11	2.86	2.99	2.32	2.64	0.61	2.73	1.72	2.71	1.92	2.63	3.83	2.52	3.32	2.55	3.18	3.75	2.72	3.16	1.17	4.38	3.61
37 Redland	1.08	2.83	3.21	3.81	3.34	3.26	1.05	3.28	1.81	2.71	1.52	3.09	4.87	2.42	3.84	3.29	4.02	4.39	3.52	2.89	1.48	5.28	3.82
38 Arapahoe	1.17	2.97	2.74	3.55	3.55	2.88	1.05	2.94	1.64	2.63	1.58	2.73	4.68	2.36	3.42	2.94	3.75	4.07	3.48	2.34	1.86	5.09	3.30
39 Karl92	2.93	4.10	3.80	4.86	4.93	4.36	2.91	4.15	2.58	3.01	2.08	4.06	6.12	2.71	4.53	4.33	5.07	5.09	4.73	2.74	3.09	6.24	4.27
40 Alliance	1.11	2.26	3.71	3.64	2.27	3.37	1.24	3.44	2.34	3.12	2.24	3.28	4.36	2.91	4.09	3.36	3.82	4.43	3.05	3.94	1.06	4.92	4.40
41 Nekota	0.86	2.60	2.27	2.77	2.86	2.07	0.53	2.39	1.82	2.95	2.24	2.21	3.68	2.78	2.88	2.06	2.94	3.52	2.90	2.63	1.85	4.33	2.95
42 Niobrara	1.41	3.06	3.83	4.28	3.43	3.74	1.44	3.82	2.41	3.20	1.99	3.57	5.26	2.90	4.40	3.82	4.48	4.92	3.83	3.56	1.58	5.72	4.39
43 Pronghorn	2.16	3.67	3.08	4.25	4.38	3.59	2.05	3.56	2.11	2.89	1.82	3.44	5.46	2.59	3.94	3.57	4.46	4.62	4.25	2.21	2.55	5.74	3.63
44 Millennium	0.56	2.37	2.63	3.08	2.74	2.58	0.37	2.68	1.55	2.62	1.72	2.57	4.04	2.41	3.24	2.51	3.28	3.77	2.94	2.75	1.32	4.56	3.37
45 NE01643	1.66	2.90	1.68	2.30	3.08	1.45	1.41	2.02	2.16	3.26	2.85	1.93	3.09	3.18	2.32	1.29	2.42	3.06	2.90	2.50	2.57	3.86	2.40

Appendix 14 Euclidean distance based on end-use quality traits (continue)

Cultivars	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45
24 Kharkof	0.00																					
25 Cheyenne	2.30	0.00																				
26 Wichita	3.38	2.99	0.00																			
27 Warrior	3.01	1.21	2.34	0.00																		
28 Scout66	3.37	1.54	2.66	0.82	0.00																	
29 Sage	2.62	1.24	2.37	1.13	0.94	0.00																
30 Buckskin	3.40	1.15	3.58	1.37	1.60	1.93	0.00															
31 Bennett	2.69	0.59	3.03	1.31	1.47	1.19	1.13	0.00														
32 Centurk78	3.89	1.95	4.47	2.26	2.55	2.91	1.06	2.08	0.00													
33 Centura	3.55	1.37	3.89	1.62	1.77	2.15	0.37	1.41	0.82	0.00												
34 Colt	3.15	1.19	2.69	0.82	0.49	0.76	1.37	1.00	2.39	1.59	0.00											
35 Siouxland	3.65	1.58	3.03	1.10	1.62	2.07	0.98	1.58	1.63	1.23	1.50	0.00										
36 TAM107	4.01	2.08	3.50	1.40	1.65	2.38	1.39	2.22	1.68	1.37	1.81	1.12	0.00									
37 Redland	3.97	1.78	4.07	1.86	2.07	2.54	0.65	1.75	0.72	0.54	1.91	1.13	1.37	0.00								
38 Arapahoe	3.50	1.26	3.66	1.53	1.78	2.08	0.25	1.18	1.04	0.50	1.51	0.99	1.54	0.58	0.00							
39 Karl92	3.56	2.17	5.05	3.17	3.35	3.25	2.01	2.16	1.83	1.94	2.98	2.83	3.27	2.09	1.91	0.00						
40 Alliance	4.82	2.82	4.18	2.21	2.41	3.19	1.90	2.90	1.83	1.81	2.55	1.58	0.88	1.56	1.96	3.59	0.00					
41 Nekota	3.69	1.69	2.91	0.77	1.00	1.73	1.24	1.72	1.97	1.39	1.15	0.86	0.76	1.49	1.39	3.24	1.50	0.00				
42 Niobrara	4.68	2.48	4.52	2.39	2.54	3.13	1.33	2.38	1.11	1.22	2.44	1.52	1.62	0.71	1.24	2.52	1.40	1.86	0.00			
43 Pronghorn	3.37	1.46	4.32	2.29	2.40	2.41	1.12	1.36	1.35	1.08	2.04	2.02	2.45	1.33	1.05	0.99	2.85	2.32	1.87	0.00		
44 Millennium	3.73	1.65	3.44	1.18	1.42	2.06	0.90	1.76	1.38	0.91	1.47	0.88	0.50	1.00	1.07	2.83	1.20	0.64	1.42	1.97	0.00	
45 NE01643	3.44	1.89	2.27	0.75	0.82	1.39	1.96	1.98	2.77	2.13	1.17	1.60	1.48	2.35	2.14	3.84	2.26	0.92	2.78	2.93	1.47	0.00

Appendix 15 Euclidean distance based on nine agronomic and four end-use quality traits

Cultivars	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
1 Karasu90	0.00																						
2 Daphan	4.89	0.00																					
3 Alparslan	4.66	5.89	0.00																				
4 Palandoken97	4.30	4.48	4.52	0.00																			
5 Nenehatun	4.41	2.32	5.05	3.88	0.00																		
6 Lancer	3.23	5.63	5.31	3.79	5.62	0.00																	
7 Dogu88	2.81	4.89	3.04	4.75	3.91	4.80	0.00																
8 Yildirim	4.45	3.44	3.91	2.88	3.56	4.11	3.86	0.00															
9 Altay2000	6.10	3.58	5.52	4.67	4.13	6.71	5.28	3.45	0.00														
10 Sultan	5.75	2.88	7.01	5.54	4.72	5.87	6.17	4.19	4.41	0.00													
11 Harmankaya	5.62	3.71	4.93	5.67	3.78	6.81	4.29	4.07	3.54	4.22	0.00												
12 Alpu	6.07	3.91	4.73	4.10	4.08	5.88	4.95	2.18	2.80	4.85	3.87	0.00											
13 Kirgiz95	4.54	4.63	4.42	1.88	3.73	3.95	4.67	3.03	5.50	6.05	6.08	4.41	0.00										
14 Atay85	5.52	2.65	6.65	5.30	4.40	5.93	5.80	3.99	3.85	0.78	3.72	4.54	5.92	0.00									
15 Aytin98	4.85	4.01	4.45	3.24	4.51	4.22	5.02	2.82	4.82	5.00	5.64	3.80	3.34	4.87	0.00								
16 Sonmez2001	6.50	4.21	5.69	4.04	4.84	6.08	6.29	3.74	3.29	5.26	5.51	3.24	4.75	4.92	3.38	0.00							
17 Gerek79	3.65	4.28	4.30	2.72	4.00	3.16	4.38	3.24	5.89	5.34	5.87	4.92	2.16	5.27	2.50	5.04	0.00						
18 Kirac66	4.30	4.73	5.79	3.45	5.28	2.84	5.74	3.89	6.20	4.91	6.76	5.68	3.53	5.04	3.27	5.36	2.46	0.00					
19 Suzen	4.07	2.94	6.15	3.01	3.45	3.72	5.20	3.25	4.84	3.57	5.41	4.63	3.38	3.61	3.79	4.76	3.12	2.82	0.00				
20 Bezostaya1	5.45	6.27	3.72	4.16	5.74	5.57	4.59	4.08	4.63	6.93	5.29	4.34	5.20	6.52	4.96	5.09	5.54	6.35	6.07	0.00			
21 Yildiz98	4.88	2.13	5.81	5.38	3.08	6.14	4.55	4.09	3.71	3.07	2.77	4.32	5.69	2.58	4.97	4.83	5.18	5.84	4.20	6.31	0.00		
22 Cetinel	6.61	4.01	6.88	4.41	4.80	5.51	6.99	4.00	5.54	3.93	5.87	4.70	4.27	4.16	4.48	4.81	4.29	4.03	3.33	7.29	5.10	0.00	
23 Turkey	3.67	6.75	4.22	4.41	6.50	2.61	4.33	4.36	6.91	7.01	7.08	6.12	4.53	6.91	4.66	6.66	3.98	4.10	5.36	4.84	7.00	6.91	0.00
24 Kharkof	4.66	7.02	6.40	5.47	7.39	3.40	6.14	5.51	7.59	6.53	7.83	7.41	5.93	6.64	5.63	7.60	5.06	3.95	5.34	6.12	7.59	7.06	3.33
25 Cheyenne	3.08	6.33	5.83	5.41	6.45	2.92	4.55	5.03	7.06	6.21	6.94	6.84	5.74	6.21	5.58	7.43	4.88	4.55	5.00	5.74	6.50	7.30	2.95
26 Wichita	4.22	6.78	3.20	3.83	5.77	4.11	3.92	4.44	6.86	7.96	7.01	5.75	3.54	7.72	4.55	6.45	3.68	5.04	5.77	4.51	7.20	7.19	2.91
27 Warrior	2.17	5.94	4.97	4.94	5.66	2.62	3.52	4.61	6.97	6.23	6.48	6.48	4.88	6.16	5.23	7.20	4.02	4.37	4.73	5.79	5.95	6.84	2.60
28 Scout66	3.20	6.28	3.49	4.62	5.33	4.25	2.61	4.54	6.34	7.42	6.23	5.84	4.65	7.13	5.10	6.61	4.54	5.78	5.78	4.02	6.30	7.81	3.29
29 Sage	3.53	5.94	2.63	4.19	5.21	4.13	2.55	3.69	5.56	6.79	5.48	4.95	4.39	6.48	4.56	5.92	4.31	5.43	5.54	3.09	5.88	7.16	2.89
30 Buckskin	2.57	6.11	4.40	5.06	5.42	4.53	2.48	4.74	6.18	6.76	5.82	6.19	5.37	6.44	5.78	7.20	5.04	5.85	5.54	4.67	5.85	7.89	3.63
31 Bennett	3.58	6.49	2.81	5.23	5.63	5.09	2.43	4.88	6.51	7.45	5.67	6.01	5.38	7.10	5.31	7.08	4.82	6.23	6.39	4.06	6.27	8.16	3.85
32 Centurk78	3.31	5.97	5.16	6.54	5.61	5.59	2.82	5.44	6.73	6.34	5.35	6.84	6.50	6.08	6.62	8.17	5.76	6.46	6.09	6.47	5.35	8.04	5.04
33 Centura	2.87	5.86	4.08	5.75	5.20	5.01	1.82	4.86	6.38	6.64	5.26	6.20	5.74	6.36	5.83	7.48	5.11	6.20	5.91	5.21	5.46	7.95	4.27
34 Colt	3.97	6.22	3.24	6.12	5.58	5.21	2.58	5.02	7.02	7.09	5.41	6.15	5.73	6.86	5.49	7.42	4.83	6.33	6.53	5.66	5.76	7.73	4.48
35 Siouxland	2.54	4.93	3.68	4.45	4.20	4.28	1.39	3.53	5.12	5.77	4.49	4.81	4.57	5.42	5.03	6.23	4.35	5.36	4.73	4.52	4.57	6.69	3.82
36 TAM107	4.44	5.72	3.26	5.21	4.09	6.32	2.36	4.90	5.84	7.43	4.73	5.43	5.08	6.99	5.77	6.71	5.21	7.10	6.32	4.62	5.45	7.84	5.86
37 Redland	3.16	5.76	4.66	6.13	5.23	5.33	2.23	4.99	6.45	6.26	4.97	6.26	6.08	5.97	6.19	7.71	5.39	6.41	5.91	5.94	5.02	7.77	4.83
38 Arapahoe	3.59	6.10	4.27	6.16	5.50	5.48	2.15	4.91	6.52	6.68	5.16	6.13	6.05	6.39	6.12	7.76	5.47	6.59	6.25	5.58	5.52	8.01	4.62
39 Karl92	5.23	7.35	4.59	7.28	6.66	7.28	3.86	6.53	7.50	8.09	5.76	7.33	7.46	7.71	7.02	8.70	6.67	8.07	7.91	5.73	6.80	9.56	6.26
40 Alliance	4.12	5.90	4.64	6.15	4.61	6.29	2.19	5.24	6.49	7.22	5.17	6.14	5.78	6.86	6.56	7.77	5.71	7.27	6.34	6.06	5.38	8.11	5.86
41 Nekota	3.69	5.76	3.10	5.28	4.54	5.27	1.66	4.55	6.31	7.15	5.09	5.51	4.93	6.84	5.37	6.95	4.66	6.42	6.02	4.82	5.54	7.62	4.71
42 Niobrara	3.77	5.74	4.34	5.86	4.68	6.07	1.90	5.02	5.84	6.85	4.54	5.72	6.00	6.41	6.29	7.29	5.78	7.18	6.21	5.03	5.03	8.18	5.60
43 Pronghorn	4.00	7.02	4.21	6.37	6.25	6.12	2.88	5.79	7.00	7.75	5.95	6.93	6.56	7.37	6.52	8.15	5.99	7.20	7.08	5.10	6.55	9.08	4.86
44 Millennium	3.40	5.66	4.43	5.91	5.00	5.10	2.11	4.61	6.41	6.38	5.14	5.95	5.58	6.16	5.96	7.53	5.14	6.24	5.75	5.84	5.20	7.48	4.60
45 NE01643	4.52	6.29	3.75	5.91	5.35	5.59	2.61	4.58	6.68	7.25	5.62	5.73	5.26	7.01	5.90	7.46	5.18	6.65	6.41	5.71	5.98	7.59	4.67

Appendix 15 Euclidean distance based on nine agronomic and four end-use quality traits (continue)

Cultivars	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45
24 Kharkof	0.00																					
25 Cheyenne	2.56	0.00																				
26 Wichita	5.63	5.11	0.00																			
27 Warrior	3.73	1.88	4.19	0.00																		
28 Scout66	5.32	3.85	2.95	3.16	0.00																	
29 Sage	5.03	3.91	2.86	3.34	1.44	0.00																
30 Buckskin	5.05	3.26	4.12	2.68	2.23	2.48	0.00															
31 Bennett	5.76	4.56	3.31	3.88	2.16	2.10	2.62	0.00														
32 Centurk78	5.95	4.16	5.79	3.38	4.23	4.26	2.73	3.86	0.00													
33 Centura	5.60	3.76	4.59	2.99	2.62	2.83	1.79	2.30	1.84	0.00												
34 Colt	6.37	4.96	4.41	3.82	3.44	3.31	3.86	2.62	3.49	2.54	0.00											
35 Siouxland	5.60	3.91	3.96	2.95	2.78	2.53	1.91	2.93	2.65	2.06	3.32	0.00										
36 TAM107	7.71	6.38	4.40	5.37	3.39	3.49	3.95	2.95	4.68	3.45	3.63	3.36	0.00									
37 Redland	6.15	4.23	5.31	3.24	3.71	3.69	2.45	3.32	1.20	1.44	2.87	2.06	3.99	0.00								
38 Arapahoe	6.15	4.33	4.94	3.43	3.35	3.26	2.37	2.81	1.75	1.21	2.55	2.12	3.74	0.99	0.00							
39 Karl92	7.41	6.20	5.89	5.73	4.61	4.53	4.24	2.78	4.14	3.24	3.60	4.51	3.83	3.80	3.36	0.00						
40 Alliance	7.57	5.72	5.25	4.54	3.70	3.98	3.28	3.67	3.05	2.48	3.44	2.65	2.69	2.36	2.28	4.21	0.00					
41 Nekota	6.66	5.11	3.81	4.03	2.45	2.68	3.16	2.14	3.71	2.24	2.13	2.64	1.90	2.94	2.53	3.52	2.23	0.00				
42 Niobrara	7.19	5.34	5.16	4.52	3.39	3.50	2.71	2.97	3.04	2.15	3.50	2.23	2.46	2.25	2.17	3.39	1.78	2.29	0.00			
43 Pronghorn	6.30	4.80	4.78	4.25	3.08	3.19	2.31	1.87	3.03	1.86	3.31	3.15	3.55	2.69	2.18	2.18	3.29	2.90	2.55	0.00		
44 Millennium	6.05	4.15	4.97	3.07	3.30	3.34	2.61	3.41	1.90	1.56	2.68	2.09	3.83	1.30	1.24	4.30	2.04	2.51	2.55	3.11	0.00	
45 NE01643	6.76	5.24	4.39	3.99	3.32	3.16	3.54	3.48	3.53	2.78	2.63	2.86	3.59	2.85	2.33	4.70	2.41	2.32	3.29	3.66	1.90	0.00