Yield Stability Analysis of Winter Wheat Genotypes Targeted to Semi-Arid Environments in the International Winter Wheat Improvement Program

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ABSTRACT

Improved winter wheat (Triticum aestivum L.) cultivars for semi-arid environments in Central and West Asia are needed to increase wheat productivity. This study was conducted to determine the performance of winter wheat genotypes for semi-arid environments, analyze their stability, and identify superior genotypes that could be valuable for winter wheat improvement or varietal release. One hundred thirty three advanced breeding lines and four check cultivars were tested over a 6-year period (2005-2010). Grain yield stability and agronomic traits were analyzed. Many genotypes produced higher grain yield and were more stable than one or more of the checks in each year. By and large, different genotypes showed superior performance under low and high productive environments, demonstrating their specific adaptability. However, 11 out of 30 highest yielding genotypes were common both under low and high productive environments. This shows that while in general different sets of genetic materials are needed under strictly semi-arid and irrigated environments, a few lines targeted towards stressed conditions possess yield plasticity resulting in superior performance both under dryland and irrigated conditions.

Keywords: GGE-biplot, grain yield, production system, semi-arid, stability, Triticum aestivum

INTRODUCTION

Winter wheat (Triticum aestivum L.) is grown under both semi-arid and irrigated management conditions in many countries in Central and West Asia. The International Winter Wheat Program (IWWIP), a cooperative breeding project between the Ministry of Agriculture and Rural Affairs of Turkey, the International Maize and Wheat Improvement Center (CIMMYT) and the International Center for Agricultural Research in the Dry Areas (ICARDA) was initiated in 1991 (cf. www.iwwip.org) to develop and distribute high yielding advanced breeding lines to facilitate introduction and exchange of improved germplasm across the region for irrigated and dryland production conditions.

Wheat breeding priorities for the semi-arid environments in Central and West Asia include high and stable yield, wide adaptation, drought and heat tolerance, grain quality, disease resistances, cold tolerance and winter hardiness (Braun et al. 1998; Morgounov et al. 2005). These priorities are addressed by IWWIP through collaboration with national partners and some successes have been outlined by Morgounov et al. (2005). Also, Kaya et al. (2006) analyzed a limited number of accessions from IWWIP tested across nine environments in Turkey in one year and found that a few genotypes had high and stable yields. However, evaluation of winter wheat genotypes across diverse sites and several years is needed in order to identify spatially and temporally stable genotypes that could be recommended for release as new cultivars and/or for use in the breeding programs.

Winter wheat management conditions in the Central and West Asian countries vary from completely rainfed to fully irrigated. Irrigated wheat production represents both partially and fully irrigated management conditions. Erratic precipitation in certain years could result in conditions where rainfed wheat could yield as if managed under irrigation. Therefore, wheat cultivars with responsiveness to a range of management conditions would be desirable for highly diverse and often unpredictable semi-arid wheat growing environments in the region.

Previous studies have reported spring wheat genotypes widely adapted to global irrigated, semi-arid and high rainfall environments (Nachit et al. 1992; Abdalla et al. 1996; Trehowan et al. 2001, 2002, 2003; Lillemo et al. 2005; Singh et al. 2007; Tadesse et al. 2010). Information on wide adaptation of winter wheat genotypes in Central and West Asia is limited to irrigated management conditions only (Sharma et al. 2010). It is critical to study yield levels and stability of elite lines across the diverse semi-arid environments in order to further utilize them in winter wheat improvement programs and/or target the best for varietal release. This study was conducted to examine yield levels and stability of experimental genotypes included in the International Winter Wheat Yield Trial for Semi-arid Environments (IWWYT-SA) in Central and West Asia and to identify superior genotypes compared to the commercial varietal checks. Though IWWYT-SA is targeted to semi-arid environments, many collaborators evaluate them under irrigated management. This gives an opportunity to examine if some of the wheat genotypes targeted for semi-arid environments also show superior performance under highly productive management conditions. Therefore, one specific objective

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The statistical analysis was conducted in each year using Genstat Discovery Edition 3 (Genstat 2007) software. Since experimental genotypes changed each year, all analyses were accomplished year by year. Each year–site combination was considered a unique and random environment, while genotypic effect was analyzed as fixed. Genotype by genotype × environment (GGE) biplots were used to identify lines that could be superior, using the GGE biplot software (Yan and Kang 2002) to determine grain yield stability and to identify superior genotypes. The details of this GGE biplot procedure have been explained in another publication (Sharma et al. 2007). This GGE biplot analysis has recently been used in identifying superior wheat and maize genotypes in South Asia (Sharma and Duveiller 2007; Sharma et al. 2007, 2008) and elsewhere (Singh et al. 2007; Yan et al. 2007; Roozeboom et al. 2008).

Although germplasm in the IWWYT-SA trials was targeted for semi-arid conditions, many collaborators grew lines under irrigated management. In order to identify superior genotypes for different management conditions, the sites were grouped into two, (i) grain yield < 3 t/ha and (ii) grain yield > 3 t/ha) production environments. This threshold of 3 t/ha was selected because of such a criteria used in IWWIP in identifying lines for semi-arid and irrigated management conditions, respectively. Within each group, the genotypes were analyzed for yield, and high yield lines were compared in order to identify lines that could be resistant to diverse environments and management conditions. Rank correlation coefficients between the means of the genotypes in individual locations and mean yield over all locations within low and high production environments were calculated to identify one or more sites that could be used as representative site(s) for selecting high yielding, stable lines. A location showing high rank correlation coefficient with the mean performance across locations would be such a representative site.
RESULTS

Mean grain yield of the experiments differed in the six years with actual values of 2.96, 4.44, 3.11, 4.00, 4.26 and 2.98 t ha⁻¹ in 2005, 2006, 2007, 2008, 2009 and 2010, respectively. This was also reflected in the yield of 'Gerek-79', the check grown in each year, which yielded 2.92, 4.24, 2.35, 3.40, 2.46 and 2.46 t ha⁻¹ in 2005, 2006, 2007, 2008, 2009 and 2010, respectively. The experimental genotypes showed large variations for grain yield, days to heading, plant height, and TKW in each of the six years.

GGE biplots for individual years revealed a great deal of diversity among genotypes and among environments (Figs. 1-6). The values for principal components 1 (PC1) and 2 (PC2) were mostly intermediate (34 to 68%). However, the relationship between the average tester axis absissa and the genotypic means was high with actual values of 0.90, 0.77, 0.67, 0.81, 0.94 and 0.68 in 2005, 2006, 2007, 2008, 2009 and 2010, respectively. This shows that despite intermediate values for PC1 and PC2, the biplots provide valid comparisons among genotypes and among sites.

Many experimental genotypes were higher in grain yield than one or more of the check varieties in each year (Table 2). GGE biplot analysis revealed that many high yielding genotypes were closer to the point of the ideal genotype in environments. Thirty such superior experimental genotypes, which were closer to the point of the ideal genotype in the biplots, are listed in Table 2. The experimental genotypes 7-11, 7-12, 7-13, 7-22 and 7-23 were closer to the point of the ideal genotypes yielding experimental genotypes were also stable across environments. Thirty such superior experimental genotypes, yielding experimental genotypes were also stable across environments. 'Dagdas-94' and 'Kirgiz-95' ranked 7th, 10th, 20th and 21st, respectively in that year. Genotypes 11-09 and 11-11 were more superior to others for grain yield in 2009 by being close to the point of the ideal genotype ('Gerek-79', 'Bagci-2002', 'Gerek-79' and 'Suzen-97' ranked 18th, 19th, 20th and 21st, respectively. Genotypes 8-15, 20th and 21st, respectively. Genotypes 9-08, 9-13, 9-16, 9-17 and 9-19 were superior experimental genotypes for grain yield in 2007 by being near to the point of the ideal genotype (Fig. 2). These five, as well as several other genotypes were also superior to all checks in the same year. The checks 'Dagdas-94', 'Bagci-2002', 'Gerek-79' and 'Suzen-97' ranked 18th, 19th, 20th and 21st, respectively. The experimental genotypes 8-12, 8-14, 8-15, 8-22 and 8-25 were superior for grain yield in 2006 by being closest to the point of the ideal genotype (Fig. 2). These five, as well as several other genotypes were also superior to all checks in the same year. The checks 'Dagdas-94', 'Bagci-2002', 'Gerek-79' and 'Suzen-97' ranked 18th, 19th, 20th and 21st, respectively. Genotypes 9-08, 9-13, 9-16, 9-17 and 9-19 were superior experimental genotypes for grain yield in 2007 by being near to the point of the ideal genotype (Fig. 3). These five, as well as several other, genotypes were also superior to all checks. The checks 'Gerek-79', 'Altay-2000' and 'Dagdas-94' ranked 14th, 15th and 24th, respectively. Genotypes 10-10, 10-16, 10-18, 10-21 and 10-22 were the most superior genotypes for grain yield in 2008 (Fig. 4). They were closer to the point of the ideal genotype than all checks. The checks 'Altay-2000', 'Karahan' and 'Bagci-2002' ranked 9th, 7th and 8th, respectively in that year. Genotypes 11-09 and 11-11 were more superior to others for grain yield in 2009 by being close to the point of the ideal genotype (Fig. 5). Among the 19 genotypes, 'Altay-2000', 'Karahan', 'Bayraktar' and 'Gerek-79' ranked 9th, 14th, 17th and 19th, respectively in 2009. In 2010, genotypes 12-8 and 12-26 were superior to others by showing higher mean and stability (Fig. 6). Among 34 genotypes, 'Altay-2000', 'Bayraktar', 'Karahan' and 'Gerek-79' ranked 15th, 23rd, 31st and 33rd, respectively in 2010. The comparison of genotypes under low and high production environments showed a low correlation between the two groups of environments. The rank correlation coefficients between low and high productive environments were 0.21, 0.32, 0.29, 0.18, 0.28 and 0.26 in 2005, 2006, 2007, 2008, 2009 and 2010, respectively. In 2005, four out of the five highest yielders (7-11, 7-12, 7-13 and 7-23) were common under low and high productive environments (Table 3). On the other hand, only one genotype (8-15) was common among the five top yielders in the two groups of environments. The three checks ('Bagci-2002', 'Gerek-79' and 'Dagdas-94') were among the five highest yielders under low productive environments only. In 2007, there were different sets of five highest yielding genotypes under low and high productive environments. None of the three checks was among the top five yielders under either group of environments. In 2008, one genotype (10-13) was common among the five top yielders in the two groups of environments. Two checks ('Gerek-79' and 'Bayraktar') were among the five top yielders under low productive environments only. In 2009, three genotypes (11-09, 11-11 and 11-16) were common among the five highest yielders. One check ('Bayraktar') was among the five highest yielders under low productive environments only. In 2010, two genotypes ('Bayraktar' and 'Dagdas-94') were common among the five top yielders. One check ('Karahan') was among the five highest yielders under low productive environments only.

The sites showing significant positive rank correlation coefficients with the mean performance of the genotypes differed under low compared to high productive environments. Tur08 (Erzurum) and Tur21 (Konya) in 2005, Afg13 (Mazar-i-Sharif), Pak05 (Gilgit), Syr01 (Aleppo) and Tur08 (Erzurum) in 2006, Afg13 (Mazar-i-Sharif), Taj01 (Gissar) and Tur21 (Konya) in 2007, Arm02 (Yerevan), Syr01 (Aleppo), Tur05 (Ankara) and Tur09 (Eskisehir) in 2008, Afg12 (Tahktar) and Tur05 (Haymana) in 2009, and Afg13 (Mazar-i-Sahri), Azb01 (Terter), Tur05 (Haymana) and Tur09 (Eskisehir) in 2010 showed significant positive rank correlation coefficient with mean performance rank of wheat genotypes under low productive environments (Table 2). GGE biplot analysis, because they were closer than all checks and were also stable, suggesting their potential as candidate cultivars. Replacement of older winter wheat cultivars with new, improved genotypes has been a slow process in most countries in Central and West Asia.

DISCUSSION

Wide variations in mean grain yields of the wheat genotypes over six years demonstrated year-to-year deviation in climatic conditions. Considering the diversity among the test locations, substantial year-to-year variation was expected. This was in agreement with previous findings using spring wheat (Nachit et al. 1992; Trethowan et al. 2001, 2003; Lillemo et al. 2004). Considerable variation in average national wheat yields in the different countries, where the trials were conducted (FAO 2011). The annual variations in climatic conditions, as represented by substantial differences in mean trial yields in the six years, offer both opportunity and a challenge to select stable genotypes in the region.

The analysis across all environments identified many superior genotypes with high grain yield stability and agronomic traits. In general, the genotypes identified superior in this study had early maturity, short to medium plant height and medium to high TKW, besides having highest grain yields. Even among the superior genotypes, a few could be considered more valuable based on the GGE biplot analysis, because they were closer than others to the point of the ideal genotype. These include 7-12 and 7-13 in 2005 (Fig. 1), 8-15 in 2006 (Fig. 2), 9-16, and 9-17 in 2007 (Fig. 3), 10-10 and 10-16 in 2008 (Fig. 4), 11-09 and 11-11 in 2009 (Fig. 5) and 12-26 in 2010 (Fig. 6). These genotypes were positioned within the innermost circle of the biplot, which qualified them as outstanding among the superior genotypes. Many experimental genotypes out-yielded the checks and were also stable, suggesting their potential as candidate cultivars. Replacement of older winter wheat cultivars with new, improved genotypes has been a slow process in most countries in Central and West Asia.
Fig. 1 GGE biplot for grain yields of 24 winter wheat genotypes evaluated across eight environments in 2005. The names in italics are locations, with the initial three letters abbreviating the country (see Tables 1 and 2 for full names of locations and genotypes, respectively).

Fig. 2 GGE biplot for grain yields of 24 winter wheat genotypes evaluated across 13 environments in 2006. The names in italics are locations, with the initial three letters abbreviating the country (see Tables 1 and 2 for full names of locations and genotypes, respectively).

Fig. 3 GGE biplot for grain yields of 24 winter wheat genotypes evaluated across eight environments in 2007. The names in italics are locations, with the initial three letters abbreviating the country (see Tables 1 and 2 for full names of locations and genotypes, respectively).

Fig. 4 GGE biplot for grain yields of 24 winter wheat genotypes evaluated across 12 environments in 2008. The names in italics are locations, with the initial three letters abbreviating the country (see Tables 1 and 2 for full names of locations and genotypes, respectively).

Fig. 5 GGE biplot for grain yields of 24 winter wheat genotypes evaluated across 14 environments in 2009. The names in italics are locations, with the initial three letters abbreviating the country (see Tables 1 and 2 for full names of the locations and genotypes, respectively).

Fig. 6 GGE biplot for grain yields of 24 winter wheat genotypes evaluated across 15 environments in 2010. The names in italics are locations, with the initial three letters abbreviating the country (see Tables 1 and 2 for full names of the locations and genotypes, respectively).
For example, ‘Gerek-79’, released in the 1979, after 30 years is still being grown over a wide area under dryland conditions in Turkey. Since many genotypes outyielded ‘Gerek-79’ in all six years, the high yielding stable wheat genotypes included in the IWWYT-SA offer a number of viable options for replacing the older cultivars.

One or more checks produced grain yield comparable to the highest yielding experimental lines across low productive environments in five out of six years (Table 3). This suggests that more improved germplasm is needed for low-
productive, semi-arid environments in the region, and also explains in part why ‘Gerek-79’ is still being grown by the farmers under rainfed conditions. On the contrary, none of the checks produced grain yield equivalent to the highest yielding experimental lines across high productive environments in any year. This finding is particularly important for wheat farming under supplemental irrigation, which is being recommended to improve wheat yields under semi-arid conditions. Eleven experimental genotypes (7-11, 7-13, 7-23, 8-15, 10-13, 10-09, 11-11, 11-16, 12-13 and 12-29) were common among the highest yielding genotypes in low and high productive environments. All these genotypes were superior to all checks based on GGE biplot analysis. This further demonstrates that certain experimental genotypes had better performance than the checks across diverse sites, and bear potential as candidate cultivars. Besides being higher yielding and more stable than the checks, the experimental genotypes were selected for resistance to wheat rusts and other diseases prevalent in target countries in the region, as well as for improved quality traits (information available on www.iwwip.org). Hence, the use of the superior genotypes identified in this study should provide additional benefits under disease epidemic conditions.

The sites that showed significant positive correlation with mean performance of wheat genotypes across locations were seldom the same for low and high productive environments (Table 4). This suggests that in order to identify high yielding and stable wheat genotypes for semi-arid environments, trials should be managed under low production conditions. This finding also suggests that there are key sites, such as Afg13 (Mazar-i-Sharif, Afghanistan), Syr01 (Aleppo, Syria), Tur05 (Eskisehir, Turkey), Tur08 (Erzurum, Turkey) and Tur21 (Konya, Turkey) which should be regularly provided additional benefits under disease epidemic conditions. The sites that showed significant positive correlation with mean performance of wheat genotypes across locations were seldom the same for low and high productive environments (Table 4).

Table 3: Comparison of highest yielding winter wheat lines under low and high productive environments, 2005-2010.

<table>
<thead>
<tr>
<th>Year</th>
<th>Entry no.</th>
<th>Pedigree</th>
<th>Yield (t/ha⁻¹)</th>
<th>Pedigree</th>
<th>Yield (t/ha⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2005</td>
<td>7-13</td>
<td>Eski-6</td>
<td>2.13</td>
<td>7-12</td>
<td>J5148/Maras</td>
</tr>
<tr>
<td>2005</td>
<td>11-11</td>
<td>TX94A59.2/2/Bby/Fox/3/Greek/N064/PEx/4/CER/5</td>
<td>1.64</td>
<td>11-16</td>
<td>Kauz/Alt 84/Aos</td>
</tr>
<tr>
<td>2010</td>
<td>11-11</td>
<td>TX94A59.2/2/Bby/Fox/3/Greek/N064/PEx/4/CER/5</td>
<td>1.64</td>
<td>11-20</td>
<td>Trichr1/11/71ST2959/Crown/4/NW/Trw/1/2138/C/CSI2643/Ler</td>
</tr>
<tr>
<td>2010</td>
<td>11-11</td>
<td>TX94A59.2/2/Bby/Fox/3/Greek/N064/PEx/4/CER/5</td>
<td>1.64</td>
<td>11-20</td>
<td>Trichr1/11/71ST2959/Crown/4/NW/Trw/1/2138/C/CSI2643/Ler</td>
</tr>
</tbody>
</table>

Table 4: Comparison of highest yielding winter wheat lines under low and high productive environments, 2005-2010.

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<td>1.64</td>
<td>11-20</td>
<td>Trichr1/11/71ST2959/Crown/4/NW/Trw/1/2138/C/CSI2643/Ler</td>
</tr>
<tr>
<td>2010</td>
<td>11-11</td>
<td>TX94A59.2/2/Bby/Fox/3/Greek/N064/PEx/4/CER/5</td>
<td>1.64</td>
<td>11-20</td>
<td>Trichr1/11/71ST2959/Crown/4/NW/Trw/1/2138/C/CSI2643/Ler</td>
</tr>
</tbody>
</table>

Table 4: Comparison of highest yielding winter wheat lines under low and high productive environments, 2005-2010.
The authors acknowledge and appreciate the assistance of collaborators in various countries, for evaluating IWNYTs and providing valuable information.

REFERENCES


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**Table 4** Rank correlation coefficients of individual sites with mean performance ranks of wheat genotypes under low and high productive environments, 2005-2010.

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<tbody>
<tr>
<td>Location</td>
<td>Low / high</td>
<td>Location</td>
<td>Low / high</td>
<td>Location</td>
<td>Low / high</td>
<td>Location</td>
</tr>
<tr>
<td>CZE02f</td>
<td>0.41 / 0.11</td>
<td>AFG09</td>
<td>-0.07 / -0.02</td>
<td>AFG13</td>
<td>0.64** / 0.31</td>
<td>ARM02</td>
</tr>
<tr>
<td>KAZ01</td>
<td>0.06 / 0.80**</td>
<td>AFG18</td>
<td>0.50 / -0.27</td>
<td>AFG18</td>
<td>0.62** / -0.06</td>
<td>AZB03</td>
</tr>
<tr>
<td>MOL01</td>
<td>0.41 / 0.59*</td>
<td>CHN08</td>
<td>-0.09 / 0.32</td>
<td>CZE02</td>
<td>-0.26 / 0.67**</td>
<td>BUL01</td>
</tr>
<tr>
<td>PAK04</td>
<td>0.58 / 0.3**</td>
<td>CZE02</td>
<td>0.17 / 0.41</td>
<td>MOL01</td>
<td>-0.42 / 0.38</td>
<td>PAK04</td>
</tr>
<tr>
<td>TUR05</td>
<td>0.15 / 0.41</td>
<td>ESP09</td>
<td>0.32 / 0.67**</td>
<td>PRT01</td>
<td>0.31 / 0.38</td>
<td>IRN11</td>
</tr>
<tr>
<td>TUR08</td>
<td>0.75** / 0.49</td>
<td>KAZ01</td>
<td>0.35 / 0.29</td>
<td>TA01</td>
<td>0.51** / 0.08</td>
<td>RUS01</td>
</tr>
<tr>
<td>TUR09</td>
<td>0.17 / 0.28</td>
<td>MOL01</td>
<td>0.22 / 0.53**</td>
<td>TUR09</td>
<td>0.54** / 0.38</td>
<td>SRB01</td>
</tr>
<tr>
<td>TUR21</td>
<td>0.52** / 0.22</td>
<td>PAK05</td>
<td>0.49** / 0.13</td>
<td>TUR21</td>
<td>0.43* / 0.18</td>
<td>SYR01</td>
</tr>
<tr>
<td>SYR01</td>
<td>0.59** / 0.19</td>
<td>TUR05</td>
<td>-0.08 / 0.12</td>
<td>TUR09</td>
<td>0.72** / -0.22</td>
<td>SYR03</td>
</tr>
<tr>
<td>UKR01</td>
<td>-0.04 / 0.52**</td>
<td>TUR08</td>
<td>0.48** / 0.15</td>
<td>TUR09</td>
<td>0.27 / 0.40</td>
<td>UZB01</td>
</tr>
<tr>
<td>UKR01</td>
<td>0.15 / 0.51</td>
<td>TUR21</td>
<td>0.16 / 0.22</td>
<td>UZB02</td>
<td>-0.01 / 0.48</td>
<td>UZB03</td>
</tr>
<tr>
<td>UZB03</td>
<td>0.22 / 0.07</td>
<td></td>
<td></td>
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</tbody>
</table>

* ** Rank correlation coefficients significantly greater than 0 at P=0.05 and P=0.01, respectively.
† Refer to Table 1 for full name of locations

Performance stability of winter wheat genotypes in Central and West Asia (Kaya et al. 2006; Sharma et al. 2010). Such information is lacking for the 133 elite lines targeted for semi-arid environments, and included in this study. While in general different sets of genetic materials are needed under strictly semi-arid and irrigated environments, the findings of this study recognize that, a few lines targeted towards stressed conditions in fact possess yield plasticity resulting in superior performance both under dryland and irrigated conditions. Such genotypes express what is called a combination of input efficiency and responsiveness and would be expected to have performance stability across diverse environments (spatial stability) and over years varying in weather patterns (temporal stability). Even though this study has focused on yield trials conducted within and around the Central and West Asia region, these genotypes have been shared with winter wheat collaborators around the world. This study presents a comprehensive analysis of yield and stability of such a globally important set of winter wheat genotypes for semi-arid environments, and the information presented could benefit national and international winter wheat improvement programs in efficient dissemination and use of valuable germplasm. The comparative analysis of superior wheat breeding lines under low and high productive environments broadens the wheat crop management domain, where the superior winter wheat genotypes of this study could find adaptation niches. This study has identified key locations in different countries in Central and West Asia, which could be used as representative sites to test winter wheat germplasm targeted for semi-arid environments in order to identify superior genotypes.

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The authors acknowledge and appreciate the assistance of collaborators in various countries, for evaluating IWNYTs and providing valuable information.

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