ORIGINAL ARTICLE

Genotype by environment interaction and grain yield stability of early maturing bread wheat (*Triticum aestivum* L.) genotypes in the drought prone areas of Tigray region, northern Ethiopia

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ABSTRACT

In an attempt to identify suitable bread wheat varieties for the Tigray Region of Northern Ethiopia, six early type varieties namely HUW-468, HI-1418, DL-788-2, GW-273, local and standard check were tested in six drought prone areas of Tigray Region. The study was conducted in farmers' fields using the mother-baby trial approach with an objective of identifying high yielding with broadly and specifically adapted varieties for drought prone areas of the Tigray region. Results of the analysis of variance for AMMI model showed significant differences among the genotypes and locations, but were not significant for GxL interaction. Similarly, the regression analysis showed that regression coefficients (b_i) of the tested genotypes were not significantly different from unity. Based on deviation from linear regression and over all mean grain yield, HUW-468 was the best performing genotype yielding 2.375 t/ha. In a similar manner, the $IPCA_1$ (interaction principal component analysis) for this variety had the lowest score (0.47), indicating its stability in all environments. Besides, HI-1418 was also a good yielder in both relatively better locations like Illalla and Atsbi with an annual rainfall of 433 and 411 mm, respectively and in less favored locations of Enderta and Wukro with environmental mean yield of less than 1 t/ha. Although it is difficult to conclude the adaptability and stability of the candidate varieties in one year trial, all of the varieties showed a wide adaptation across the tested locations that indicated the change in environment had negligible effect on their grain yield. The local and standard checks were relatively sensitive to variation across locations. This indicate that these check varieties lack wider adaptability even within the drought prone areas of the region and a higher yield is expected, especially from the standard check in relatively better environments. Since the varieties HUW-468, HI-1418 showed an excellent performance over the local and standard checks, they can be recommended to moisture stressed wheat growing areas of Northern Ethiopia.

Keywords: *Bread wheat, GxE interaction, Stability, Yield*

INTRODUCTION

Bread wheat is one of the most important cereal crops principally grown in the highlands of Ethiopia, basically in the southeast, central and northwest parts. Small amount is also produced in the north and south regions (CSA, 2002). It is one of the major cereal crops largely grown in the mid and high land areas of the region. Its productivity however has been very low because of lack of early maturing, drought tolerant, and high yielding genotypes, poor soil fertility, and high moisture stress (Ministry of Agriculture, 2007). Research in the region has not given proper attention to the development of wheat genotypes adapted to specific environments. Furthermore, although many improved bread wheat varieties have been released at national level, their dissemination and acceptance by farmers of the region have been unsatisfactory. Hence, farmers continue growing local landraces and few released varieties which are developed outside the Tigray environments. As a result, most of the varieties performed poorly under farmers' conditions (Jalleta, 2004). In line with this, the national wheat breeding program in Ethiopia breeds for wide adaption with low priority given for drought tolerance (Tefera, 2006). Therefore, the low acceptance of the improved varieties by farmers of the region has been attributed to the aforementioned problems coupled with low attention given by plant breeders to genotype by environment (GxE) interaction. GxE interaction is the phenotypic effect of interactions between genes and the environment. It is an important aspect in any crop improvement program because relative performance of genotypes often varies across different locations and over years.

In statistical terms there are quantitative and qualitative genotypes by location interaction. The former type of interaction is not a problem to a breeder because, regardless of where or how the comparison between varieties is conducted, a given variety is always superior to other variety and therefore there will be no doubt as to which variety to select. But, the problem for the breeder is when the GxE interactions are of qualitative (cross-over) type, because in this case the decision of which variety is the best depends on where the comparison is conducted (Ceccarelli *et al*., 2001). The GxE interaction reduces association between phenotypic and genotypic values and thus, a genotype that performs well in a given environment may not necessarily respond well in other environment. So if environments are sufficiently different, GxE interaction can result in different yield ranking of evaluated genotypes. In addition, the relationship between selection environments and target production environment had been a fundamental problem because many of the selection activities performed by the conventional approach are in on-stations which are good production environments (Cecareelli *et al*., 2000). Unfortunately, this approach has by-passed marginal regions (low production environments) that have not benefited from modern varieties. The development of varieties in this approach is the responsibility of plant breeders. Farmers are recipients of varieties only when they have been released by scientists and included into the official recommendation list of the agricultural extension system. This is therefore the reason for why farmers are reluctant to uptake the improved varieties (Banziger and Cooper, 2001). Hence, on-farm participatory varietal selection (PVS) in determining GxE interaction and yield stability can result in the most productive varieties suitable for the specific drought prone areas (Cecareelli *et al*., 2000).

According to Walter and Juliana (2008), participatory varietal selection (PVS) is defined in different ways for different crop reproductive systems. In self pollinating crops for instance it is the selection of released or pre-released advanced lines. In open-pollinating species, it is the selection of cross-pollinating populations, and in vegetatively propagated crops, it is the selection of advanced clones. Despite the on station trial in the conventional approach, the selection process in PVS is mainly performed by farmers in their target environments using their own selection criteria. Landraces or local varieties can also be included in all types of trials. Basically, PVS provides varietal choices to the targeted farmers under their specific environmental conditions, promotes participatory approaches to variety testing, and selects and disseminates the preferred variety. PVS is about testing new varieties with farmers that can be done in many ways. No set protocol exists and methods vary for different crops and for different researchers' and farmers' circumstances. Meanwhile in the current study, an on farm trail on GxE interaction and yield stability of early maturing bread wheat varieties was carried out in six locations aimed at identifying varieties which are high yielding with broadly and specifically adapted for drought prone areas of Tigray region. Furthermore, the research aimed at determining GxL interaction and yield stability of the elite varieties. Therefore it is paramount important to study this GxE interaction so as to find out best genotypes that suit the drought prone wheat growing environments of the region.

MATERIALS AND METHODS

Description of the study sites

The trail locations were Hawzein, Wukro, Atsbi, Illala, Ganta Afeshum and Enderta, which represent drought prone wheat growing environments of the region with an annual mean rain fall of 359.3 mm (Table 1). Mean annual rainfall during the study year was the highest at Atsbi (433 mm) followed by Illala (401 mm) whereas the mean rainfall was the lowest for Enderta (330 mm) followed by Wukro. Above all, rainfall distribution in most of the locations was erratic with an early secession from day of flowering to physiological maturity of the crop.

Treatments and experimental design

Four introduced genotypes namely HUW-468, HI-1418, DL-788-2, GW-273, standard and local checks were used in this study. The introduced varieties were released by India Agricultural Research Institute. HI-1418 was released as Naveen Chandausi in 2000; DL-788-2 was released as Vidisha in 1997; HUW-468 was released as Malaviya 468 in 1999; and GW-273 was released in 1998. All these varieties are earlier to mature (80 to 90 days), medium plant height, high terminal drought tolerance, amber and hard grains with good chapatti making quality, and high disease resistance. These varieties are introduced to Ethiopia in 2007 and two of the varieties (HUW-468 and HI-1418) are registered by the national variety release committee in 2011. The local check used during the study was called 'Shehan' and it is known in the region for its earliness and white seeded colour. Similarly, HAR-2501 (Hawi) was the one which is being cultivated and promoted in the region for moisture stressed wheat growing areas and hence was used as a standard check.

The trial was conducted at six drought prone wheat growing locations and followed the 'mother-baby' approach as suggested by Witcombe (2002). The mother trials have all test varieties and baby trials have one test variety alongside farmers' own variety in paired plots. Both mother and baby trials are single-replicate trials with replications across farmers and are conducted under farmer management. But for this paper, only mother trials were considered for analysis. The study was executed at a total of 23 experimenting farmers and hence, 23 on-farm mother trials were conducted in the 2009 production season at all of the locations. In each farmer's field, the complete set of the genotypes were sown in an initial equal plot size of 20 m^2 and the plots were 0.5 m apart. A seeding rate of 160 kg/ha was used uniformly and sown in broadcast in the on-farm trial. The trials were managed as per farmers' practice including land preparation, weeding and other management. The harvestable area in each of the experimenting farmers was 9 m^2 and as mentioned above, the farmers' were considered as a block. Days to maturity, grain yield and farmers perception were taken.

Statistical analysis

Stability analysis of variance and stability parameters like linear regression coefficient (bi) and deviation from regressions of genotypes measured over environmental index (S^2d_i) were computed for grain yield as suggested by Eberrhart and Russell (1966) using GenStat Version 12 (Virk and Witcombe, 2008).

RESULTS AND DISCUSSION

The analysis of variance for AMMI (additive main effect multiplication interaction) model revealed non-significant differences among the genotypes while significant variations among locations for grain yield (Table 2). This indicates that the locations are different in productivity that might be attributed to variations in soil type, soil fertility, moisture availability, management and temperature. In line with the current study, a finding on GxE interaction on bread wheat lines in Southern Sudan revealed similarly significant difference in location (Mohhamed, 2009). Mean while, in the present case the result showed non-significant difference in the variety by location interaction. This means the candidate varieties mainly the new genotypes respond similarly to all the locations and showed a good fit to the target environments of Tigray region.

Mean grain yield over all trials in the six locations were significantly highest for HUW-468 which was 2.375 t/h. HUW-468 had shown a 25.60% yield advantage over the local check and 23.24% more over the standard check (HAR-2501). HI-1418 was the next highest yielder (2.173 t/ha) with a yield increment of 15.00% and 12.76% over the local and standard checks, respectively (Table 3). These varieties also matured earlier than both checks (the checks were used to be known for their earliness in the areas) with 84 to 90 days to maturity and this feature makes them ideal to areas of the Tigray region which suffer a lot from early or late season moisture stress. Furthermore, the two varieties are also the most selected and preferred varieties by farmers based on their earliness, spike length, disease resistance, and grain yield. Their significant plant biomass was also an added advantage as livestock feeds to farmers of the region.

Table 2. Mean grain yield of varieties tested over six environments in 2009

Varieties	Locations						Mean
	Atsbi	Enderta	Ganta-Afeshum	Hawzen	Illala	Wukro	
DL-788-2	20.73	13.22	16.60	14.97	31.91	16.40	18.67
GW-273	19.57	12.70	16.23	16.92	31.17	16.06	18.64
HI-1418	19.69	15.52	18.23	19.45	35.58	15.48	20.65
HUW-468	22.80	16.17	22.1	19.75	32.09	16.89	21.56
LOCAL	20.04	15.97	17.37	17.57	23.91	13.61	18.39
STANDARD	19.79	17.00	16.0	14.33	30.44	14.85	18.66
LSD (5%)	6.01	4.38	3.6	3.46	7.12	4.57	2.07
CV	16.40	21.23	26.35	22.94	15.67	17.75	
MEAN	20.44	15.10	17.76	17.17	30.85	15.55	19.30

LSD (5%) =least significant difference at p = 0.05 probability level; CV=coefficient of variation

Table 3. Mean grain yield of genotypes in comparison with local and standard check

Variety	Mean yield (t/ha)	Increased over local (%)	Increased over standard (%)
DL-788-2	1.964	3.86	2.00
GW-278	1.993	5.39	3.40
HI-1418	2.173	15.00	12.76
HUW-468	2.375	25.60	23.24
LOCAL	1.891	0.00	-1.86
STANDARD	1.927	2.00	0.00

Table 4. Parameters of regression analysis of variety mean grain yield onto trial mean grain yield

Variety	Over all mean grain yield t/ha	Intercept(a)	Regressions coefficient (b_i)	S^2d_i	R^2
DL-788-2	1.964[a]	-1.08	1.00[Ns]	0.08	0.86
GW-278	1.993[a]	-0.15	0.97[Ns]	0.07	0.88
HI-1418	2.173[ab]	-3.20	1.21[Ns]	0.10	0.85
HUW-468	2.375[bc]	1.70	1.07[Ns]	0.09	0.86
LOCAL	1.891[a]	1.74	0.83[Ns]	0.12	0.70
STANDARD	1.927[a]	0.98	0.89[Ns]	0.11	0.74
Grand mean	2.054				

*Values in the same column followed by same letter are not significantly different at p = 0.05 level; where bi, regression slope; S^2d_i, deviation from regression; R^2, coefficient of determination; Ns, non significant

Since the GxL interaction in the ANOVA for AMMI model showed non-significant difference (p = 3.1), to further assess the adaptation trends and stability of the varieties a regression analysis for location interactions of individual variety mean grain yield was regressed on to environmental indexes that use means of all the varieties in the trials (Table 4). This is in line with study of Yates and Cochran (1983) in which the stability analysis used the regression coefficient (b_i) and deviation from linear regression (Sd_i) as first developed by Yates and Cochran and then modified by Eberrhart and Russell (1966) and Perkins and Jinks (1968). According to these authors, a stable variety is one with high mean yield, a coefficient of regression equal to unity (b_i =1) and deviation from regression equal to zero.

From the GxL interaction and stability analysis, all of the candidate varieties showed regression coefficient not significantly different from unity (b_i=1). For this reason, the stability performance comparison will be decided on the basis of deviation from regression and over all mean grain yield of the tested genotypes. Similarly regardless of the types of checks, all the new varieties had higher coefficient of determination (R^2 > 85%) (Table 4) and this ensures the minimal effect of the environment on the genotypes that are attributable to the nature of the varieties. This is also in line with the study of Hardwick and Wood (1972).

Hence, considering the aforementioned stability parameters, HUW-468 gave the highest grain yield with regression coefficient of 1.07 revealing a relatively stable performance across the testing locations. In a similar manner, the $IPCA_1$ (interaction principal component analysis) for this variety had the lowest score (0.47), indicating its stability in all environments. The result also coincides with a trial conducted in Pakistan on wide and specific adaptability of bread wheat inbreed lines. Hence, one inbreed line showed highest yield, regression coefficient of 1.03, and lowest deviation from regression showing its stability across the environments (Khan *et al*., 2007). In the present study, HI-1418 was also high yielding with regression coefficient value slightly greater than unity (b_i=1.21) and low deviation from regression and therefore is mostly adapted to the relatively favorable locations like Illalla and Atsbi. But, this same genotype also performed well in the low yielding environments showing its plasticity in yielding ability (Fig. 1). On the other hand, the local and standard checks with lower mean yield than the grand mean (Table 4) had higher S^2d_i value. For this reason, these checks are relatively sensitive to environmental changes. Especially the standard check is expected to give a relatively better yield when the environment is conducive.

There were differential response of the genotypes reflected by both cross over and non cross over type of GxL interactions (Fig. 1). The present study also agrees with the work of Abay and Bjorntad (2007) in determining GxE interaction of barley varieties in the Tigray region. Accordingly, the differential response of the varieties depicts the locally developed barley variety was found superior in the low yielding environments of region while the nationally released standard checks were inferior and rejected by farmers in these areas. In the present study, the type of interaction existed in HUW-468 and HI-1418 with respect to the rest of the candidate varieties is a quantitative type of interaction and this indicated that the two genotypes are superior in all locations. On the other hand, there was clearly a qualitative or cross over type of interaction among the two best varieties. This revealed that variety HUW-468 had better yielding performance in low yielding locations (less than 0.5 t/ha) while HI-1418 was better in relatively high yielding locations (1 to 2.5 t/ha).

CONCLUSION AND RECOMMENDATION

Most of the new genotypes had good performance in all of the tested environments but varieties HI-1418 and HUW-468 out-yielded local and standard checks but not significantly different. This single year trial and other subsequent trails which are not actually included in this article showed that these varieties are widely adapted and relatively most stable to the drought prone areas of the region. Accordingly, both varieties are registered by the national variety release committee in 2011. Therefore, these varieties are recommended for scaling out and popularizing in the moisture stressed areas of the Tigray region and areas in other parts of Ethiopia that share similar moisture regime.

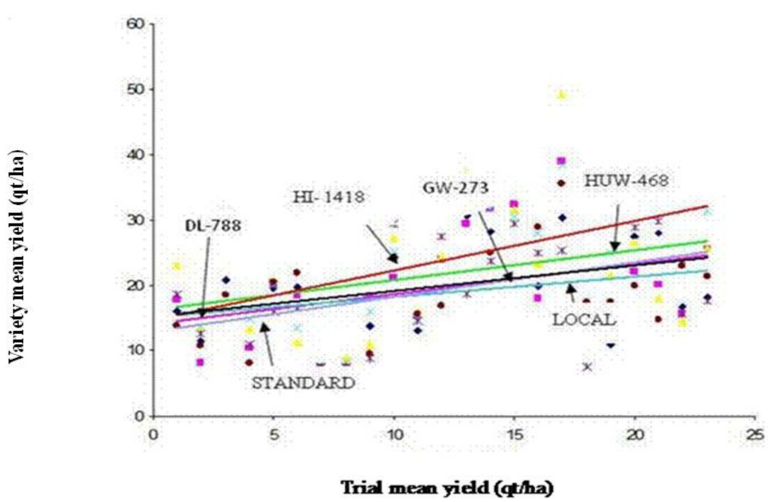

Figure 1. Regression lines for variety grain yield of six genotypes onto trial mean grain yield tested over six environments.

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REFERENCES

Abay, F. 2007. Diversity, adaptation and GxE interaction of Barley (*Hordeum vulgare* L.) varieties in Northeren Ethiopia. The Norwegian university of life sciences, Norway.

Bänziger, M and Cooper, M. 2001. Breeding for low input conditions and consequences for participatory plant breeding: Examples from tropical maize and wheat. *Euphytica* **122:**503–519.

CSA (Central statistical authority). 2002. Agricultural sample survey report on area, production and yields of major crops. Central statistical Authority, Addiss Ababa, Ethiopia. Abstract No. 26.

Ceccarelli, S, Grando, S, Tutwiler, R, Baha, J, Martini, AM, Salahieh, H and Goodchild, A. 2000. A methodological study on participatory barley breeding. *Euphytica* **111:**91–104.

Ceccarelli, S. Grando, s, Amri, A, Asaad, FA, Benbelkacem, A, Harrabi, M, Maatougui, M, Mekni, MS, Mimoun, H, El-Einen, RA, El-Felah, MA, El-Sayed, F, Shreidi, AS and Yahyaoui, A. 2001. Decentralized and participatory plant breeding for marginal environments. *In*: (Cooper, HD, Spillane, C and Hodgink, T. Eds.) Broadening the Genetic Base of Crop Production. CABI, New York (U.S.A.)/FAO, Rome (Italy)/IPRI, Rome (Italy). pp. 115-136.

Ceccarelli S, Grando, S, Singh, M, Michael, M, Shikho, A, Al Issa, M, Al Saleh, A, Kaleonjy, G, Al Ghanem, SM, Al Hasan, AL, Dalla, H, Basha, S and Basha, T. 2003. A methodological study on participatory barley breeding. *Euphytica* **133:**185–200.

Eberhart, SA and Russel, WA. 1966. Stability parameters of comparing varieties. *Crop science* **6**:36-40.

Hardwick, RC and Wood, JT. 1972. Regression method for studying genotype interaction. *Heredity* **28**:229-290.

Jalleta, T. 2004. Participatory evaluation of the performance of some improved bread wheat (Triticum aestivum) varieties in the Jijiga plains of eastern Ethiopia. *Experimental Agriculture* **40:**89-97.

Khan, Azam, AJF, Ali, A, Tariq, M, Amin, M and Muhammed, T. 2007. Wide and specific daptation of bread wheat inbred lines for yield under rainfed conditions. *Pakistan Journal of Botany* **39(1)**:67-71.

Ministry of Agriculture. 2007. C*rop variety register*. Ministry of agriculture, Addis Ababba, Ethiopia **10**:7-8.

Mohammed Maarouf I. 2009. Genotype X Environment Interaction in Bread Wheat in Northern Sudan Using AMMI Analysis. *American-Eurasian Journal of Agriculture and Environmental Science* **6(4)**:427-433.

Tefera, H. 2006. *Plant Breeding and Biotechnology Capacity Survey Ethiopia*. FAO consultation paper, Addis Ababa.

Walter, S de Boef and Juliana Bernardi Ogliari. 2008. Participatory crop improvement and informal seed supply: general introduction. In: Thijssen, M.H., Z. Bishaw, A. Beshir and W.S. de Boef, 2008 (Eds.). *Farmers, seeds and varieties: supporting informal seed supply in Ethiopia.* Wageningen, Wageningen International. pp. 177-184.

Perkins, JM and Jinks, JL. 1968. Environmental and genotype environment components of variability III in multiple inbred lines and crosses. *Heredity* **23**:339-356.

Virk, DS and Witcombe, JR. 2008. Evaluating cultivars in unbalanced on-farm participatory trials. *Field Crops Research* **106:**105-115.

Witcombe, JR. 2002. Mother and baby trial system. *In*: (Witcombe, JR, Parr LB and Atlin, GN. eds.). Breeding Rainfed Rice for Drought-Prone Environments: Integrating Conventional and Participatory Plant Breeding in South and Southeast Asia. Proceedings of a DFID Plant Sciences Research Programme/IRRI Conference 12-15 March 2002, IRRI, Los Baños, Philippines. pp. 79-89.

Yates, F and Chochran, WG. 1983. The analysis of group of experiments. *Journal of Agricultural science* **28**:55-580.