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Univariate Stability Analysis for Determining Genotype by Environment Interaction in Tef [*Eragrostis tef* (Zucc.) Trotter] at South and Southwestern Ethiopia

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Abstract

Objective of the study is to identify high yielding and stable tef varieties using Univariate Stability parameters. Twenty-one released tef varieties obtained from tef breeding program based at Debre zeit Agricultural Research center and evaluated in 2018 main cropping season. The experiment was conducted using randomized complete block design in three replication across six locations. Data for all relevant agronomic traits were collected, but only plot yield data converted to kg/ha was subjected to statistical analysis Combined analysis of variance indicated that genotype by environment interaction significantly influenced grain yield performance of tef varieties across locations. Different stability parameters identified different stable varieties. According to coefficient of determination G2, G9 and G8 were stable and coefficient of variation identified G21,G18 and G14 as stable varieties. Variety G13, G12 and G6 and G15,G11 and G1 were stable according to wricke's ecovalence and cultivar superiority respectively. Pekins and Jinks for tef varieties identified G11,G10 and G6 as stable varieties. According to non parametric stability (S^1 and S^2) variety G11, G12 and G21 and G11, G15 and G4 identified stable varieties respectively. Based on some of the stability parameters and mean performance G11, variety Heber-1 (1034.1kg/ha), G1, variety Quncho (959kg/ha) and G15, variety Dukem (1086.3kg/ha) were the most stable and recommended for their broad adaptation of south and southwestern Ethiopia.

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Correlation, Genotype x environment interaction, Stability parameter, Univariate

Introduction

Tef [*Eragrostis tef* (Zucc.) Trotter] is the major cereal crop in Ethiopia where it is staple food for about 50 million people (Kebebew *et al*., 2015). The high level of resilience to extreme environmental conditions and high in nutritional values makes tef the most preferred crop among both farmers and consumers (Plaza *et al*., 2015). Among the food crops grown in Ethiopia, tef is cultivated on about 3 million hectare producing 5.02 million tons (CSA, 2017). In spite of the low productivity, tef is widely cultivated by over six million small-scale farmers' households in Ethiopia. It is considered to be an orphan crop because it has benefited little from international agricultural research system (Kebebew *et al*., 2015).

Tef is the most preferred crop as source of food and animal feed in Ethiopia. Besides, it's tolerant to drought, water logging and pests particularly against storage pests. Now a day, tef has become a globally popular crop for its gluten free property that makes it conducive for people suffering from celiac disease and diabetic because of its slow release of carbohydrates. Hence, it is regarded as a promising alternative food replacing gluten containing cereals like wheat, barley and rye in products such as pasta, bread, beer, cookies and pancakes (Spaenij *et al*., 2005). Recently, Gina *et al*., (2014) supported this fact with results from the genome sequence initiative. Tef has high iron content that makes it appropriate for pregnancy related anemia (Alaunyte *et al*., 2012). The iron content mainly seems to play an essential role in Ethiopia, as there is absence of anemia in areas of tef consumption (BoSTID, 1996).

The production and productivity of tef can be increased either by increasing cultivated area or by increasing yield per unit area. Currently, it is nearly impossible to increase production due to competition with other crops and because of different stress factors. Therefore, the only alternative left is to increase yield per unit area by better crop management techniques and introducing high yielding varieties with tolerance against environmental stresses. However, cultivars often do not perform in a similar manner when tested in multiple environments. This phenomenon is due to the presence of genotype by environment interaction (GEI). Genotype by environment interaction is differential genotypic expression across environments. It complicates identification of superior genotypes, pointing out the need for growing different cultivars in different areas of the target region.

Thus, detection of areas in which genotypes perform similarly becomes a priority for cultivar evaluation and recommendation (Gauch and Zobel 1997). Genotype by environment interaction is of major importance because it provides information about the effects of different environments on cultivar performance and plays a key role in assessing the yield performance and stability of breeding materials. it’s important that new tef varieties are evaluated in different environments for several years/seasons before being released. The new varieties with desired traits that add value to the product should be tested for the stability of these traits in the target environments (Kang, 1998).

Evaluation of different genotypes in multi-environments and/or years is not only important to determine high-yielding cultivars, but also to identify sites that best represent the target environment (Yan *et al.*, 2001). Moreover, the successfully developed high-yielding potential new cultivar should have a stable performance and broad adaptation over a wide range of environments. A genotype or cultivar is considered stable if it has adaptability for a trait of economic importance across diverse environments.

The environmental component (E) generally represents the largest component in analysis of variance, but it is not relevant to cultivar selection; only G and GE interaction are relevant to meaningful cultivar evaluation and must be considered simultaneously for making selection decisions (Yan & Kang, 2003).Although, there is no single method developed so far that equally satisfy breeders for the study of G x E interactions, there are many different statistical analysis in use today, including parametric and non-parametric, to study the nature of interactions of genotypes with environments (Kaya *et al.*, 2006).

Many methods of analysis for stability have been proposed. Some of the parametric one were; Francis and Kannenberg (1978) proposed the use of the coefficient of variation (CV) as a measure of genotype stability. Pinthus’s (1973) approach uses the coefficient of determination (CD) of linear regression model for determining stability. Wricke (1962) proposed the concept of ecovalence, which is the contribution of a genotype to the GEI sum of squares; the G × E interaction for a genotype, squared and summed across all environments, is the stability measure for that genotype.

Unlike parametric stability models, non parametric stability models have the following properties:

(i) They are based on the ranks of genotypes in each environment but did not need any assumptions (ii) They reduce biases caused by outliers, and easy to interpret and use in plant breeding program where the ranking order of the tested genotype is very crucial. (iii) Addition or deletion of one or few genotypes does not cause much variation in estimating value of the stability models (Huehn, 1990).

The level of association among stability estimates of different models is signal of whether one or more estimates should be obtained for prediction of cultivar behavior, and also helps the breeder to choose the best stability parameter (s) (Duarte and Zimmermann 1995). The objective of the present study was to determine stability of grain yield in tef varieties and evaluate the level of association among the stability parameters.

Materials and Methods

Description of the study sites

The experiment was conducted during the 2018 main cropping season at six locations, namely: Melko, Bedele, Omonada, Arjo, Ambo and Areka. These locations represent the varying agro-ecologies with stressful nature and the major tef growing areas of Ethiopia in South and South-Western Ethiopia (Table 1).

Experimental materials

Twenty-one nationally released tef varieties were included in the study (Table 2). They were obtained from Debre Zeit Agricultural Research Center (DZARC).

Data were recorded on plot and single plant basis and taken from the central eight rows of the plot. Individual plant based data were taken from five plants in each plot taken randomly from the central eight rows of each plot.

Data collected on plot basis

Days to heading (DH): The number of days from 50% of the plots showing emergence of seedlings up to the emergence of the tips of the panicles from the flag leaf sheath in 50% of the plot stands

Days to maturity (DM): The number of days from 50% of the plots showing seedling emergence up to 90% of the plants in the plot reaching phenological maturity stage (as evidenced by eye-ball judgment of the plant stands when the color is changed from green to yellow color of straw)

Grain filling period (GFP): The number of days from 50% heading to 90% maturity of the stands in each plot

Lodging index (X): The value recorded following the method of Caldicott and Nuttall (1979) who defined lodging index as the sum of product of each scale or degree of lodging (0-5) and their respective severity percentage divided by five, where 0 value is fully upright (90^0), 1 = 0-15^0lodging, 2=15-30^0 lodging 3 = 30-45^0 lodging, 4 = 45-60^0 lodging and 5 = 60-90^0 lodging and the plants become completely flat

Total biomass yield (g/plot): The weight of all the central row plants including tillers harvested at the level of the ground

Grain yield (g/plot): The weight of grain for all the central row plants including tillers harvested at the level of the ground

Straw yield (g/plot): The weight of straw plus chaff of all the central row plants including tillers harvested at the level of the ground

Thousand seed weight (TSW): The weight of thousand kernels in gram sampled from the entire plot

Harvest index: The value computed as the ratio of grain yield to the total (grain plus straw) biomass multiplied by 100.

Data collected on plant basis

Plant Height (cm): Measured as the distance from the base of the stem of the main tiller to the tip of the panicle at maturity

Panicle Length (cm): The length from the node where the first panicle branch starts up to the tip of the main panicle at maturity

Culm Length (cm): The length of the main shoot node from the ground level up to the point of emergence of the panicle branches

Fertile Tillers: The number of panicle-bearing fertile tillers produced per plant

Data Analysis

Combined analysis of variance was done on grain yield that obtained from six environments according to the Comstock and Moll (1963) Method. Six stability parameters were applied to assess stability performance of genotypes and to identify superior genotypes; Coefficient of variation (CV%), Coefficient of determination (R^2), Wricke's ecovaence, Cultivar superiority index, Perkins and Jinks and non-parametric stability parameters (S^1 and S^2). All analysis was performed using the statistical package G-EAR (Genotype by environment interaction with R) software. Spearman's coefficient of rank correlation was computed for each pair of the possible pair-wise comparison of the stability parameters by Minitab computer software (Minitab, 1996) and the significance of the rank correlation coefficient was tested according to Steel and Torrie (1980).

Results and Discussions

Combined analysis of variance presented in Table 3. Combined analysis of variance was performed to determine the effects of environment, genotype, and GE interaction on grain yield of tef varieties according to result of Bartlett's homogeneity test. The main effects of genotype, environments and the genotype by environment interaction were highly significant ($P < 0.01$), (Table 3). The high significance of GEI for grain yield of 21 tef varieties tested across six locations during one year revealed the presence of crossover types of GEI. Complexity of grain yield as a quantitative trait is a result of diverse processes that occur during plant development. The larger degrees of GEI cause to the more dissimilar the genetic systems controlling the physiological processes conferring adaptation to different environments.

Partitioning sum squares to its components revealed that genotype by environment interaction effect was highly significant and contributed 17.5% of total variation, 7.9% due to genotype and 69.4 % was due to environment. The big contribution of environment (69.4%) the total variation of grain yield shows the testing locations are diverse (Table 3).

Stability parameters

The results for the different stability parameters are presented in Table 3.In this study, several stability models were used for interpreting genotype by environment interaction. In this study several stability models are used for interpreting genotype by environment interaction. For using regression slopes as stability parameters, regression model need that heterogeneity of genotype regressions account relatively (Annicchiarico,1997).The most favorable genotype is the one that combines both high mean yield and stability performance together and so it is acceptable over a wide range of environmental conditions (Allard and Bradshaw, 1964). This idea for identifying favorable genotypes reflects dynamic concept of stability. Mohebodini *et al.,* (2006), Dehghani *et al.,* (2008) and Karimizadeh *et al.,* (2012) reported that the regression coefficients of the most of the regression models benefits from dynamic concept of stability and could be useful for detecting the most stable genotypes. Anyhow, each stability statistic reflects different aspects of yield stability concepts and no single method can adequately explain genotype performance across different environments (Flores *et al*., 1998; Sabaghnia *et al*., 2006). Therefore, it seems that for reliable decision about GEI and effective selection of favorable genotypes, it is better multi-environment trials dataset is evaluated through different aspects of stability concepts.

Francis and Kannenberg's Coefficient of variation (CV %)

According to Francis *et al.,* (1978), stable genotype is the one that provides a high yield performance and consistent low CV. Accordingly, variety G18 and G14 had low coefficient of variation and mean grain yield of above grand mean, thus the varieties were considered as high yielding and stable across locations. The varieties G13,G17 and G9 had large value of coefficient of variation and mean grain yield below the grand mean, hence considered as low yielding and unstable varieties (Table 4).

Coefficient of determination (R^2)

Coefficient of determination ranged from 0.4 to 0.98 which indicated that 40 to 98% of the mean grain yield variation was explained by genotype response across environments and indicating stability differences among genotypes (Table.4). The coefficient of determination is often considered a better index for measuring the validity of the linear regression than S^2di, because its value ranges between zero and one. Bilbro and Ray (1976) suggested that Ri^2 could be useful in measuring dispersion around the regression line and therefore related to the predictability and repeatability of the performance within environments. The coefficient of determination of some tef varieties was very high. This was possibly due to evaluating in quite different locations. Varieties with high coefficient of determination were variety G13 (0.98),G11 (0.97) and G21 (0.96) were stable and varieties with low coefficient of determination such as G2,G9 and G8 were unstable. Several authors used the parameter to estimate the stability of genotypes viz Mulusew *et al*.(2014) in field pea and Hassaen *et al.,* (2016) in canola.

Perkins and Jinks (1968)

Perkins and Jinks (1968) discussed linear regression of genotypic components of a genotype into environment components. Their method allows orthogonal partition of genotype by environment interactions into a part due to regression and a part due to deviation, and thus, provides an accurate test as to whether or not the interaction observed in an experiment is a linear function of the environment components. According to Perkins and Jinks, variety Quncho (G1) and Tesfa (G10) were stable varieties and variety Felagot and Negus were unstable.

Lin and Binns Cultivar Superiority Measure (Pi)

Lin and Binns (1988) define stability as the deviation of a specific genotype's performance from the performance of the best cultivar in a trial. This implies that a stable cultivar is one that performs in tandem with the environment. This procedure appears to be considerably more of a genotype performance measure, rather than a stability measure over sites. The genotype mean yield could then rather be used to identify a superior yield performing cultivar. According to Lin and Binns (1988) for cultivar superiority measure (Pi) analysis, the genotype with low or small Pi value is considered to be the more stable. Accordingly the high yielding varieties, namely Dukem (G15), Quncho (G1) and Heber-1(G11) showed low cultivar superiority value and highest yield performance indicating stability of those varieties. On the other hand, the varieties Enatite (G21), Kena (G3) and Guduru (G2) which showed high Pi value and lowest mean yield were considered to be unstable.

Wricke's Ecovalence Analysis (Wi)

Ecovalence indicates the contribution of each genotype to the GEI (Wricke 1962). The cultivars with the lowest ecovalence contributed the least to the GEI and are therefore more stable. The five most stable tef varieties according to the eco-valence method of Wricke's (1962) were Gibe, Wellenkomi, Dagim, Heber-1 and Tesfa. Varieties ranked for mean yield 17th, 19th, 7th, 2nd and 18th respectively (Table 3). The most interactive and unstable varieties based on the ecovalence method were Negus (G8), Guduru (G2), Felagot (G9), Kena (G3) and Quncho (G1). These varieties were ranked for mean yield as 10th, 16th, 20th, 21th and 3rd respectively.

Nassar and Hühn's mean absolute rank difference (S^1) (Non parametric)

Nassar and Hühn (1987) described non-parametric measures of stability based on ranks and provide a viable alternative to existing parametric analyses. This non-parametric test is based on the ranks of the genotypes across locations. This gives equal weight to each location or environment. Genotypes with less change in rank are expected to be more stable. The mean absolute rank difference (S^1) estimates are all possible pair wise rank differences across locations for each genotype. The S^2 estimates are simply the variances of ranks for each genotype over environments (Nassar and Hühn, 1987; Hühn, 1990). For S^1, entries may be tested for significantly less or more stable than the average stability/instability For the variance of ranks (S^2), smaller estimates may indicate relative stability. Often, S^2 has less power for detecting stability than S^1. The S^1 may loose power when genotypes are similar in their interactions with the environments. Usually S^1 is the preferred parameter because of its ease of computation, its clear and relevant interpretation. Furthermore, an efficient test of significance is available (Hühn, 1990).

Table.1 Location and descriptions of weather condition for six locations

Location	Geographic position		Altitude (m.a.s.l)	Soil type	Temp (^{0}C)	Rainfall (mm)
	Latitude (N)	Longitude (E)				
Ambo	8^{0}57′	38^{0}07′	2175	Vertisol	18	1018
Areka	7^{0}09′	37^{0}41′	1830	Alfisol	27	1539
Arjo	8^{0}74′	36^{0}50′	2457	Nitosol	18	1850
Bedele	8^{0}27′	36^{0}21′	2087	Nitosol	18	1700
Melko	7^{0}47′	36^0 47′	1753	Nitosol	22	1639
Omonada	7^{0}41′	37^{0}12′	1975	Nitosol	20	1600

Source: Research Centers and Agricultural Offices of the Respective Weredas

Table.2 Tef varieties used for the study

Code	Variety name	Common name	Year of release
G1	DZ-Cr-387 RIL355)	Quncho	2006
G2	DZ-01-1880	Guduru	2006
G3	23-Tafi Adi-72	Kena	2008
G4	DZ-01-3186	Etsub	2008
G5	DZ-Cr-438 RIL133 B	Kora	2014
G6	DZ-Cr-438 RIL91A	Dagim	2016
G7	DZ-Cr- 438 RIL7	Abola	2016
G8	DZ-Cr-429 RIL125	Negus	2017
G9	DZ-Cr-442 RIL77C	Felagot	2017
G10	DZ-Cr-457 RIL181	Tesfa	2017
G11	DZ-Cr-419 (DZ-Cr-974 X PI 222988)	Heber -1	2017
G12	DZ-01-787	Wellenkomi	1978
G13	DZ-Cr-255	Gibe	1993
G14	DZ-01-99	Asgori	1970
G15	DZ-01-974	Dukem	1995
G16	DZ-01-1285	Koye	2002
G17	DZ-01-2053	Holetta Key	1998/99
G18	DZ-Cr-37	Tsedey	1984
G19	DZ-CR-409 (sel. 50D)	Boset	2012
G20	DZ-01-196	Magna	1970
G21	DZ-01-354	Enatite	1970

Table.3 Combined ANOVA for Grain yield (kg/ha)

Source of variation	Degrees of freedom	SS	%SS	MS
Environment	5	36913429.26	69.4	7382685.85**
Replication with E (R/E)	12	208288.87	0.391	17357.41^{ns}
Genotype	20	4223319.35	7.94	211165.97**
Interaction (GEI)	100	9377492.99	17.5	93774.93**
Residuals	240	2431273.26	4.57	10130.31
Total	377	53153803.73		
Mean=826.5	**R^2=0.95**	**CV = 12.5**		

*, **, ns =significant, highly significant and non-significant at the level of P<0.01 and 0.05 respectively,CV = coefficient of variation, SS =sum square, MS=mean square GEI =genotype by environment interaction

Table.4 Summary of overall mean grain yield (kg/ha) of different stability parameters and their rank (R) order for 21 tef varieties tested in six locations of South and Southwestern Ethiopia

Variety Code	Variety Names	Grain yield	R	R^2	R	CV (%)	R	S^1	R	S^2	R	Dji	R	Wi	R	Pi	R
G1	Quncho	957.3	3	0.87	11	47.5	13	1.93	7	25.6	10	31354.75	1	162990	17	40180	3
G2	Guduru	763.5	16	0.41	1	46.6	10	3.57	19	52.3	19	94788	12	443429	20	134620	19
G3	Kena	662.8	21	0.72	4	40.2	6	2.93	16	44.4	18	24978.94	15	164396	18	160102	20
G4	Etsub	783.3	14	0.87	10	51.6	16	1.4	5	15.25	3	26136.36	16	112032	12	97594	13
G5	Kora	808	10	0.91	15	49.1	14	2.87	14	37.8	16	18192.45	17	80724	7	81456	9
G6	Dagim	865.5	7	0.96	18	46.9	11	2	9	21.6	7	8397.351	18	50982	3	59542	7
G7	Abola	940.7	4	0.83	8	43.9	9	1.83	6	29.45	12	37006.66	19	155808	16	44234	4
G8	Negus	792.2	11	0.64	3	63.5	21	4.53	21	83	21	115751.8	20	483095	21	125344	18
G9	Felagot	703.3	20	0.44	2	52.7	17	3.57	20	53.85	20	96296.5	21	428392	19	161378	21
G10	Tesfa	720.2	18	0.91	12	47.3	12	3	17	34.2	14	14300.67	2	58377	5	119684	16
G11	Heber -1	1032.2	2	0.97	20	40.8	8	0.57	1	2.9	1	5936.799	3	52263	4	17903	2
G12	Wellenkomi	712.5	19	0.92	16	50.4	15	2	8	18.4	6	11617.8	4	46639	2	121529	17
G13	Gibe	731	17	0.98	21	56.5	19	1.13	4	18.25	5	4068.572	5	41399	1	109126	15
G14	Asgori	897.5	5	0.79	6	34.2	3	2.27	11	21.8	8	24281.89	6	118900	13	52955	5
G15	Dukem	1084.3	1	0.93	17	39.7	5	0.6	2	3	2	14626.27	7	88266	8	11564	1
G16	Koye	839.5	9	0.82	7	35.8	4	2.9	15	33.1	13	20316.34	8	103723	11	72140	8
G17	Holetta Key	784.2	12	0.91	14	57.1	20	2.6	13	34.4	15	23026.66	9	130044	14	91333	10
G18	Tsedey	872	6	0.84	9	34.1	2	2.57	12	29.05	11	17437.05	10	91931	9	59271	6
G19	Boset	851.8	8	0.91	13	53.9	18	2.1	10	23.05	9	20914.74	11	99695	10	98156	14
G20	Magna	784	13	0.76	5	40.3	7	3.17	18	38.45	17	28898.78	13	136323	15	95904	11
G21	Enatite	765.5	15	0.96	19	31.7	1	1	3	17.05	4	2490.772	14	60909	6	97002	21

R^2= Coefficient of determination, CV (%) =Coefficient of variation, Mean absolute rank difference ($Si^{(1)}$) and variance of ranks ($S^{(2)}$) =non parametric=Perkins and Jinks (agronomic),Wi= wricke's ecovalence ,Pi=Cultivar superiority index

Table.5 Spearman's coefficient of rank correlation for six genotype-environment interaction stability parameters of 21 tef varieties evaluated in six environments in South and Southwestern Ethiopia, 2018

	GY	CV	R^2	S^1	S^2	PJ	Wi	Pi
GY								
CV	-0.37363							
R^2	0.34091	-0.13637						
S^1	-0.55134**	0.31609	-0.71997**					
S^2	-0.53178*	0.42094*	-0.73944**	0.93962**				
PJ	-0.25987	0.43715*	-0.88649**	0.7301**	0.83525**			
WI	-0.26382	0.38706	-0.90942**	0.70843**	0.82408**	0.99129**		
Pi	-0.95025**	0.40761	-0.56009**	0.61863**	0.63752**	0.47447*	0.48949*	

*, **, ns =significant, highly significant and non-significant at the level of P<0.01 and 0.05 respectively,GY=grain yield CV =Coefficient variation R^2=Coefficient of determination, ($S(^1)$ and $S(^2)$=Nassar and Hühn's (1987) absolute rank difference and variance of ranks respectively PJ = Perkins and Jinks (Agronomic), Wi=Wriecke's ecovalence Pi =Cultivar superiority

Two rank stability measures proposed by Huhn (1979) were worked out and expressed as and are in below Table 4. The varieties (Heber-1) G11, Dukem (G15), Enatite (G21) and Gibe (G13) had the Si^2 lowest value of and ranked 2nd, 1st15th and 17th for grain yield. Heber-1 (G11) and Dukem (G15) had highest grain yield and lowest absolute mean rank difference and they were stable varieties according to the principle of Nassar and Hun's mean absolute rank difference. However, G21 and G13 had low value of absolute mean rank difference.G8,G9 and G2 had highest absolute mean rank difference value indicating to be highly unstable varieties.

Interrelationships Among Stability Parameters

Correlation matrix was computed for the various stability parameter for grain yield were computed in Table 5 below. The mean grain yield was highly significant negative association with S^1 (r=-0.55134**) and cultivar superiority index (r=-0.95025**) and non-significant association with coefficient of variation, Perkins and Jinks and Wricke's ecovalence. Also it have positive but non-significant association with coefficient of determination (r=0.34091).Coefficient of variation was non-significant and positive association with S^1,Wi and Pi and negative association with coefficient of determination. Coefficient of variation showed significant and positive association with S^2 and PJ. Coefficient of determination had highly significant and negative association with all stability parameters and S^1 and S^2 showed positive and significant association with all stability parameters. PJ positive association with Wi and Pi. Mean grain yield was negatively correlated with most of the stability models implying that compatibility of high yield and stability of grain yield performance is an important, but difficult to achieve at the same time (Kang *et al.*, 1991). Significant positive associations between different methods indicate that genotypes are similarly classified as to stability. Methods may be supplying redundant information, and only one would be sufficient to select the best genotypes (Carnelutti *et al.*, 2009)

In conclusion, using of different stability parameter was important to identify high yielding and stable varieties for countries like Ethiopia where environmental variations are high and unpredictable. Different stability parameters identified different stable varieties. Overall,it could be concluded that based on most stability parameters and mean performance, variety Hebere-1(G11),variety Quncho (G1) and, variety Dukem (G15) (1086.3kg/ha) were the most stable and recommended for their broad adaptation of South and Southwestern Ethiopia.

Conflict of interest

The authors have not declared any conflict of interest

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