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GENOTYPE-ENVIRONMENT INTERACTIONS IN *VERNONIA GALAMENSIS*

Tsige Genet
Faculty of Agricultural and Environmental Sciences, Bahir Dar University, P.O.Box, 1626, Bahir Dar, Ethiopia; Tel: +251-582-200602; Fax: +251-582-202025; Mobile: +251-918-340121; Email: tsigegenet@yahoo.com

Abstract: Seed yield of nine *Vernonia galamensis* genotypes, tested in a randomised complete design with three replications across six environments in Ethiopia (three locations and two years) was analysed using different stability models. The objectives were to assess genotype-environment (G-E) interactions, determine stable genotypes, and to compare the stability models. Combined analysis of variance across locations indicated that year, location and genotype by year were the most dominant source of interactions. Highly significant rank correlations were found among stability variance, ecovalence and additive main effects multiplicative interactions that indicated their close similarity and effectiveness in detecting stable genotypes over a range of environments. The stability analyses identified 'Boke Kuni' as more stable genotype and 'Gelemso' specifically adapted to some environments.

Key words: G-E interaction; stability parameters; *Vernonia galamensis;* yield

INTRODUCTION

Vernonia galamensis ssp. *galamensis* var. *ethiopica* is a new industrial crop originating in Ethiopia, which combines all possible merits for semiarid tropics and subtropics with abundant rainfall (Gilbert, 1986, Baye *et al.*, 2000). It is limited in distribution and endemic to primarily East African countries as a weed colonizing disturbed areas and bare agricultural lands. The seed of *V.galamensis* contains 35-40% oil with 72-80% vernolic acid (12,13-epoxy-18: 1Δ9), a natural epoxy fatty acid. It is used in oleochemical industry, in formulation of additives, coatings, epoxy resins, lubricants and lubricant additives, sealants, toughened elastomers, and other industrial raw materials (Ayorinde *et al.*, 1990).

Vernolic acid is a naturally occurring epoxidized fatty acid with a unique physical properties, particularly low viscosity which may replace the chemically epoxidized soyabean/linseed oil. The defatted meal could be used as animal feed, and the plant can be grown in agroforestry system because it can tolerate shade. Various parts of the plant can be used as medicine to treat a variety of diseases. *V. galamensis* is a major source of natural vernolic acid, and hence a wide potential market is available for Ethiopian farmer. Agronomic data in Ethiopia show that the plant requires a well-drained red soil (Nitosols). So far efforts have been made in Ethiopia to explore, collect, and evaluate diverse germplasm source of *V. galamensis* for high yield, oil and vernolic acid content. However, information on genotype-environment interaction is lacking in this new industrial crop.

Knowledge of genotype-environment (G-E) interaction can help plant breeders to reduce the coast of expensive genotype evaluation by eliminating unnecessary testing sites (Shafi *et al.*, 1992; Kang and Magari, 1996, Basford and Cooper, 1998). The presence of large G-E interaction may necessitate the establishment of additional testing sites. Hence, if cultivars are being selected for a large group of environments, mean yield and stability across all environments are more important than yield for specific environments (Piepho, 1996).

The concept of stability has been defined in several ways and several biometrical methods including univariate and multivariate ones have been developed to assess stability (Hill, 1975; Lin *et al.*, 1986; Westcott, 1986; Becker and Lèon, 1988; Crossa, 1990). Joint regression analysis is the most popular among univariate method because of simplicity of calculation and applications (Becker and Lèon, 1988). Additive main effect multiplicative interaction (AMMI) is gaining popularity and is currently the main alternative multivariate approach to joint regression analysis in many breeding programs (Annicchiarico, 1997). AMMI combines the analysis of variance for the genotype and environment main effects with several graphically represented interaction of principal component analyses (IPCAs) (Crossa, 1990; Abamu and Alluri, 1998). Moreover, AMMI helps in summarizing the patterns and relationships of the genotypes, environment and their interactions (Gauch and Zobel, 1996)

No information is available on *V. galamensis* and its adaptation pattern under Ethiopian conditions. Hence, the stability analysis study was initiated on nine genotypes across six environments to generate information towards understanding the genotype-environment interaction and to identify stable genotypes of *V. galamensis*.

MATERIALS AND METHODS

Nine genotypes of *V. galamensis*, which were selected from collections of eastern Ethiopia material, were studied. The experiment was conducted at three rain-fed locations: Finote Selam (10°84'N, 37°36'E, and 1935 meters above sea level) Sirinka (11°44'N, 39°37'E, and 1868 masl) and Zema (11° 08'N, 37°42'E and 1845 masl). The experiment was layed out in a randomized complete block design (RCBD) with three replications. Each plot consisted of six rows spaced at 30 cm apart and 5m long. The net plot harvested was 6 m^2. Date of planting varied from mid June to early July. Fertilizer (N and P_2O_5) was applied at the rate of 23/23 $kgha^{-1}$ each at the time of planting. A seed rate of 10 kg/ha was applied for six rows. Seed and fertilizer were drilled into soil uniformly by hand. Weeding was carried out 30 days after emergence and 45 days after the first weeding. Neither herbicides nor insecticides were applied. Harvesting of heads was done when the involucres-surrounding the seeds are dry and spreading out to release a fully matured seeds that are firm and 90% black in color. The seed was separated from the pappus by winnowing. Data on seed yield were taken from the middle four rows of each plot, leaving aside the guard rows on both sides of the plots. Plot yield data at 8% seed moisture was converted to kg/ha.

Statistical Analyses

Combined analyses of variance for six environments (three locations and two years) were conducted using Agrobase 2000™ (Agrobase, 2000) and SAS (1996) computer programs. Stability statistics were computed as follows: 1) Francis and Kannenberg coefficient of variability (CV_i (%)) (Francis and Kannenberg, 1978); 2) Shukla's procedure of stability variance ($\sigma^2 i$) (Shukla, 1972); 3) Lin and Binns cultivar performance measure (P_i) (Lin and Binns, 1988); 4) Finlay and Wilkenson's regression analysis and coefficient (b_i) (Finlay and Wilkenson, 1963); 5) Eberhart and Russell's deviation from regression ($s^2 d_i$) (Eberhart and Russell, 1966); 6) Wricke's ecovalence (W_i) (Wricke, 1962); 7) Pinthus coefficient of determination (r_i^2) (Pinthus, 1973); 8) AMMI model (Gauch, 1988). Since the AMMI model does not make provision for quantitative stability measure, such a measure is essential in order to quantify and rank genotypes in terms of yield stability. AMMI's stability value (ASV) was calculated using the following formula, as suggested by Purchase (1997).

$$ASV = \sqrt{\left[\frac{IPCA1SS}{IPCA2SS}(IPCA1)\right]^2 + \left[IPCA2score\right]^2}$$

Where, ASV=AMMI stability value, SS=sum of squares and IPCA1=Interaction of principal components analysis one. IPCA2=interaction of principal component analysis two.

Spearman's coefficient of rank correlation (r_s) (Steel and Torrie, 1980) was employed to compare stability analysis procedures. All the genotypes evaluated were respectively assigned stability values according to the procedure and definitions used, and were then ranked in order to determine Spearman's rank correlation coefficient between the different procedures. Spearman's rank correlation coefficient (r_s) can be described as:

$$r_s = \frac{6\Sigma d^2_i}{n(n^2 - 1)}$$

Ranking numbers are whole numbers and when two or more equal ranking numbers occur, the average of the ranking numbers that they otherwise would have received are ascribed to each genotype.

RESULTS

The result for combined and AMMI analyses of seed yield across years and locations are given in Table 1. The source of variation for the combined analyses was highly significant (P<0.01) for years, locations and their interaction for genotype–year (G-Y) interaction. Significant (P<0.05) variations were also observed in genotypes, genotype-location (G-L), and genotype-year-location (G-Y-L) interactions. The partitioning of sum of squares of components indicated that 66% of the total variance was due to locations, 2.84% for genotype-location (G-L), 4.5. % due to genotype-year-location (G-Y-L) interaction and

3.8% due to genotype-year interaction. This variability could be mainly due to the distribution of rainfall, which differed greatly across the locations and seasons during the experimental year.

Table 1. Combined analysis of variance and Gallob tests of interaction principal components in AMMI for seed yield (kg/ha) of nine genotypes of *V. galamensis* tested in six environments in Ethiopia, 2002-2003.

Source	df	SS	MS	F-value
Combined analysis				
Year (Y)	1	251915.19	251915.19	9.67**
Locations (L)	2	10952833.68	5476416.84	210.28**
Y-L	2	14371.36	7186.68	2.76
Genotype (G)	8	446492.28	55811.54	2.14*
G-Y	8	636153.78	79519.22	3.05**
G-L	16	470542.61	29408.91	1.13*
G-Y-L	16	737763.17	46110.19	1.77*
R (Y-L)	12	446281.47	37190.12	1.43
Residual	96	2500183.06	26043.57	
Total	161	16585879.32		
AMMI analysis				
Locations	5	11348785.73	2269757.15	63.98**
Reps within L	12	425722.46	35476.87	
Genotype	8	446602.50	55825.31	1.21
G-L	40	1844910.53	46122.76	1.77*
IPCA1	12	1461788.94	121815.75	4.68**
IPCA2	10	177021.80	17702.18	0.68
Residual	96	25001777.28	26043.51	

*, ** Significant at 0.05 and 0.01, respectively

Grand mean=593.74; CV%= 27.18; SS=sum of squares; MS=Mean squares.

The analysis of AMMI showed that the first interaction of principal component analysis (IPCA 1) was highly significant ($P < 0.01$), while the subsequent ones were not. The IPCA 1 explained 79.23 % of the G-E interaction sum of squares, where as IPCA 2 explained 9.60%. The first two IPCAs totally accounted 88.83% of the total variation. The remaining being the residual or noise, which is not interpretable and thus discarded (Purchase, 1997). The IPCA scores of a genotype in the AMMI analysis are reported as indications of the stability of a genotype across environments. The closer the IPCA scores are near to zero, the more stable the genotypes are across their testing environments (Gauch and Zobel, 1996; Yau, 1995; Purchase, 1997)

The average seed yield and their ranks and coefficients of variability for nine genotypes tested across three locations over two years are presented in Table 2. The highest yield of 1237.30 kg/ha was obtained from Gelemso at Sirinka and the lowest yield of 308.75 kg/ha from genotype Metta at Finote Selam. The genotype Gelemso out yielded all others with a mean yield of 707.57 kg/ha across the localities and years (Table 3). Genotypes Boke Kuni and Chirro were the best performing too. As shown in Table 3 the over all yield performance of 2002 was higher than 2003 by 14%, due to erratic distribution of rainfall.

Both mean yields across three locations (Table 2) and those over two years (Table 3) showed substantial changes in ranks among the genotypes, reflecting the presence of high G-E interactions.

The result of Eberhart and Russell (1966) model shows non-significant differences among the genotypes and genotypes by environment interaction. According to them a stable genotype is the one with unity regression coefficient and minimum deviation from regression. In the stability analysis, the regression of a genotype mean yield on the environmental index resulted in regression coefficients ranging from 0.800 to 1.514. This large variation in regression values indicated large differences in genotype responses to different environments. Genotype Gelemso has regression coefficient greater than one (b_i=1.514), which is poorly adaptable as it significantly deviated from linearity, and had high coefficient of variation. (Table 4). Genotype Boke Kuni had b_i values near to one and

Table 2. Mean seed yield (kg/ha), its rank (R) and coefficient of variability (CV%) of nine *V. galamensis* genotypes tested for two years per location in Ethiopia, 2002-2003.

		F/Selam			**Sirinka**			**Zema**		
NO	**Genotypes**	**Yield**	**Rank**	**CV**	**Yield**	**Rank**	**CV**	**Yield**	**Rank**	**CV**
1	Bedeno	364.75	3	22.5	886.35	6	26.5	462.78	6	19.7
2	Melkabelo	365.02	2	28.8	864.20	7	37.2	467.22	5	35.1
3	Harar Zuria	355.33	5	16.7	854.40	9	23.3	469.28	4	33.7
4	Boke Kuni	385.23	1	33.8	1010.25	2	16.8	563.68	2	26.3
5	Metta	308.75	9	41.3	963.53	4	28.0	416.40	8	11.0
6	Chirro	332.65	7	9.5	932.75	5	28.1	577.93	1	29.0
7	Gelemso	356.80	4	34.9	1237.30	1	34.0	528.62	3	36.3
8	Mixed	328.35	8	18.6	859.13	8	33.5	396.20	9	39.9
9	AD-01-09	334.40	6	24.1	973.62	3	20.9	436.45	7	30.7
	Mean	347.92			953.50			479.84		
	LSD (P=0.05)	77.27			243.90			96.25		
	SED	45.62			143.99			56.82		
	CV (%)	22.71			26.16			20.51		
	Repeatability	0.53			0.51			0.73		

low deviations from regression indicating relatively stable performance over environments. The lowest b_i values of Melkabelo (0.800) indicated that its performance was relatively better in low yielding environments and less well adapted to favourable environments. The genotype Boke Kuni had well adapted to the complete range of productivity level giving superior yields in low as well as high-yielding environments.

Table 3. Mean seed yield (kg/ha), and its rank (R) of nine *V. galamensis* genotypes tested over two years, across three locations in Ethiopia.

		2002		**2003**		**Mean**	
NO	**Genotypes**	**Yield**	**Rank**	**Yield**	**Rank**	**Yield**	**Rank**
1	Bedeno	504.40	9	638.19	1	571.29	5
2	Melkabelo	548.46	7	582.50	2	565.48	6
3	Harar Zuria	593.52	5	525.82	7	559.67	8
4	Boke Kuni	728.96	2	577.16	3	653.06	2
5	Metta	561.02	6	564.77	4	562.89	7
6	Chirro	694.96	3	533.93	6	614.44	3
7	Gelemso	858.70	1	556.44	5	707.57	1
8	Mixed	536.26	8	519.53	8	527.89	9
9	AD-01-09	672.43	4	490.54	9	581.49	4
	Mean	633.19		554.32		593.76	
	LSD (P=0.05)	157.11		88.76		91.35	
	SED	93.67		52.92		55.06	
	CV (%)	31.38		20.25		27.82	
	Repeatability	0.80		0.91		0.82	

The genotypes Gelemso, AD-01-09 and Metta showed higher b_i values (1.514, 1.100 and 1.058) indicating their suitability only for highly favourable environments respectively.

Table 4 presents a summary of the joint regression, AMMI and other stability parameters. Francis and Kannenberg's (1978) coefficient of variability, Pinthu's (1973) coefficient of determination, Shukla's (1972) stability variance, Lin and Binns (1988) cultivar superiority performance and Wricke's (1962) ecovalence were also used for comparison. Except Pinthu's (1973) coefficient of determination and the AMMI stability value nearly all of them identified Boke Kuni as the most stable genotype.

Table 4. Mean yield (kg/ha) and various stability measurements and their ranking (R) orders of nine *V. galamensis* genotypes evaluated across six environments in Ethiopia, 2002-2003.

	Genotypes	$\bar{x}$	R	CV_i (%)	R	σ^2_i	R	b_i	s^2d_i	R	r_i^2	R	W_i	R	P_i	R	IPCA1	IPCA2	ASV	R	Overall Rank
1	Bedeno	571.57	5	47.9	3	87336	8	0.831*	18392	8	0.999	3	121755	7	67859	8	12.574	-4.617	103.93	8	5
2	Melkabelo	565.48	6	53.2	5	18479	6	0.800	-5122	5	1.000	1.5*	32495	6	52848	7	5.865	-0.186	48.79	5	7
3	Harar Zuria	559.67	8	46.7	2	4536	1	0.827	-8586	6	1.000	1.5*	14421	1	49070	6	3.807	4.816	25.94	3	8
4	Bolke Kuni	653.06	2	46.7	1	9958	2	1.012	-3682	4	0.995	6	21449	2	20459	2	-3.575	3.528	29.73	4	1
5	Metta	562.81	7	59.9	8	12810	3	1.058	-3093	3	0.997	4	25147	3	41025	5	0.616	-8.144	9.60	1	9
6	Chirro	614.45	3	49.6	4	18011	4	0.960	-1228	1	0.957	9	31889	4	30388	4	-2.584	9.690	23.44	2	2
7	Gelemso	707.57	1	66.5	9	190965	9	1.514**	27283	9	0.990	8	256089	9	4772	1	-18.729	-5.026	154.74	9	4
8	Mixed	527.90	9	57.3	7	54784	7	0.900	9816	7	0.992	7	79558	8	69669	9	9.171	-0.486	75.73	7	6
9	AD-01-09	581.47	4	55.1	6	18221	5	1.100	-2043	2	0.996	5	32161	5	28025	3	-6.425	0.426	53.06	6	3

Note: R=ranks; X =Mean yield; CV_i (%)=Francis and Kannenberg's (1978) Coefficient of variability; σ^2_i = Shukla's (1972) Stability variance; b_i =Finlay & Wilkinson's (1963) regression coefficient; s^2d_i =Eberhart & Russell's (1966) deviation parameter; r_i^2 =Pintus (1973) coefficient of determination ; W_i = Wricke's (1962) ecovalence; P_i =Lin and Binn's (1988) cultivar superiority performance; ASV=Purchase (1997) AMMI stability value.

* For Spearman's rank correlation coefficients equal rank values are averaged.

*, ** Significant at 0.05 and 0.01, respectively

Spearman's coefficient of rank correlation was determined for each of the possible pair wise comparisons of different stability statistics (Table 5). The Wricke's procedure of stability statistic shows the highest significant positive correlation ($P<0.01$) with Shukla (0.983**). Lin and Binn's procedure shows highly significant positive correlation ($P<0.01$) with mean yield. This highly significant rank correlation of mean yield with P_i indicates that selection for yield would change yield stability leading to the development of genotypes that are specially adapted to environments with optimal growing conditions.

AMMI stability value shows positive and highly significant rank correlations with Shukla ($r=0.850$**), Wricke (0.833**) and significant positive correlation with s^2d_i ($r=0.750$*). Positive and non-significant rank correlations were also observed between coefficient of determination (r_i^2), cultivar superiority performance (P_i) and coefficient of variation. AMMI has also negative correlation with mean seed yield.

DISCUSSION

Successful varieties of *Vernonia galamensis* need to be adapted to a broad range of environmental conditions in Ethiopia in order to ensure their yield stability and economic return. Farmers are interested in varieties that produce consistent yields under their growing conditions and breeders have to fulfil these conditions. Hence, the information on G-E interaction and stability is of prime importance for breeders and farmers under a set of environments.

The highest significant differences ($P<0.01$) of the combined analyses across years and locations indicated the fluctuations of genotypes in their responses to the different environments. There were also tremendous changes in yield ranks of the genotypes across locations and years (Tables 2 and 3). Yield stability analysis of teteraploid wheat (Tesfaye et al., 1998) also revealed very high fluctuations in the growing environments of Ethiopia that comply with this result. This shows the difficulties encountered by the breeders in selecting new cultivars for release; which arise mainly from the masking effects of the variable environments.

Table 5. Spearman's rank correlation coefficients for eight genotype-environment (G-E) stability parameters of nine *V. galamensis* genotypes evaluated in six environments in Ethiopia.

	$\bar{x}$	CV_i (%)	σ^2_i	s^2d_i	r_i^2	W_i	P_i
CV_i (%)	0.033						
σ^2_i	-0.200	0.496					
s^2d_i	0.083	0.167	0.600				
r_i^2	-0.513	0.329	0.263	-0.138			
W_i	-0.133	0.617	0.983**	0.583	0.329		
P_i	0.833**	-0.100	0.155	0.250	-0.454	0.167	
ASV	-0.233	0.279	0.850**	0.750*	0.138	0.833**	0.050

Note: R=ranks; $\bar{x}$ =Mean yield; CV_i (%)=Francis and Kannenberg's (1978) Coefficient of variability; σ^2_i = Shukla's (1972) Stability variance; s^2d_i =Eberhart & Russell's (1966) deviation parameter; r_i^2 =Pintus (1973) coefficient of determination ; W_i = Wricke's (1962) ecovalence; P_i =Lin and Binn's (1988) cultivar superiority performance; ASV=Purchase (1997) AMMI stability value.

*,**=Significant at p=0.05 and 0.01, respectively.

Pham and Kang (1988) indicated that the G-E interactions minimize the usefulness of genotypes by confounding their yield performance. Thus, it is important to study in depth the yield levels, adaptation patterns and stability of genotypes in multilocation trials.

Among the joint regression stability measures, s^2d_i was largely used to rank the relative stability of cultivars (Becker and Leon, 1988). The indication was that b_i values could be used to describe the general response to the goodness of the environmental conditions, where as s^2d_i actually measures the yield stability.

The Wricke's procedure of stability statistics shows the highest significant positive correlation ($P<0.01$) with Shukla (0.980**) indicating that the two procedures are equivalent for ranking purposes. Shukla's stability variance is a linear combination of the ecovalence and both are equivalent for ranking purposes (Wricke and Weber, 1980). Purchase (1997) and Tsige (2002) have also reported similar correspondence between the two stability parameters.

Different stability parameters identified 'Boke Kuni' as the most stable variety, while 'Gelemso' was narrowly adapted to specific environments. This variety also posseses other desirable characteristics, such as high oil content, early maturity and tolerance to damping off, wilt, and powdery mildew (Tsige Genet Unpublished). A stable variety that performs well under a range of conditions is essential for unpredictable environments.

All the methods examined here to study the stability of genotypes are valid, although they are based on very different concepts of stability. The linear regression techniques despite its imperfection will continue to play an important part in furthering our understanding of G-E interactions, because it does have twin merits of simplicity and biological relevance. Certain multivariate techniques are statistically very complex, and the availability of software has severely limited the usefulness of such techniques in country's like Ethiopia. In general "Boke Kuni" was found the most stable genotype and is thus recommended for commercial release in Ethiopia.

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