Participatory Variety Selection on Improved Sorghum (Sorghum bicolor L. Moench) at Lowland Areas of North Gondar

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Abstract

This research was initiated with the objectives to evaluate and select improved sorghum varieties for high yield and other agronomic traits through farmers' participation in decision making during the selection process. Nine sorghum varieties were tested at Metema, Tachiarmachiho and Belesalow land districts of North Gondar during 2015-2016 main cropping seasons. The experimental design was a randomized complete block design with three replications. Yield and yield related traits were studied. Farmers' choice of their best variety by traits of interest was also investigated. The analysis of variance showed that all parameters exhibited highly significant among treatments. Year and location variation also had a significant effect on performance of yield and yield components. The highest average grain yield was recorded from the genotype Melkam (4340 kg/ha) followed by Mesay (3655 kg/ha) and Girana one (3508 kg/ha) across locations. The highly significant Genotype by Environment Interaction indicated that genotype performance was inconsistent across testing locations. Some univariate and multivariate stability statistics such as ecovalence method of Wricke, Kang's yield stability index, Additive Main Effects and Multiplicative Interaction Stability Value and the Genotype main effects and Genotype by Environment Interactionbiplot model were conducted. Genotypes Melekam and Girana one was selected based on high yield and stability value for those stability parameters. Farmers' also rankedvarietiesMelkam, Mesay and Girana-1 that performed well under their circumstances. Therefore, based on the farmers' evaluation and selection of improved sorghum, Melkam, Mesay and Girana-1 varieties were found promising for production in the lowland areas of North Gondar zone.

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Introduction

Sorghum (*Sorghum bicolor L.* Moench) in Ethiopia is the main staple food crop, ranking third after tef, and maize in total production and it ranks second after maize in productivity per hectare and in area harvested (CSA, 2014). It grows in moisture stressed parts of the country where other crops can least survive and food insecurity is a critical problem with a total land area covering of 1.9 million ha (CSA, 2014). It has tremendous uses for Ethiopian farmers, and no part of this plant ignored. The grains used for human foods such as local bread (injera) porridge, Nefiro, infant food, syrup, and local beverages known as "Tella" and "Arekie". The leaf and stalks used for animal feed, fuel, and construction of houses and fences (AmeleworkBeyene*et al.*, 2016). North Gondar has one of major high potential agro-ecologies for sorghumproductionin Amhara region and contributes the highest share (43.74%) as compared to other crops grown in the area (CSA, 2014). Generally, the area under sorghum cultivation in low land areas of North Gondar has steadily increased over the years but the average yield trends down wards (Abate Setie, 2016). Amongthe main yield reducing factors in sorghum productionin the region are predominant cultivation of low yielding local varieties, poor soil fertility, drought, pests, weed and diseases (GeremewGemechu *et al.*, 2004).

In this case, it can increase average yield production of sorghum by using appropriate variety in these areas. Over the last decades, more than 15 improved multipurpose sorghum varieties with various desirable characteristics that give high grain yield, feed and fuel wood were releases by conventional breeding approach for the major agro ecologies (Ethiopian Sorghum Improvement Project, 2013). Among these around 20 varieties were releases for low land agro ecologies. Even though different varieties were introduced and released for different trait needs, the varieties are not being adopted by the farmers and not well assimilated into the production system as expected. This may happen because evaluation and selection activity is done by plant breeders, without farmers' participation. Such practice does not fit well with farmers' growing conditions and lack of widely adapted varieties and farmers' lack of knowledge about the varieties.

Hence, the present study concerned with Participatory Varietal Selection (PVS) has as an option to the problem of fitting the crop to a multitude of both target environments and users' preferences and to determine stability of sorghum genotypes based on grain yield response. It is worth mentioning that although farmer participation is often advocated on the basis

of equity, there are sound scientific and practical reasons for farmer involvement to increase the efficiency and the effectiveness of a breeding program (Ceccarelli and Grando, 1996). Participatory Variety Selection (PVS) can effectively be used to identify farmer-acceptable varieties and thereby overcome the constraints that cause farmers to grow old varieties (Joshi and Witcombe, 1996; Witcombe*et al.,* 1996). If farmers are allowed to participate in variety testing and selection work, research costs can be reduced and adoption rates increased (Joshi *et al.,* 1995). Hence, production increases when farmers adopt new varieties identified in participatory research (Witcombe, 1999).

Therefore, the current study was conducted with the objectives to selecthigh yielder and stable improved sorghum varietiesthrough farmers' participation in decision making during the selection process.

Materials and Methods
Plant materials and test environments

The experimental materials were eight lowland sorghum varieties released from Melkasa Agricultural Research Center and Sirinka Agricultural Research Center and a local check (Table 1). The criteria for selecting these genotypes were based on best yield performance, release of year and suitability of adaptation for the testing sites

etc. Accordingly, the eight sorghum genotypes were tested across six environments (year and location combinations) during 2015-16 under rain fed condition (Table 2).

Experimental Design and Crop Management

The trial was laid out in randomized complete block design (RCBD) with three replications. The experimental plots consisted of 6 rows, each 5 m in length with 0.75m row to row and 0.15 m plant-to-plant spacing. The total area of each plot was evaluated on 22.5 m^2 plots (0.75m x 6 rows x 5m). Sowing was done by hand drilling.

The seed rate for each plot was calculated as per the recommendation for row planting (10 kg/ha). Then, thinning was done two weeks after emergence to adjust plant to plant spacing. The 100 kg/ha of DAP fertilizer was applied during planting in the seed furrow. Urea fertilizer was applied as top dressing at the rate of 50 kg/ha at knee height stage. The field was kept free of weeds during the period of the experiment. All of the other recommended agronomic management practices such as land preparation and insect pest control were applied as requiredand the required data were also collected on time. Plot and plant based data were collected from the central four rows and five randomly sampled plants

based on the descriptors for sorghum (IBPGR/ICRISAT, 1993), respectively. Data on yield (kg/ha) and yield related traits like flowering date, maturity date, plant height, inflorescence length and stand count at harvest were collected.

Statistical analysis

Analysis of variance (ANOVA) for each environment was done for grain yield and other traits, using the Statistical Analysis System computer program (SAS Ins., 2001). The mean separation among the genotypes for grain yield significant at P 1% and 5%. Genotype by Environment Interaction (GEI) was quantified using the most common procedure; *i.e.*, pooled analysis of variance which partitions the total variance into its component parts (genotype, environment, GEI and pooled error). The stability and the interaction analysis had computed using Gen stat (2007) for Additive Main effect and Multiplicative Interaction Stability Value (AMMI biplot ASV), the genotype main effects and GEI effects (GGE model analysis) and different stability parameter.

Models

The effects of genotypes, locations as well as their first order interaction are determined from the ANOVA using the following model: $\mu = Y_{ijk}$.

Wrick's (1962) ecovalence (W_i) or stability of the ith genotype: Is its interaction with the environments, squared and summed across environments and expressed as: $W_i =$

$$\sum_j (Y_{ij} - \overline{Y_{i.}} - \overline{Y_{.j}} + \overline{Y..})^2$$

Kang's yield stability index (YSI)(1988): A new approached known as YSI which incorporate both mean yield and stability is a single criteria for grain yield and stability of genotypes across environments.

The AMMI statistical model can be expressed as: $Y_{ij} = \mu + G_i + E_j + \sum_{i-1}^{n} \lambda_k \alpha_{ik} \gamma_{jk} + e_{ij}$.

AMMI Stability Value (ASV) =

$$\sqrt{\left[\frac{IPCA1 sum of squares}{IPCA2 sum of squares} (IPCA1 score) \right]^2 + [IPCA2\ score]^2}$$

A GGE Biplot Basic Model: The term GGE is the contraction of G + GE.

Farmer's participation

In this study both male (46) and female (24) farmers involved from all locations to select their best sorghum variety with their trait of interest that represent their conditions. The farmers were randomly selected irrespective of wealth, religion, and caste. The selection scoring was carried out at physiological maturity.

The farmers' own selection criteria was assessed using pair-wise ranking matrix, both male and female participants prioritized and agreed on eight traits (Table 3). Pair-wise ranking, one kind of Participatory Rural Appraisal technique, is a structured method for ranking the selection criteria in priority order in a consensus-oriented manner. The rank assignments were determined from the number of times each selection criterion was preferred by the group (Lelo*et al.,* 1995).

Farmers' selection data were analyzed using simple ranking method in accordance with the given value (De Boef&Thijssen, 2006). Simple ranking is a tool often used to identify promising varieties based on farmers' preferences (Table 4). The ranking procedure was explained for farmer participants and then each selection criterion was ranked from 1 to 5 (1 = not preferred, 2 = less preferred, 3 = moderately preferred, 4 = highly preferred and 5= excellent) for each variety. Ranking was done on consensus where differences are resolved through discussion (De Boef&Thijssen, 2006).

Result and Discussion
Farmers' participation

Farmers involved in the participatory varietal evaluation selected eight preferred sorghum characteristics and ranked through matrix system as shown in (Table 3). Farmers' participatory varietal evaluation has indicated eight preferred sorghum characteristics and ranked through matrix system as shown in (Table 3). The farmers' selection criteria were focusing more on yield and yield related traits like head size, pedicel length together with maturity and plant heightto select their best variety. Among those characters highgrain yield got the highest score and ranked 1st followed by head size and pedicel length. Consistent result was also reported by Rashid *et al*. (2004) who evaluated farmers' selection criteria on wheat varieties were focusing more on yield. During the evaluation, it was able to observe that farmers' preference coincided with biological selection criteria for sorghum yield.

Farmers' overall mean preference ranking for each genotype ranged from 2.2 to 4.7 (Table 4). Melkam (4.7) scored the highest value and the lowest was scored by Local variety (2.2). Mesay (3.9) and Girana one (3.5) were ranked second and third best varieties by farmers, respectively. The farmers' selection criteria werefocusingmore on yield and yield related traits (Table 3). Relatively those preferred varieties have large head size and long pedicel length that might contribute to

produce more grains, thereby increase yield.

Combined ANOVA For Grain Yield and Yield Related Traits Over Locations

Before pooling the data over locations, Bartlett's test of homogeneity of error variance was performed for each parameter to determine the validity of the combined analysis of variance of the data. Error variance revealed homogeneous and so a combined ANOVA could be done. The main effects of location and genotype and genotype by interaction (GEI)were highly significant (p<0.01) for grain yield and yield related traits (Table 5). This result indicated the presence of genetic variation among the genotypes and the diversity of the growing environments in their productivity. Significant genetic effect of genotypes and location on yield of sorghum varieties was also reported by different authors (Almeida *et al.,* 2014; Adugna, 2007; Fahri, 2012).

Mean performance of varieties

From the tested genotypes long days to head (82 days) and maturity (129 days) was recorded from local check (Table 6). Consistent result was also reported by KassahunAmare*et al*., (2010) that, agronomic factors affecting maturity and production of farmers sorghum cultivar in

the low land agro ecology. Moreover, late maturity genotypes tend to increased plant height vegetative growth than shorter season sorghum genotypes (Sauer, 2012). This study also confirmed the above findings since, the local check gave maximum plant height (252cm). However, other varieties like Melkam, Mesay and Girana -1 are medium maturing type and were found to be high yielder with optimum plant height across location. Genotypes that have longer head length andhigher number of heads harvested would have higher grain yield and number of seeds per head (Baumhardt*et al*., 2005). According to the above author considerable amount of result similarities was observed in this study for those traits.

In relation with responses of genotypes in terms of mean grain yield across locations, the highest was achieved from treatmentMelkam (4340 kg/ha) followed by Mesay(3655kg/ha) and Girana-1 (3508 kg/ha) and the lowest yield have been achieved fromGobye (2669 kg/ha) and Localvariety (3011 kg/ha) (Table 6). According to (GeremewGemechu *et al*., 2004) consistent result was reported that lowland varieties Melkam, Mesay and Girana-1gave reasonable yield and significantly out yielded the local check. There for based on both biological data and farmer's preference varieties

MelkamandMesay were selected as best sorghum varieties suited for lowland areas of North Gondar and similar agro ecologies.

Stability Analysis

The model that has been in frequent use by breeders are statistical procedures proposed by (Wrick's, 1962) ecovalence, Kang's yield stability index (YSI), 1993and AMMI Stability Value (ASV) that consider both yield and stability were used (Table 7). Genotypes with low ecovalence have smaller fluctuations across environments and therefore they are stable. The most stable genotypes according to the ecovalence method of Wricke (1962) were Girana one and Melekam. These genotypes gave high mean yield which was greater than grand mean (3331 kg ha^{-1}). Based on the AMMI we can calculate the AMMI Stability Value (ASV) and the yield Stability Value (YSV) using the function index (Purchase, 1997). In ASV ranking method genotypes with least ASV score is the most stable. Hence, according to ASV ranking, the following genotypes were the most stable Girana one, Gobeye and Melekam specially Girana one and Melekam genotypes high yielding and more stable. Kang's yield stability index (YSi) parameter simultaneously selects genotypes for higher yield and stability

(Kang, 1993). According to Kang's yield stability index (YSi) positive values of this parameter shows desirable genotypes with high mean yield and stability. As a result, the selected genotypes were Melekam, Mesay, Dekeba, Girana one and Teshale which had both higher yield and stability value. This study is in agreement with the finding of (LaliseArarsa, 2015; Solomon Admassu, 2006) who evaluated the stability of maize hybrids in different environments.

GGE biplot Analysis based on Grain yield and Stability of Sorghum Genotypes

Performance and stability of genotype were visualized graphically through GGE biplot (Fig. 1). This can be evaluated by average environment axis (AEA) method (Yan, 2002). The line with single arrow head is the AEA abscissa. AEA abscissa passes through the biplot origin and a marker for average environment which point towards to the center of concentric circles which shows the position of ideal environment and ideal genotype that have higher mean values and stable. Good genotypes and environments are close to ideal genotype thatcan be identified based on the center of concentric circles. Based on this, from Fig.1, G3 had the highest mean yield and was the best performer while G7 had the lowest mean yield and stable since it far

from the center of to the center of concentric circles. Environments E4 (Metema in 2009) and E6 (TachiArmachiho in 2009) were favorable to the performance of most of the genotypes and representative environments that are useful for selecting widely adapted genotypes. On the contrary, the other environments were unfavorable discriminating environments that are useful for selecting specifically adapted genotypes.

Conclusions and Recommendations

Farmer participation in the breeding of crop varieties for low-resource farmers is necessary to ensure acceptance and eventual adoption. As it has been demonstrated by farmers, a new and promising varieties were identified using the participatory varietal evaluation methodology and the method contributed a lot to facilitate variety selection based on farmers' preference and created access for the communities to improved sorghum varieties. Thus, farmers selected variety Melkam, Mesay and Girana-1. Accordingly, breeders have to emphasize farmers' attitudes during selection; otherwise their varieties may not be well accepted by the users.

Analysis of variance exhibited highly significant difference among treatments across location and year. Year and location difference also contributed significant effect on yield and yield performance of varieties. Among tested varieties Gobye is early martyring type variety and low yielder in all testing location and year and local check also took long time to maturity in all location. Generally, based on AMMI stability, GGE biplot and different stability parameters Melkam and Girana1 showed best performance and stability which had higher grain yield than the grand mean across tested environments. They exhibited average responsiveness with high degree of stability indicating general adaptability for wider areas and thus can be recommended for the test and similar environments. The overall results of the present study showed that Melkam, Mesay and Girana-1 were selected by researchers as well as farmers. Therefore, those varieties are recommended for production in the low land areas of North Gondar zone.

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Table 1. Experimental materials used in the study

Entry Code	Genotypes	Pedigree	Seed Source
1	Dekeba	IESV92186-DL	MARC
2	Mesay	IESV92152-DL	MARC
3	Melkam	IESV92040-DL	SARC
4	Mesker	MISKER (PGRC/E# 69441 x P-9401)	SARC
5	Girana one	GIRANA-1 (Cr:35 x DJ1195 x N-13	SARC
6	Teshale	IESV92168-DL	MARC
7	Gobeye	IESV92199-DL	MARC
8	Gambela	IESV92057-DL	MARC
9	Local		Local

MARC, Melkasa Agricultural Research Center; SRARC, Sirinka Agricultural Research Center

Table 2. Agro-ecological features of the experimental locations

Location	Zone	Wereda	Altitude(m.a.s.l)	Average Rainfall(mm)	Soil Type	Geographic coordinates		Average Temp. (ºC)	
						Latitude	Longitude	Max.	Min
Metema	N/ Gondar	Gendwa	745	1391.2	Red loam	10º 8ˈ 21N	34º 18ˈ 21ˈˈ E	35.2	19.6
Tachiarmachiho	N/ Gondar	Sanja	800	1210.7	Black soil	14º 8ˈ 21N	10º 15ˈ 21ˈˈ E	35.0	13.0
Belesa	N/ Gondar	Arbaya	1000	1120.9	Black soil	10º 35ˈ N	39º 63'E	33.2	12.0

Where: *m.a.s.l*, meters above sea level; E, east; N, north; Min, minimum; Max, maximum; T, temperature.

Table 3. Pair-wiseranking of farmers' selection for sorghum at North Gondar *woredas* in 2015-2016 main seasons

Criteria	Plant height	Maturity	Head thickness	Head length	Stock thickness	Striga resistance	Disease/pest	Total	Rank
Plant height								3	5
Maturity	Plant height							4	4
Head thickness	Head thickness	Head length						6	2
Head length	Plant height	Head thickness	Head thickness					5	3
Stock thickness	Maturity	Maturity	Head thickness	Head length				1	7
Striga resistance	Head length	Maturity	Head length	Head thickness	Stock thickness			2	6
Disease/pest	Head thickness	Maturity	Plant height	Striga resistance	Head length	Striga resistance		0	8
Grain yield	Grain yield	Grain yield	Grain yield	Grain yield	Grain yield	Grain yield	Grain yield	7	1

•Number of participants -70

Table 4. Combined mean preference of farmers over location and year

Selection criteria	Dekeba	Mesay	Melkam	Misiker	Giran1	Teshale	Gobye	Gambela	Local
Head thickness	4	3	5	4	4	4	1	3	3
Head length	3	4	5	3	3	3	1	3	2.5
Medium height	4	4	5	3	4	3	3	3	2
Stock thickness	3	5	5	3	4	3	3	3	3.5
Disease/pest	3	3	4	3	3	3	2	3	2
Striga resistance	2	3	4	3	3	3	4	3	2
maturity date	3	5	5	5	4	3	3	3	1
Total	22	27	33	24	25	22	17	21	16
Mean	3.2	3.9	4.7	3.4	3.5	3.2	2.4	3	2.2
Rank	5	2	1	4	3	5	7	6	8

* Number of participants -70

Rating of the performance of a variety for a criterion: (1 = not preferred, 2 = less preferred, 3 = moderately preferred, 4 = highly preferred and 5= excellent)

Table 5. Mean square of yield and yield related traits of combined ANOVA

Traits	Mean Squares				
	Genotype (Df=6)	Location (Df=4)	GEI (Df=39)	Replication (Df=11)	Pooled error (Df=95)
GYLD	4129646.3**	25825369.2**	601884.4**	912698.2*	267587.8
DH	252.31**	650.45**	56.85**	5.19ns	5.59
DM	3395.97**	2141.47**	3125.58**	15.11ns	2.68
PLH	26908.57**	12443.30**	2711.25**	459.68**	131.04
HDL	279.56**	83.35**	5.13**	1.90*	2.69
HHA	485.32**	16796.52**	499.30**	337.35*	131.51
Striga	303911.49**	4386337.78**	136700.79*	620779.54**	85304.63

*and ** denote significant difference at $P<0.05$ and $P<0.01$, respectively. NS = Non significant difference.DE, Days to heading (days); DM, Days to maturity (days); PH, Plant height (Cm); HL, Head (inflorescence) length (Cm); HHA, Heads harvested (number); Striga count; GY, Grain yield (kg/ha).

Table 6. Overall combined Mean performance of nine improved sorghum varieties tested at Metema, TachArmachiho and Belesa in 2015-2016 main seasons

Treatments	DHA	DMA	PLH	HDL	HHA	Striga	GYLD
DEKEBA	74ab	116c	151.1e	20.4cd	120.0abc	514.1a	3383.6bc
MESAY	71b	115d	216.1b	21.3b	120.5abc	372.3abc	3655b
MELKAM	74ab	117c	159.9d	26.5a	123.7abc	540.5a	4340.3a
MISKER	76a	121a	205.2c	19.8de	116.3cd	438.3ab	3008.3de
GIRANA-1	76a	119b	229.3abc	19.7de	118.3c	317.6cb	3508bc
TESHALE	71b	115d	235.8ab	19.0ef	124.2ab	373.6abc	3213.8cd
GOBYE	71b	113e	147.7e	20.9c	126.8a	193.8c	2669.5e
GAMBELA	77a	118.2b	209.8bc	18.5f	123.8abc	541.0a	3188.4cd
LOCAL	82.5a	129.2a	252.08a	18.2f	109.6d	224.0c	3011.7de
Mean	73.7	116.7	194.4	21.84	120.41	390.62	3371
CV (%)	8.2	1.4	6.5	7.51	9.52	74.76	16
LSD (5%)	2.1	1.8	13	1.08	7.58	193.25	595

DHA=Days to heading, DMA=Days to maturity, PLH=Plant height, HDL= Head length, HHA= Heads harvested (number), Striga count and GYLD=Grain yield.

Table 7. Estimates of stability and yield performance simultaneously selection parameters

Trt..No	GEN	Mean Rank	Wricke'secovalence (W_i)	Rank	ASV	Rank ASV	Kang's yield stability (YSi)	Rank
1	Dekeba	(4)	1146036	(6)	30.16	3	3 +	6
2	Mesay	(2)	1820317	(9)	42.99	9	2 +	8
3	Melekam	(1)	267719	(2)	10.23	1	12 +	9
4	Mesker	(8)	1223867	(7)	33.87	7	-4	2
5	Girana 1	(3)	87868	(1)	0.13	4	8 +	7
6	Teshale	(5)	493837	(3)	12.62	6	4 +	5
7	Gobeye	(9)	700001	(4)	8.78	5	-2	1
8	Gambela	(6)	1329207	(8)	28.23	8	-5	4
9	Local	(7)	955312	(5)	24.17	2	-3	3
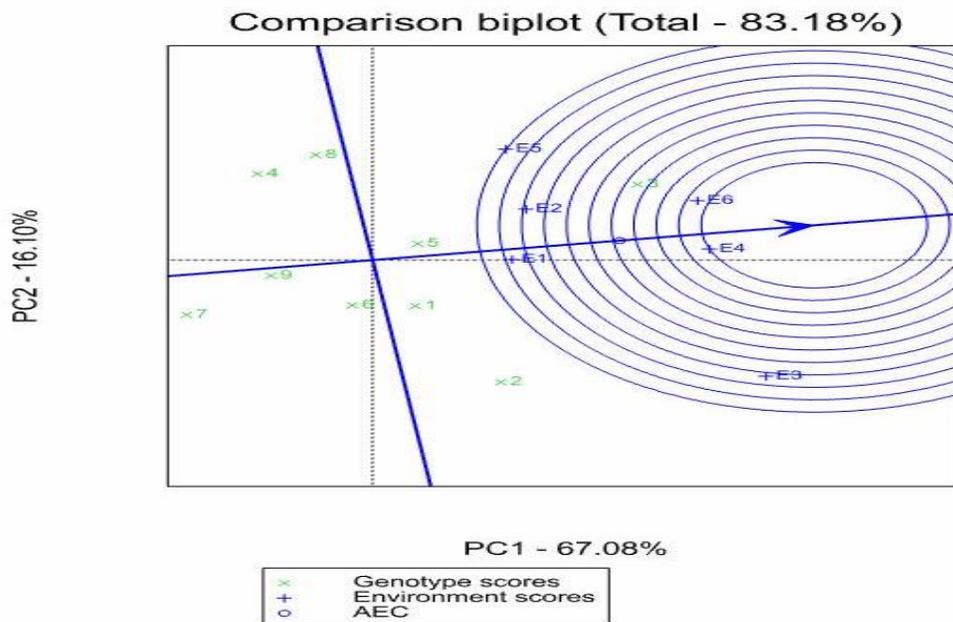
Figure 1 GGE biplotfor Grain yield stability

$$W_i = \sum_j (Y_{ij} - \overline{Y_{i.}} - \overline{Y_{.j}} + \overline{Y..})^2$$

The AMMI statistical model: $Y_{ij} = \mu + G_i + E_j +$

$\sum_{i-1}^{n} \lambda_k \alpha_{ik} \gamma_{jk} + e_{ij}$.

AMMI Stability Value (ASV) =

$$\sqrt{\left[\frac{IPCA1 sum of squares}{IPCA2 sum of squares} (IPCA1 score) \right]^2 +}$$

$[IPCA2\ score]^2$

A GGE Biplot Basic Model: The term GGE

is the contraction of G + GE.