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Genotype by Environment Interaction (G x E) and Grain Yield Stability Analysis of Ethiopian Linseed and Niger Seed Varieties

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ABSTRACT
General Background: Niger seed [(*Guizotia abyssinica* (L.F.) Cass.), 2n = 30] and Linseed [(*Linum usitatissimum* L.), n=15] are indigenous oil crops of Ethiopia. Over many years, there are a few Linseed and Niger seed varieties developed and released through intensive breeding and genetics research program in Ethiopia. However, whether these varieties are stable, adaptable to the environments of Western Ethiopia and similar agro-ecologies are not clear.
Objectives: The objectives of the study were to (i) assess genotype by environment interaction (G x E) and (ii) identify stable and adaptable Linseed and Niger seed varieties for specific and wide adaptions.
Materials and methods: All Niger seed and Linseed released varieties of Ethiopia between the years 1984 and 2008 were tested for multi-locations and years. Independent experiments of linseed and Niger seed varieties were evaluated in Randomized Complete Block Design replicated three times. Eight varieties of Linseed with one local variety were evaluated at Arjo, Gute and Shambu locations. In addition, five Niger seed varieties including one local variety were tested at Bako, Gute and Shambu locations.
Summary of the result and application of the findings: The seed yields ranged between 0.898 tons ha^{-1} and 1.575 tons/ha for Linseed and between 0.600 tons ha^{-1} and 0.690 tons ha^{-1} for Niger seed. Analysis of variance using additive main effects and multiplicative interactions (AMMI) model revealed significant differences ($p \leq 0.01$) for genotype, environment, genotype x environment interaction and interaction principal component (IPCA1) for Linseed, while only environment was found to be significantly different for Niger seed. Based on AMMI analysis, Kulumsa-1 was the best yielding, stable and widely adapted, while CI-1525 and Berene were high yielding but unstable and specifically adapted Linseed varieties to high yielding environments. Belay 96, Chilalo, Tole and CI-1652 were moderately stable and adapted to high yielding environments. Among Niger seed varieties, Shambu-1 and Esete-1 had comparable seed yield with moderately stable for the tested environments whereas Kuyu and local variety were unstable and not adopted to the testing environments.
Key words/phrases: Adapted variety, Additive main effect and multiplicative interaction (AMMI), Genotype x environment (G x E) interaction, Stable variety

INTRODUCTION

Niger seed [(*Guizotia abyssinica (*L.F.) Cass.), 2n = 30] and Linseed [(*Linum usitatissimum* L.), n=15] are indigenous oil crops of Ethiopia. Niger seed is cultivated at altitudes ranging from 500 - 3000 m.a.s.l. (Figure 1) in Ethiopia. Elevation between 1600-2200 m.a.s.l is ideal for Niger seed production (Nigussie and Yeshanew, 1992). The major Linseed growing areas in Ethiopia are located at altitudes ranging from 1800 - 2800 m (Figure 1), although it is uncommonly grown at altitude as low as 1680 m or as high as 3430 m (Adefris *et al*., 1991). Ethiopia is the fifth world producer in Linseed (Wijnands *et al*., 2009) and the second leading exporter of Niger seed mainly to the US (Table 1).

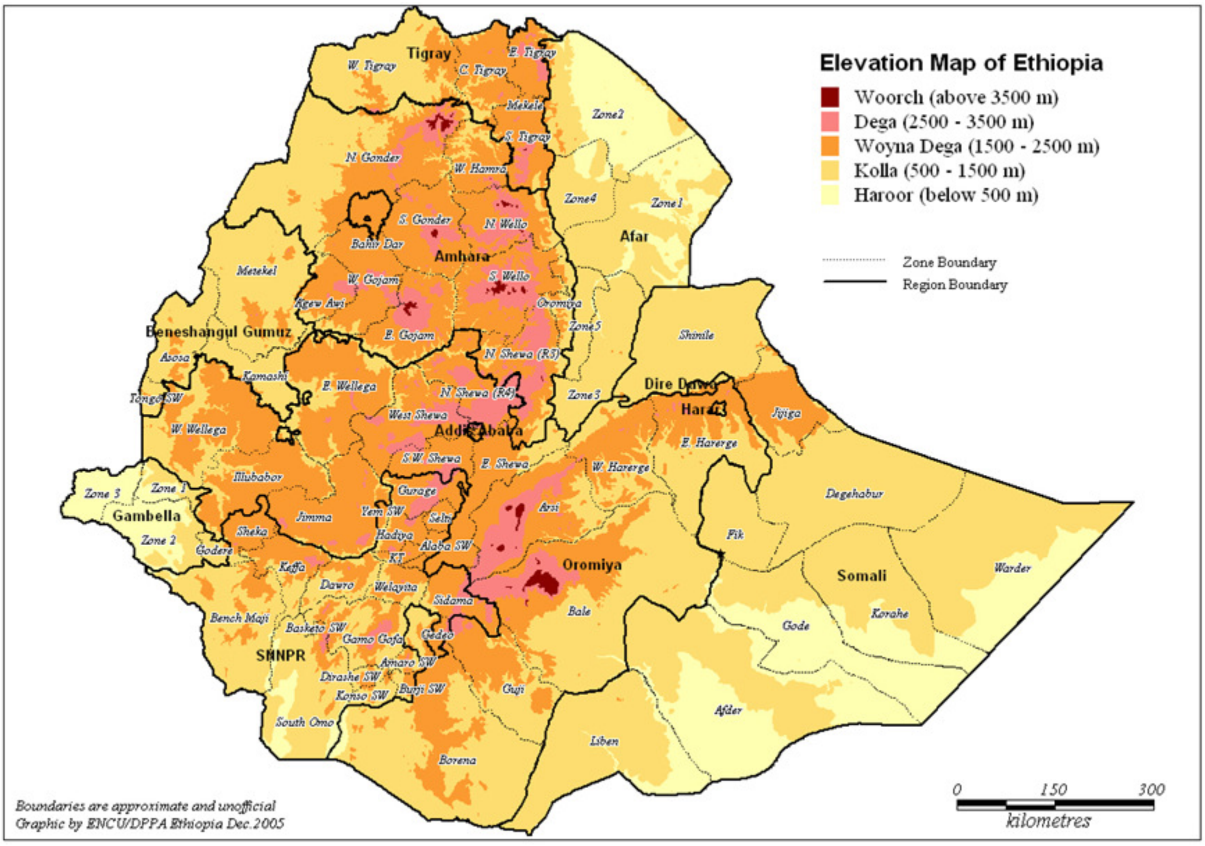

Figure 1: Elevation (in meters) Map of Ethiopia (Source: ENCU/DPPA 2005).

Table 1: Imports of Niger seed to the United States of America in 2003

Origin	Quantity (tonnes)	Value (thousand US$)
India	22 609	12 225
Ethiopia	18 290	9750
Myanmar	7 043	4781
Singapore	1 463	933
Nepal	61	42
Pakistan	54	31
Indonesia	19	8
Canada	3	5
Total	4 9542	27 775

Source: FAO 2005

The world production of Linseed was 2.9 million tons. The largest share was from Canada (38%) followed by USA (17%), China (17%) and Ethiopia with 125,000 tons (4%) (Wijnands *et al*., 2007). In addition, Niger seed is the first and the most important oil crops followed by linseed in area coverage in Ethiopia and Oromia regional state (potential Linseed and Niger seed region in Ethiopia) (CSA, 2008). In the year 2007/08 cropping season, the total land of 285,237 ha and 142,846.2 ha were allocated for Niger seed and 152,129 ha and 105,811.5 ha for Linseed production in Ethiopia and in Oromia region, respectively (CSA, 2008). In terms of area under oil seeds, West Ethiopia (West Shoa, East Wollega, Horo Guduru Wollega, West Wollega and Kelem Wollega) contribute high share to the Ethiopian Niger seed (37.24%) and Linseed (10.07%) production. Despite the large contribution to the country's oil seed production, the average yield of Niger seed and Linseed obtained by the farmers in Western Ethiopia is very low as compared to high yielding varieties (0.947t/ha for Niger seed and 1.69 t/ha for Linseed) developed by different research centers. The lower productivity could be attributed mainly due to lack of stable and adaptable high yielding improved varieties of Niger seed and Linseed crops in the region. There are several stability parameters used in identifying high yielding genotypes for wide and specific environments. Multivariate analyses viz., AMMI is a powerful tool in assessing stable and adapted varieties for multi locations. It has substantial ability to partition a signal-rich model from a noise-rich discarded residual, thereby gaining accuracy (Gauch, 1988). The fundamental reason AMMI is appropriate for agricultural research is that the ANOVA part of AMMI can separate the G and E main effects and the G x E interaction effects that present researchers with such vastly different problems and opportunities (Gauch *et al*., 2008). One of its greatest advantages is its ability to extract interaction PCA axes along which there is a maximum variation, thereby indicating the number of components necessary to explain the pattern in the interaction residual (Girma, 1999). AMMI also offers better opportunities for graphically displaying of mega-environments and adaptive responses thereby identify superior and stable varieties. This study was, conducted with the objectives of testing the adaptability and stability of all improved Niger seed and linseed released varieties in Ethiopia between 1984 and 2008 for specific and wide recommendation domains.

MATERIALS AND METHODS

Improved Linseed and Niger seed varieties developed and released between the years 1984 and 2008 in Ethiopian (Table 2) were evaluated in independent experiments in 2008 and 2009 main cropping seasons. The trials were arranged in Randomized Complete Block Design (RCBD) replicated three times. Eight varieties of Linseed with one local variety were evaluated at Arjo, Gute and Shambu locations. Five varieties of Niger seed including a local variety were tested at Bako, Gute and Shambu locations. Each plot comprises six rows of five-meter length for both crops, with width of 20 cm for Linseed and 30 cm for Niger seed. Seeds were drilled within the rows using seed rate of 25kg ha^{-1} and 10kg ha^{-1} for Linseed and Niger seed, respectively. Fertilizer rates of 23/23kg ha^{-1} of N/P_2O_5 were applied at planting for both crops. Other agronomic management practices were used uniformly as required. Data were recorded on plot bases. The central four rows were harvested and seed yield was adjusted at 10% seed moisture content before data processing for analysis. Stability analysis was carried out using AMMI models using Agrobase 20 software (Agrobase, 1999).

Table 2: Released varieties of linseed and Niger seed between the years 1984 and 2008 in Ethiopia

Linseed	Year of release	Centre of release
Kulumsa-1	2006	KARC/EIAR
Tole (CI2698 x PGRC/E 13611/B)	2004	HARC/EIAR
Berene (PGRC/E 01 3627)	2001	HARC/EIAR
Geregera (R7-2D)	1999	ADARC/ARARI
Belay-96 (IAR/Li)	1996	HARC/EIAR
Chilalo	1992	HARC/EIAR
CI-1525	1984	HARC/EIAR
CI-1652	1984	HARC/EIAR
Niger seed		
Shambu-1	2002	HARC/EIAR
Kuyu	1994	HARC/EIAR
Fogera	1988	HARC/EIAR
Esete-1	1988	HARC/EIAR

KARC=Kulumsa Agricultural Research Center; HARC=Hollotta Agricultural Research Center; ARARI=Amhara Regional Agricultural Research Institute; ADARC=Adet Agricultural Research Center; EIAR=Ethiopian Institute of Agricultural Research

AMMI combines analysis of variance and principal component analysis (PCA) into a single model with additive and multiplicative parameters (Gauch and Zobel, 1996). The AMMI model equation is:

$$Y_{ger} = \mu + \alpha_g + \beta_e + \sum_n \lambda_n \gamma_{gn} \delta_{en} + \rho_{ge} + \varepsilon_{ger}$$

Where Y_{ger} is the observed yield of genotype g in environment e for replication r; Additive parameters: μ is the grand mean; α_g is the deviation of genotype g from the grand mean and β_e is the deviation of environment e; Multiplicative parameters: λ_n is the singular value for interaction principal component axis (IPCA) n, γ_{gn} is the genotype eigenvector for axis n, and δ_{en} is the environment eigenvector; ρ_{ge} is PCA residuals (noise portion) and ε_{ger} is error term.

Genotypes with low magnitude (score of the same sign) of interaction principal component analysis (IPCA) scores have general adaptability while those with high magnitude of IPCA scores have specific adaptability to environments. The results can be graphed in a very informative biplot that shows both main and interaction effects for both genotypes and environments (Gauch and Zobel, 1996).

RESULTS AND DISCUSSION

Yield performance of Linseed and Niger seed varieties: Mean yield performance of Linseed across years and locations is presented in Table 3. Mean square for seed yield was significantly different for all locations except at Shambu in the year 2008. From the pooled mean yield, it can be seen that the best yielding genotype was CI-1528 with the mean yield of 1.576 tons ha^{-1} followed by Kulumsa-1 (1.565 tons ha^{-1}), Berene (1.562 tons ha^{-1}), and CI-1652 (1.51 tons ha^{-1}). Local variety was the poorest in seed yield and it gave a mean yield of 0.898 tons ha^{-1}. When looking at the pooled mean yield in Table 3, it can be clearly seen that released Linseed varieties are by far greater than local variety. For instance, the yield advantage of the top yielder over the local variety was 72.28%. Following the analysis of mean yield data, all the released varieties are useful in boosting Linseed production and productivity in western Ethiopia.

Table 3: Mean seed yield (ton ha^{-1}) of linseed across locations (Arjo, Gute and Shambu) and years (2008 - 2009)

Variety	Mean seed yield in ton ha^{-1} Year-2008 Arjo	Gute	Shambu	Year-2009 Arjo	Gute	Shambu	Pooled Mean
Kulumsa-1	1.330	2.150	1.760	1.420	1.590	1.140	1.565
Tole	1.280	2.160	1.900	0.940	1.610	0.950	1.473
Berene	1.820	2.060	2.000	0.970	1.530	0.990	1.562
Geregera	1.200	1.980	1.600	1.110	1.620	1.090	1.433
Belay-96	1.410	2.240	1.860	1.130	1.300	1.020	1.493
Chilalo	1.510	2.040	1.940	0.970	1.310	1.010	1.463
CI-1525	0.950	1.780	1.890	1.970	1.250	1.610	1.575
CI-1652	1.210	1.810	2.110	1.660	1.280	0.990	1.510
Local variety	0.990	0.840	1.280	0.610	0.930	0.740	0.898
MEAN	1.301	1.896	1.818	1.197	1.380	1.059	1.442
CV	21.900	13.180	21.850	36.680	13.710	20.950	
LSD	0.406	0.356	0.566	0.626	0.269	1.140	
F – test	*	**	ns	*	**	*	

CV=coefficient of variation; LSD=least significant difference; *, **= significant level at 5% and 1% probability level, respectively.

Table 4 shows the average mean yield of five Niger seed varieties in six environments. The pooled mean yield was ranged from 0.69 tons ha^{-1} to 0.60 tons ha^{-1}. The highest yield was recorded by Shambu – 1 while the least was recorded by Kuyu. The analysis of variance indicated that there was no significant variation observed among the varieties in all testing environments. In other words, no variability was observed among the varieties. Different from Linseed, locations mean yield data showed that Bako and Shambu were found to be high yielding environments for Niger seed production in 2008 and 2009. In general, analysis of variance makes it clear that the differences among released Niger seed varieties as well as local variety were insignificant.

Table 4: Mean seed yield (ton ha^{-1}) of Niger seed across locations (Arjo, Gute and Shambu) and years (2008 - 2009)

Variety	Mean seed yield in ton ha^{-2} Year-2008 Bako	Gute	Shambu	Year-2009 Bako	Gute	Shambu	Pooled Mean
SHAMBU-1	1.040	0.470	1.020	0.530	0.250	0.800	0.690
KUYU	1.050	0.390	0.690	0.640	0.230	0.590	0.600
FOGERA	0.990	0.450	0.980	0.490	0.220	0.890	0.670
ESETE-1	1.090	0.400	0.900	0.620	0.250	0.770	0.670
LOCAL VARIETY	0.840	0.460	0.950	0.540	0.150	0.710	0.610
MEAN	1.002	0.432	0.909	0.563	0.218	0.753	0.650
CV	14.670	24.490	36.210	20.720	32.130	22.220	
LSD	0.223	0.161	0.500	0.177	0.107	0.254	
F – test	ns	ns	ns	ns	ns	ns	

CV=coefficient of variation; LSD=least significant difference; *, **= significant level at 5% and 1% probability level, respectively.

Additive Main effects and Multiple Interaction (AMMI) model: Analysis of variance for seed yield over six environments based on AMMI model for Linseed was presented in Table 5. Significant differences ($p \leq 0.01$) were observed among environments, genotypes and genotypes x environments interaction. The significant interactions among genotype by environment showed that the genotypes varied across the environments in seed yield. Genotypes x environments interaction was further partitioned into principal component axes and only the first IPCA was significantly different and explained the largest proportion (62.25%) of the interaction, while the remaining proportions of the interaction sum of squares were not significant. As a result the analysis was entirely depends on the AMMI1 model. The AMMI biplot involved the values of IPC1 axis and mean yield in which the genotypes and environments were dispersed around the center biplots, indicating a substantial amount of variability in genotypes and environments. These results are in concurred with the findings of many studies- for common bean (Abeya *et al*., 2008); for durum wheat (Alamnie *et al*., 2004a), for barley (Alamnie *et al*., 2004b) and for maize (Wende and Labuschangne, 2005).

Table 5: Analysis of variance for Additive Main effects and Multiple Interaction (AMMI)

Source of variation	DF	Mean squares	Eigen value	% G x E interaction explained
Total	161			
Environments	5	3.104**		
Reps within Env.	12	0.477		
Genotype	8	0.791**		
Genotype x Env.	40	0.197**		
IPCA 1	12	0.409**	1.64	62.25
IPCA2	8	0.158^{ns}	0.53	20.04
Residual	96	0.097		

Grand mean = 1.441; R^2 = 0.7926; CV (%) = 21.57; Reps=replications; Env. = environment; *, **= significant level at 5% & 1% probability level, respectively.

In contrast to Linseed analysis result, the AMMI analysis of variance for Niger seed showed that only the mean square due to environment was found to be significantly different (p ≤ 0.01%) while the remaining parameters were not significant for seed yield (Table 6), indicating that variability in genotypes were contributed through the environments. The percentage of variability due to IPCA1 and IPCA2 were 77.96% and 17.03% though IPC was not significant.

Table 6: Analysis of variance for Additive Main effects and Multiple Interaction (AMMI)

Source of variation	DF	Mean squares	Eigen value	% G x E interaction explained
Total	89			
Environments	5	6.596**		
Reps within Env.	12	0.020		
Genotype	4	0.029		
Genotype x Env.	20	0.022		
IPCA 1	8	0.042	0.112	77.96
IPCA2	6	0.012	0.025	17.03
Residual	48	0.031		

Grand mean = 0.647; R^2 = 0.833; CV (%) = 27.15; Reps=replications; Env. = environment; *, **= significant Level at 5% & 1% probability level, respectively.

Biplot graphs (Figure 2 and 3.) with X-axis plotting mean seed yield (ton ha^{-1}) and Y-axis plotting IPCA1 scores illustrate stability and adaptability of Niger seed and Linseed varieties. It has been reported that the IPCA scores of a genotypes in AMMI analysis are an indication of the stability or adaptation over environments (Alberts, 2004; Lourens, 2003). It is further stated that the greater the IPCA scores, negative or positive, the more specific adapted is a genotypes to certain environments. The more the IPCA scores approximate to zero, the more stable or adapted the genotypes is over all the environments sampled.

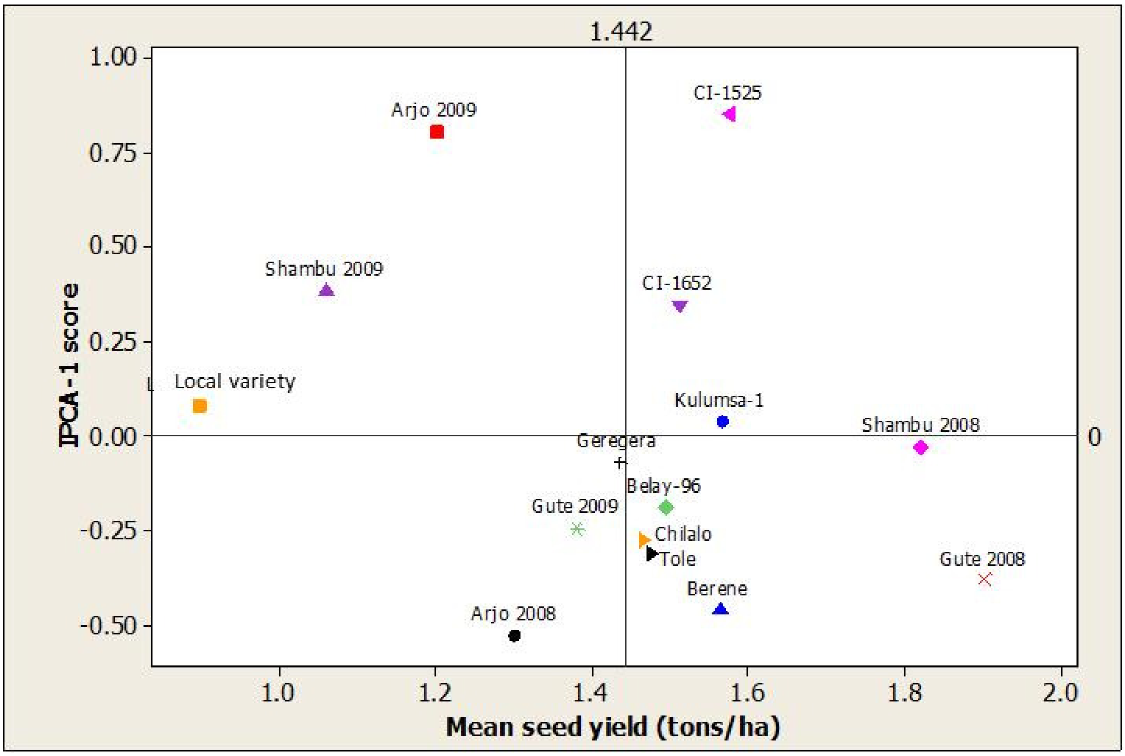

Figure 2: Matrix plot of genotypes mean seed yield (ton ha^{-1}) versus IPCA-1 scores, indicating stability and yield performance of the tested Linseed varieties and test environments

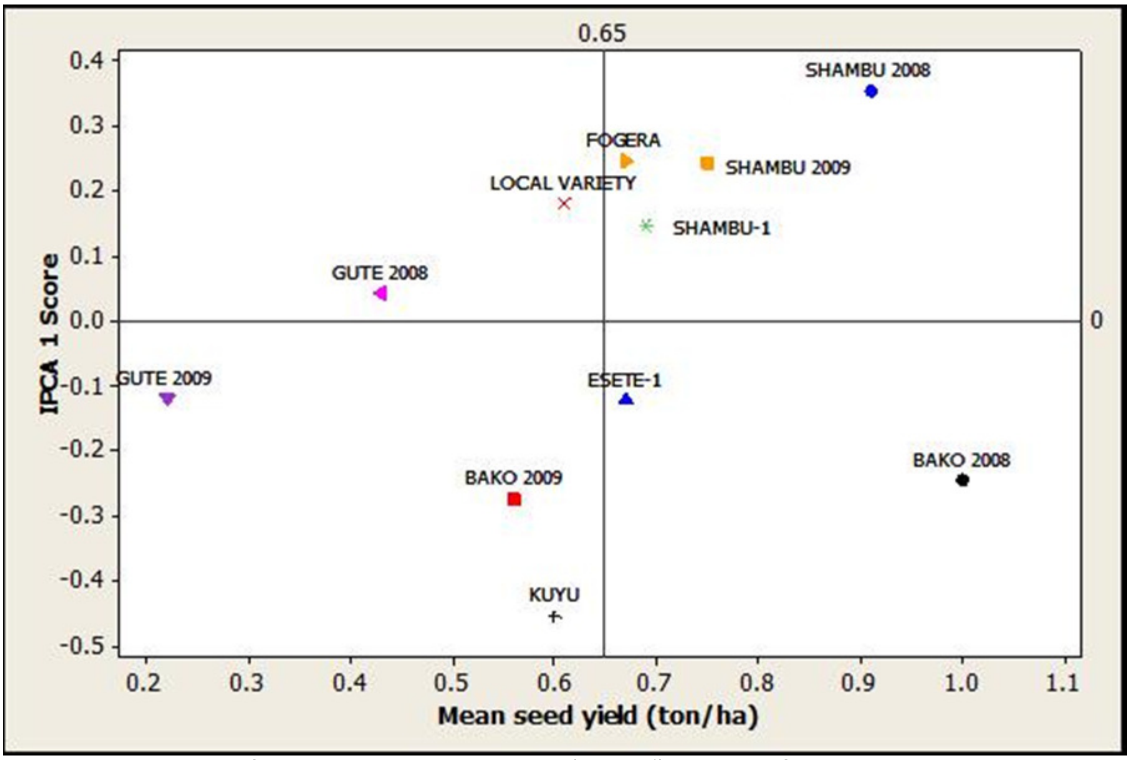

Figure 3: Matrix plot of genotypes mean seed yield (ton ha^{-1}) versus IPCA-1 scores, indicating stability and yield performance of the tested Niger seed varieties and test environments

The high yielding environments were those in quadrants II and III while the lower yielding environments were in quadrants I and IV. Accordingly, in linseed adaptation trial, the high yielding environments (Gute and Shambu in 2008) were clustered together in III quadrants and the low yielding environments (Arjo and Shambu in 2009) were clustered in quadrate I. Locations, Arjo in 2008, and Gute in 2009 were clustered in quadrant IV (Figure 2). The graph indicates seed yield in year 2008 was better than in year 2009 except for Arjo. This might be due to delay in rainfall at on set in 2009. When looking at Figure 3, Shambu site was high yielding environment during both seasons and thus it is considered an ideal site for Niger seed production. However, the remaining locations fell below the average mean yield for Niger seed. Furthermore, Bako in 2008 and in 2009, and Gute in 2009 clustered together in quadrant IV, which was considered as lower yielding environment. There was a great variability attained in seed yield among Linseed varieties while less variation was obtained among Niger seed varieties. All the Linseed varieties except local variety were produced high yields but local variety produced below average yield (Figure 2). However, considering the IPCA1 scores, Kulumsa-1, and Gergera Linseed varieties were found to be high yielders with less interaction to the environments (Figure 2), indicating that these varieties were the most stable and widely adapted to all environments. Belay-96, Chilalo, Tole and CI-1652 were moderately stable and adapted to high yielding environments. CI-1525 and Berene were unstable varieties adapted to high yielding environments while local variety was moderately stable variety to unfavourable environments. Among the tested Niger seed varieties, Shambu-1 and Esete-1 were moderately stable and Fogera was unstable but adapted to favourable environments. Varieties in low yielding environments (Kuyu and local variety) were unstable and not adapted to the testing environments.

CONCLUSION

Additive main effects and multiplicative interaction (AMMI) model identified stable and adapted Linseed and Niger seed varieties for specific and wide environments. Stable and adapted Linseed varieties viz., Kulumsa-1, Geregera, and Belay-96 are recommended for wide adaptation, while the high yielding varieties of Linseed viz., CI-1525 and Berene were recommended for high yielding environments. Similarly, Shambu-1 and Esete-1 are among Niger seed varieties recommended for favourable environments.

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