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Selection for High Yield and Stability among Early Maturing Greengram Genotypes

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Abstract

Greengram, *Vigna radiata* (L.) Wilczek is an important source of proteins and micronutrients to small holder farmers in eastern and northern regions of Uganda. Most of the landraces currently grown by small scale farmers are characterized by low yields and late maturity. In order to identify high yielding and stable varieties, an experiment was conducted to evaluate the yield performance of introduced early maturing genotypes from the World Vegetable Centre (AVDRC) in seven locations of Uganda. Yield performance data for the genotypes was subjected to analysis of variance (ANOVA) to test the significance of genotype × environmental interactions as well as stability analysis using the yield – stability statistic (YS_i) as an aid for simultaneous selection for high yield and stability. Analyses of variance showed that genotype × environmental interactions (G×E) were significant and therefore could not be ignored. Following the detection of significant genotype × environmental interactions, yield – stability statistics (YS_i) were generated and used for simultaneous selection for high yield and stability among the introduced genotypes. Yield-stability statistics (YS_i), indicated that three introduced genotypes (Filsan, Sunshine, and Blackgram) in addition to the local check were stable and high yielding. These genotypes need to be assessed for farmer preferences/tastes and other quality traits in on-farm participatory trials before they can be recommended for release.

Keywords: yield- stability statistic, *Vigna radiata*, *Vigna mungo*, Genotype × Environmental interaction

1. Introduction

Greengram *Vigna radiata* (L.) Wilczek is one of the important pulse crops widely grown by small holder farmers in the eastern and northern regions of Uganda (Apio Ibedo, 2014). It is a rich source of proteins and micronutrients particularly, iron and zinc with low ant-nutritional factors. Greengram is considered a wonder crop among smallholder farmers due to its ability to tolerate and perform well under drought conditions, short maturity periods and ability to improve soil fertility through nitrogen fixation (Swaminathan et al., 2012). Greengram production in Uganda like much of Sub-Saharan Africa (SSA) still depends largely on late maturing and indeterminate varieties (Shanmugasundaram et al., 2009). However, shifts in rainfall patterns and seasons due to climatic change require the development of varieties that are early maturing. Such new varieties must show high performance for yield and other essential agronomic traits and their superiority should be consistent (stable) over a wide range of environmental conditions (Becker & Leon, 1988). Yield stability between genotypes is variable due to the wide occurrence of genotype × environmental interactions (G×E) i.e. the ranking of genotypes depends on particular environmental conditions where they are grown (Becker & Leon, 1988). Genotype × environment (G×E) interaction pauses a continuous challenge among plant breeders and agronomists in making cultivar recommendations to farmers because of the associated consequences especially when selection is based on yield alone (Kang, 1993). This is due to lack of emphasis on both yield and stability in most breeding programs (Mekbib, 2002) as well as lack of appropriate policy support for instance the new Ugandan Plant Variety Protection Bill (2010), which governs variety release in the country does not consider yield and stability simultaneously. Kang (1993) warns that cultivar recommendations made by breeders and/ or agronomists on the basis of yield alone as is conventionally done pause a serious risk to growers.

Kang (1993) recently developed a statistic called yield-stability (YS_i) that integrates both yield and stability in selecting genotypes tested across a range of environments. Recommendation of high yielding and stable

Greengram genotypes is particularly important in eastern and northern Uganda due to variations in environmental conditions, production is rain-fed and means of modifying the environment are unavailable. This study therefore aimed at identifying high yielding varieties that have a stable performance across regions using the YS_i selection criterion.

2. Materials and Methods

Twelve early maturing genotypes (11 for *Vigna radiata* and one for *Vigna mungo*) were evaluated in seven locations and different seasons. The locations were; Arua (at AbiZARDI), Kaberamaido (at Kaberamaido TVC), Kumi (at Kumi TVC), Moroto (at NabuinZARDI), Lira (at Ngetta ZARDI), Serere (at NaSARRI), and Tororo (at Tororo DATIC) located in eastern, north eastern and north western Uganda from 2013-2014. These locations represent the major Greengram growing areas in Uganda and are characterised by arid and semi arid conditions. All the genotypes except local check (control variety) used in the study were obtained from the World Vegetable Centre (AVDRC) as shown in Table 1. In 2013 first season (2013A), evaluations were conducted only in Serere while in the second season (2013B), genotypes were evaluated in Kumi and Lira. In the first season of 2014 (2014A), genotypes were evaluated in all the sites while in the second season (2014B), genotypes were planted in Arua and Serere. In all locations, genotypes were planted in 2.4 m × 3 m plots at a spacing of 60 cm × 30 cm laid out in a Completely Randomised Block Design (RCBD) with each genotype replicated three times. In each season, experimental plots were kept free of weed by hoeing. Fertilizers and/or supplementary water through irrigation were not applied during the trials. Pre-flowering pests especially aphids were controlled by 1-2 sprays (depending on pest pressure) using Dimethoate 40%EC at recommended rates. Post flowering pests such as flower thrips (*Megalurothrips sjostedti* Trybom), pod borers (*Maruca vitrata* Fabricius) and pod sucking bugs were controlled by 2 sprays using Roket 44 EC (Profenofos 40% + Cypermethrin 4%) starting from the budding stage. Pods from each plot were harvested at physiological maturity (i.e when the ripe pods changed colour), dried under the sun for three to four days before threshing and winnowing. The threshed grain was then weighed on a plot basis to obtained plot grain yield which was later extrapolated to yield per hectare. A combined analysis of variance to assess the significance of genotype × environment interactions was carried out before computing the yield and yield-stability statistics (YS_i). Shukla's Stability Variance and Kang's Yield - Stability (Ys_i) Statistics were calculated according to (Kang, 1993). All analyses were carried out using R version 3.1.2 (R Core Team, 2014).

Table 1. List of AVDRC Genotypes evaluated in the study

Cultivar Name	Species	Country of origin
Filsan	*Vigna radiata*	Taiwan
Blackgram	*Vigna mungo*	Thailand
Mauritius 1	*Vigna radiata*	Mauritius
VC614850-12	*Vigna radiata*	Thailand
VC6173B10	*Vigna radiata*	Thailand
Yellow mungo	*Vigna radiata*	Philippines
KPS 1	*Vigna radiata*	Taiwan
VC6137B14	*Vigna radiata*	Thailand
VC63724560	*Vigna radiata*	Thailand
VC6153B20P	*Vigna radiata*	Thailand
Sunshine	*Vigna radiata*	Unknown
Local check	*Vigna radiata*	Uganda

Note. AVDRC = World Vegetable Center.

3. Results

Analysis of variance (Table 2) showed that genotype × environmental interactions were significant ($p < 0.001$), therefore it was inappropriate to select genotypes on the basis of yield alone. The effect of genotype was also significant (at $p = 0.001$) though the interaction and environmental effects were more significant (at $p < 0.001$). There were differences in mean performance of genotypes at the different locations (Table 3).

Table 2. Analysis of variance for genotype × environmental interaction effects

Source of variation	DF	Mean square	P value
Genotypes	11	72814.4	0.001
Environments	11	1145137	<0.001
Interactions	121	23018.4	<0.001
Heterogeneity	11	0.58	0.838
Residual	110	11960.5	<0.001
Pooled error	264		

Note. DF = degrees of freedom.

Table 3. Average Yield (Kgha^{-1}) of all the genotypes evaluated at the different locations

Parameter	Arua		Kaberamaido	Kumi		Moroto	Lira		Serere			Tororo
Season/year	2014A	2014B	2014A	2013B	2014A	2014A	2013B	2014A	2013A	2014A	2014B	2014A
Mean yield	338.8	209.1	536.3	474.5	763.2	360.7	173.3	538.2	258.9	431.9	392.7	431.5
SE	22.4	24.2	13.3	26.1	17.2	8.2	15.6	40.2	25.4	25.9	25.6	15.2

Note. SE = standard error.

Following the detection of significant genotype × environmental interactions, YS_i statistics for the twelve genotypes were calculated as listed below as described by Kang (1993) to give results in Table 4.

1) Determine the contribution of each genotype to Genotype × Environmental interaction by calculating σ_i^2 (Shulka, 1972) as follows:

$$\sigma_i^2 = [1/(s-1)(t-1)(t-2)] \times [t(t-1)\sum_j(\mu_{ij}-\overline{\mu_i})^2 - \sum_i\sum_j(\mu_{ij}-\overline{\mu_i})^2] \quad (1)$$

Where, $\mu_{ij} = X_{ij} - \overline{X_j}$, X_{ij} = observed yield value of the ith genotype in jth environment, $\overline{X_j}$ = mean of all genotypes in jth environment, $\overline{\mu_i} = \sum_j \mu_{ij}/s$, s = number of environments and t = number of genotypes. Shukla's Stability Variance, σ_i^2 and Kang's Yield - Stability (YS_i) statistics were computed using *Agricolae* package in R (Felipe de Mendiburu, 2014).

2) Arrange genotypes from highest to lowest yield and assign yield rank *(Y'),* with the lowest yielding genotype receiving the rank of 1.

3) Calculate protected $LSD_{\alpha(2)}$ for mean yield comparisons [α(2) refers to a two-tailed test] as $t_{\alpha(2)}$, v (2EMS/s × $r^{1/2}$), where EMS = error mean square, v = df associated with EMS, and r = number of replications.

4) Adjust *Y'* according to LSD, and determine adjusted yield rank (Y) [as shown in Table 4].

5) Assign respective stability-variance statistic (σ_i^2 values to genotypes and determine whether or not σ_i^2 is significant at α(2) = 0.10, 0.05, 0.01, using an approximate test with (s - 1),v df [a significant σ_i^2 indicates that genotype performance across environments was unstable].

6) Assign stability rating (S) as follows: -8, -4, and -2 for σ_i^2 significant at α= 0.01, 0.05, and 0.1, respectively; and 0 for non significant σ_i^2 [The stability ratings of - 8, - 4, and - 2 were chosen because they changed genotype ranks from those based on yield alone (Y') (Kang, 1993).

7) Sum adjusted yield rank (Y) and stability rating (S) for each genotype to determine YS_i statistic.

8) Calculate mean YS_i as $\Sigma YS_i/t$. Select genotypes with YS_i > the mean YS_i.

Table 4. Yield-stability statistic (YS_i) for simultaneous selection for yield and stability in Greengram trials

Genotype	Mean Yield	Yield Rank (Y)	Adjustment to rank*	Adjusted Y	Stability variance	Stability rating (S)	YS_i
Filsan	463	12	3	15	54522.4**	-8	7+
Blackgram	454.6	11	3	14	53573.6**	-8	6+
Sunshine	428.8	10	3	13	22254.3**	-8	5+
Local check	417.8	9	3	12	24233.3**	-8	4+
VC61485012	382	8	-3	5	28630.2**	-8	-3
Mauritius1	375.5	7	-3	4	16726.2**	-8	-4
VC6173B10	372.3	6	-3	3	13740.3**	-8	-5
Yellowmungo	369	5	-3	2	26554.7**	-8	-6
KPS1	344.4	4	-3	1	11756.6**	-8	-7
VC6137B14	342	3	-3	0	10034.5**	-8	-8
VC63724560	339.9	2	-3	-1	6162.5**	-8	-9
VC6153B20P	337.1	1	-3	-2	8032.8**	-8	-10
Mean	**385.5**						**-2.5**
LSD (0.05)	**0.55**						

Note. YS_i = yield-stability statistic; + Genotypes selected on the basis of YS_i.

* Adjustment for +1 for mean yield > overall mean yield (OMY); +2 for mean yield ≥ 1LSD above OMY; +3 for mean yield ≥ 2LSD above OMY; -1 for mean yield < OMY; -2 for mean yield ≤1LSD below OMY; and -3 for mean yield ≤ 2LSD below OMY.

** σ_i^2 Significant at α = 0.01

Three introduced genotypes (Blackgram, Filsan, and Sunshine) in addition to the local check had yield-stability statistic (YS_i) values greater than the mean YS_i value (-2.5) (Table 4). These genotypes gave high mean yield values with low genotype × environment interaction (an indicator of wide adaptability) and are therefore preferred since they can express high yield potential in varied environments. Therefore these genotypes are both stable and high yielding and are suitable for cultivation in the Ugandan environments in which they were tested. These genotypes will be subjected to farmer preference assessment and other quality parameters in on-farm participatory trials before they can be submitted for release and subsequent production.

4. Discussion

The presence of Genotype × Environmental interactions pause a challenge to plant breeders because it implies that the behaviour of the genotypes in the trial depends upon the particular environment in which they are grown (Ceccarelli, 1989; Hill, 1975). Thus the performance of any one of the genotypes relative to the remaining genotypes grown in the same environment will be inconsistent, such inconsistencies resulting either in alteration to the ordering of the genotypes from one environment to the next, or to changes in the absolute differences between genotypes which leave the rank order unchanged. Such interactions make utilizing data from multi-environmental trials complex (Tukamuhabwa et al., 2012). When there are Genotype × Environmental interactions, they can be dealt with through; 1) ignoring them (by using genotypic means across environments); 2) avoid them (by grouping similar environments together) or 3) exploit them in breeding objectives by analyzing and interpreting genotypic and environmental differences (Eisemann et al., 1990). The first approach pauses a great risk to growers (Kang, 1993) while with the second approach, useful information about environments may be lost especially if broad adaptation were the goal (Kang, 1997). Third approach enables researchers to identify the causes of genotype × environmental interactions and provides opportunities to address them through genetic or environmental manipulations to enhance productivity. In order to conserve resources, genotypes that are widely adaptable and with reliable performance across environments need to be identified through analysis and utilization of genotype × environmental interactions. In order to analyze genotype × environmental interactions, it is important to integrate both yield and stability of genotype performances across environments using reliable stability statistics (Kang, 1993). A yield-stability statistic (YS_i) that uses Genotype × Environmental interaction with great emphasis on stability component has been recommended in identifying high yielding and stable genotypes (Kang, 1993). In this study, YS_i was used in studying the performance of introduced Greengram and Blackgram genotypes in different growing areas in Uganda. The results in this study showed that genotype × environmental interactions were significant, therefore it was inappropriate to select genotypes on the basis of mean yield alone as is conventionally done (Kang, 1993) but instead both genotype yield and stability of performance were needed to evaluate genotype performance. Kang (1993) highlighted the fact that researchers who emphasize stability of performance than currently done in the selection process would benefit farmers. Farmers would have a greater risk of suffering yield losses when a variety is chosen only on the basis of mean yield alone than when selection is based on yield and stable performance. It is a fact that farmers would prefer to use a high-yielding cultivar that exhibits temporal adaptation and might be willing to sacrifice some yield if they are guaranteed, to some extent, that a cultivar would produce consistently from year to year (Kang et al., 1991). Breeding for stability of performance under variable conditions is a complex and difficult task because selection pressure is variable and unpredictable. Therefore, evaluation of varieties under different environments and adoption of simultaneous selection for yield and stability is a reliable selection criterion that has to be used in any plant breeding programme (Mekbib, 2002). The finding that the local check commonly grown by farmers gave a stable yield performance across the test environments is not surprising since farmers especially in marginal areas always grow landraces that are suitable to their environments as well as those that meet their needs and preferences (Vernooy, 2003). The mean yield values for the genotypes evaluated in this study are still below those required for an ideal variety (> 2 tons/ha) (Shanmugasundaram et al., 2009) and therefore more needs more research is needed in breeding as well as crop agronomy in order to raise yield so as to enhance returns to farmers.

In addition to the stable performance of the three genotypes identified in this study, other traits need to be considered as these may be useful to farmers through on-farm participatory trials. This is because it enables researchers to take advantage of farmers' knowledge and experience thus allowing a quick identification of promising genotypes and eventually contributing to the improvement of a breeding program (Abidin et al., 2005).

5. Conclusion

High Genotype × Environmental interaction complicates breeding work because it makes it difficult to predict how genotypes selected under a given set of conditions will perform in a different set of conditions. By exposing a number of genotypes to a set of contrasting environments it is possible to identify genotypes with a high average yield and low G × E interaction. Such genotypes are commonly referred to as widely adapted genotypes and they possess characteristics, such as resistance to pests and tolerance to environmental stress factors that enhance their performance. With the help of YSi, it was possible to identify three genotypes (Blackgram, Filsan and Sunshine) that are both high yielding and stable among the introduced genotypes that would be beneficial to farmers if they are released for production.

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