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Harnessing cultivar performance and stability for deploying superior groundnut plant types in the Lake Albert Crescent Zone of Uganda

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Groundnuts (*Arachis hypogaea* L.) are the second most important legume crops after beans, an important source of protein (23 to 25%), fats/oils (40 to 52%) and carbohydrates (10 to 20 %) and widely grown and consumed in Uganda including the Lake Albert Crescent Zone (LACZ). Due to susceptibility of local varieties to groundnut rosette, National Agricultural Research Organisation (NARO) through the National Semi Arid Resources Research Institute (NaSARRI) developed and released the serenut varieties. Adaptive trials were therefore established in the LACZ, to select the most location specific adapted varieties for promotion in this ecologically diverse zone. Four serenut varieties namely serenut 5, 8, 10 and 14 and a locally grown variety (Red beauty) were planted on three farmers' fields in each of the three sub-ecological areas. Data were collected on total pod dry weight (yield), number of pods and on 100 seed weight. In this study, we show that overall yields of serenut 5, serenut 14, serenut 8 and serenut 10 were highly significantly ($P \leq 0.001$) different for all traits measured across the sub-ecological areas. Best yields were recorded from the humid tropical rain forest sub-ecological area where 1900 kg/ha were obtained for serenut 14, 2366 kg/ha for serenut 10, 1763 kg/ha for serenut 8 and 1795 kg/ha for serenut 5. The yields obtained from these varieties were generally worst in the semi-arid sub-ecological area. These serenut varieties are generally adapted to wider environmental conditions although their performance per se was found to be generally inconsistent. This study has also found that among all the varieties tested, Serenut 5 was the best adapted across all the sub-ecologies. Overall, we therefore recommend farmers in this ecologically diverse zone to grow these groundnut varieties with improved growing practices such as timely planting, timely weeding, earthing up and pest and disease management in order to obtain consistent high yields.

Key words: Groundnut, performance, stability, sub-ecological area.

INTRODUCTION

Groundnut (*Arachis hypogaea* L., 2n = 4x= 40) is the second most important legume crop in Uganda. It is a major food and income source. Groundnut is some nutrient-dense food rich in digestible protein, unsaturated fatty acids (for example, oleic acid), minerals (for example, copper and manganese), vitamins (for example, biotin, niacin, folate, B1), fibre, and polyphenolic antioxidants (for example, p-coumaric acid and resveratrol) (Ros, 2010; Craft et al., 2010; Settaluri et al., 2012).

In addition, the crop is also a source of income to many small-scale farmers, contributing significantly to poverty alleviation (Kassie et al., 2011; Okello et al., 2014). Given the importance of this crop, production is still constrained by several factors including abiotic and biotic stresses. To overcome some of these production constraints, the National Groundnut Improvement Programme has released several groundnut varieties (Deom and Okello, 2018). However, a significant proportion of the groundnut growers are still using local cultivars because they are considered to be superior to improved varieties (Mugisha et al., 2014). Continued cultivation of local cultivars has resulted in persistently low productivity at farm level (Kaizzi et al., 2012; Okello et al., 2014; Deom and Okello, 2018), often leading to unreliability of the crop's yields and thereby undermining food security at household and national level (Kebede and Tana, 2014; Gadgil et al., 2012).

The other factor contributing to the low groundnut yield levels in the country is the shortage of high yielding and stable varieties which have farmer preferred traits (Mugisha et al., 2014). Groundnut production is also characterised by low input use and production under rain fed conditions (Shiferaw et al., 2010; Mugisha et al., 2011; 2014). Under such circumstances, and in fluctuating environments, it is necessary to develop and/or promote varieties with attributes such as high yield, wider adaptability, biotic and abiotic stress resistance, which are also and low cost management practices. Moreover, the new varieties will only positively impact farmers' incomes, if they are accepted by the community (Khan et al., 2008; Bucheyeki and Mmbaga, 2013). Therefore, the need to develop and promote improved groundnut varieties with farmer-preferred traits in the Lake Albert Crescent Zone (LACZ) is of paramount importance.

New varieties must show high performance for important agronomic traits and their dominance should be consistent over a wide range of production environments (Becker and Leon, 1988). Yield stability among genotypes can become inconsistent due to the wide occurrence of genotype x environment interactions (GE), that is, the ranking of genotypes depending on prevailing conditions at the production environment. GE remains an outstanding challenge to 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).

Stability analysis is useful for the identification of stable genotypes and predicting the responses of various genotypes over changing environments. The stable genotypes adjust their phenotypic responses to provide some measure of uniformity in spite of environmental fluctuations (Minde et al., 2017). However, Kempton and Fox (1997) argued that identification of genotypes which can exploit particular environments would be the source of future breeding gains as agricultural environments change. Therefore, stability analysis studies are needed for identification of stable genotypes and in predicting the responses of various genotypes over changing production environments.

Development of new varieties requires full participation of stakeholders (Scoones et al. 2009). On-farm trials have been identified as vital tools for speeding up of breeding processes and enhancing cultivar adoption rates in farming communities (Assefa et al., 2005, Joshi et al., 2007). This is because on-farm trials enable the incorporation of farmers' opinions and ensures testing of technologies under farmers' management conditions (Kaizzi et al., 2006). As a result, increased rates of adoption and reduced variety abandonment have been reported when farmers' knowledge and experiences are acknowledged (Moser and Barrett, 2003, Sibiya et al., 2013).Therefore, an attempt has been made in the present study to;

(1) Evaluate the performance of different groundnut varieties across different locations to know the role of G × E interactions and also to analyse the stability of genotypes for pod yield and its contributing characters, under farmer management conditions,
(2) Identify superior groundnut genotypes for promotion in the LACZ of Uganda.

MATERIALS AND METHODS

The LACZ is ecologically diverse with three major sub-ecologies; namely, the semi-arid rift valley lying sub ecological area (SRV), the humid tropical rain forest sub ecological area (HTR), and the woodland savanna sub ecological area (WS).

In this study, 4 improved groundnut varieties; serenut 5 (S5), serenut 8 (S8), serenut 10 (S10) and serenut 14 (S14) and one locally grown variety, red beauty (Table 1) were planted out on farmers' fields in each of the three sub-ecological areas of LACZ. In each sub ecological area, three farmers were selected to host the trials on whose fields each of the five groundnut varieties were planted on three random 3x5 m plots arranged as randomized complete block design (RCBD) with the three sub-ecological zones considered as blocks and nine replications (three farmers per sub-ecological zone and three plots planted per variety by each farmer).

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Table 1. Characteristics of groundnut varieties used in the study.

Variety	Special attributes	Expected yield (Kg/ha
Serenut 5	Medium to large seed Tolerant to drought Resistant to rosette virus Resistant to leaf spot	2500-3000
Serenut 8	Drought tolerant Uniform mat-type growth Rosette and leafspot resistant, stay green trait	2500-3700
Serenut 10	Drought tolerant Rosette and leafspot resistant stay green trait	2500-3700
Serenut 14	Drought tolerant Rosette and Leafspot resistant stay green trait	2500-3700
Red beauty	Multiline of Red Valencia	1900-2500

Adopted from Okello et al. (2014).

Single groundnut seeds were planted at 15cm between plants and in rows, which were 45 cm apart running perpendicular to the slope. These trials were farmer managed and the trials were run over 3 seasons; September to December 2014 (season 1), March to July 2015 (season 2), and September to December 2015 (season 3). Data were collected on overall yield (total dry weight of unshelled pods), Number of pods per plant and weight of 100 seeds (HSD). All data were analyzed using Genstat version 14 (Payne et al., 2011) and differences between means compared using Fisher's protected least significance difference (LSD) at 5% significance level.

In addition, the relative consistency performance technique (Ketata et al., 1989), was used to show behaviour interpretation of genotypes in different environments. Using Excel software, biplots were generated for each trait by simultaneous use of genotype means and standard deviation of the genotype ranks from different locations to aid interpretation of cultivar performance and stability (Table 1).

RESULTS

Combined analysis for yield and yield components over the three growing seasons are presented in Table 2. There were highly significant ($P \leq 0.001$) differences between genotypes for all traits which explained over 60% of total variation. Highly significant ($P \leq 0.001$) differences due to seasons and ecologies main effects were also observed for all traits measured. The interactions between variety and season were highly significant for all the traits, except for the hundred seed weight. Additionally, the interaction between season x variety and ecology was not significant, except for number of pods per plant (Table 2).

Mean values for yield and associated traits combined over locations are presented in Table 3 and supplementary Tables S1, S2, and S3. The mean values for yield in season 2014B ranged from 1529 to 2268 with an average yield of 1876 kg/ha. Season 2015A yields ranged from 819 to 1624 with an average of 1375 kg/ha, which is 27% lower than season 2014B. Season 2015B yields ranged from 509 to 1416 with an average of 1122 kg/ha, which is 18% and 40% lower than season 2015A and season 2014B, respectively.

Mean values for yield and associated traits combined over seasons are presented in Table 4. The mean values for yield in Humid tropical rain forest sub-ecological area ranged from 1177 to 2366 with an average yield of 1800 kg/ha. The woodland savana sub-ecological area yields ranged from 1120 to 1571 with an average of 1084 kg/ha. The semi-arid rift valley sub-ecological area yields ranged from 524 to 1549 with an average of 1102 kg/ha, which is 40% lower than average yield in the humid tropical rain forest sub-ecological area.

The results for consistency of performance (stability) of genotypes across sub-agro ecologies are presented in Figure 1. The results based on hundred seed weight indicated that serenut 10 was consistently superior while serenut 8 and serenut 5 were consistently and

Table 2. Mean squares for combined analysis of selected agronomic attributes for groundnut varieties tested in different sub-agro ecologies of LACZ over three seasons (2014B, 2015A, and 2015B)

Source of variation	DF	Yield	Explained SS (%)	DF	No. of pods/plant	Explained SS (%)	DF	Hundred Seed weight	Explained SS (%)
Replication	2	11194360	45	2	175.504	31	2	1452.29	69
Ecology (E)	2	10528871***	42	2	162920***	28	2	2554.19***	122
Season (S)	2	8083795***	32	2	249.296***	44	1	2024.01***	48
Variety (V)	4	15922281***	63	4	123.557***	43	4	809.29***	77
E × S	3	10623576***	42	3	305.350***	80	2	228.53NS	11
E × V	7	699756NS	3	6	13.815NS	7	4	57.66NS	5
V × S	5	6375984**	25	4	75.764***	26	2	142.62NS	7
V × E x S	4	982533NS	4	5	15.215*	7	2	68.05NS	3
Error	27	6776440	-	27	5.819	-	18	90.12	-
Total	56	-	-	55	-	-	37	-	-

*Significant at P ≤ 0.05; **Significant at P ≤ 0.01, ***Significant at P ≤ 0.001; NS = Not significant (P > 0.05).

Table 3. Genotypic performance of groundnut varieties combined over sub-agro ecologies for three seasons (2014B, 2015A, and 2015B)

Genotype	2014B			2015A			2015B		
	HSD (g)	No. of Pds/plt	Yield (Kg/ha)	HSD (g)	No. of Pds/plt	Yield (Kg/ha)	HSD (g)	No. of Pds/plt	Yield (Kg/ha)
Serenut 5	-	7.74	2268	38.6	11.6	1624	35.59	7.08	1416
Serenut 8	-	7.14	1667	50	11.2	1496	34.96	6.06	1168
Serenut 10	-	9.24	2041	48.8	4.95	819	33.69	5.67	1122
Serenut 14	-	6.83	1529	51.7	11.38	1560	38.04	6.45	1396
Red-beauty	-	7.74	1876	47.3	9.78	1375	26.09	3.08	509
Mean	-	7.74	1876	47.3	9.78	1375	33.67	5.67	1122
LSD (0.05)	-	4.38	392.1	NS	0.98	526	6.77	1.41	537
CV (%)	-	37.7	26.7	32	21.1	31.6	19.4	24.5	47.6

No. of Pds/plt = No. of pods per plant; HSD = Hundred seed weight.

Table 4. Genotypic performance of groundnut varieties in the three major sub-agro-ecologies combined over three seasons (2014, 2015A, and 2015B)

Genotype	Humid tropical rain forest sub-ecological area			Woodland savana sub-ecological area			Semi-arid rift valley sub-ecological area		
	HSD (g)	No. of Pds/plt	Yield (kg/ha)	HSD (g)	No. of Pds/plt	Yield (Kg/ha)	HSD (g)	No. of Pds/plt	Yield (Kg/ha)
Serenut 5	35	10.72	1795	28.3	9.15	1429	48.5	7.83	1257
Serenut 8	38.66	8.89	1763	38	7.9	1327	40.5	6.17	1077
Serenut 10	39.66	11.46	2366	42.1	7.21	1571	43.8	6.38	1102
Serenut 14	45.33	8.57	1900	34.8	8.09	1120	42.3	8.65	1549
Red-beauty	39.66	5.57	1177	17.7	8.09	-	43.8	2.86	524
Mean	39.66	9.04	1800	32.2	8.09	1084	43.8	6.37	1102
$LSD_{(0.05)}$	6.92	2.76	458	13.91	NS	626.9	NS	3.18	555.9
CV (%)	16.8	30.2	25.3	35.7	82.4	57.2	25.9	46.8	46.4

No. of Pds/plt = No. of pods per plant; HSD = Hundred seed weight; NS = not significant at P>0.05.

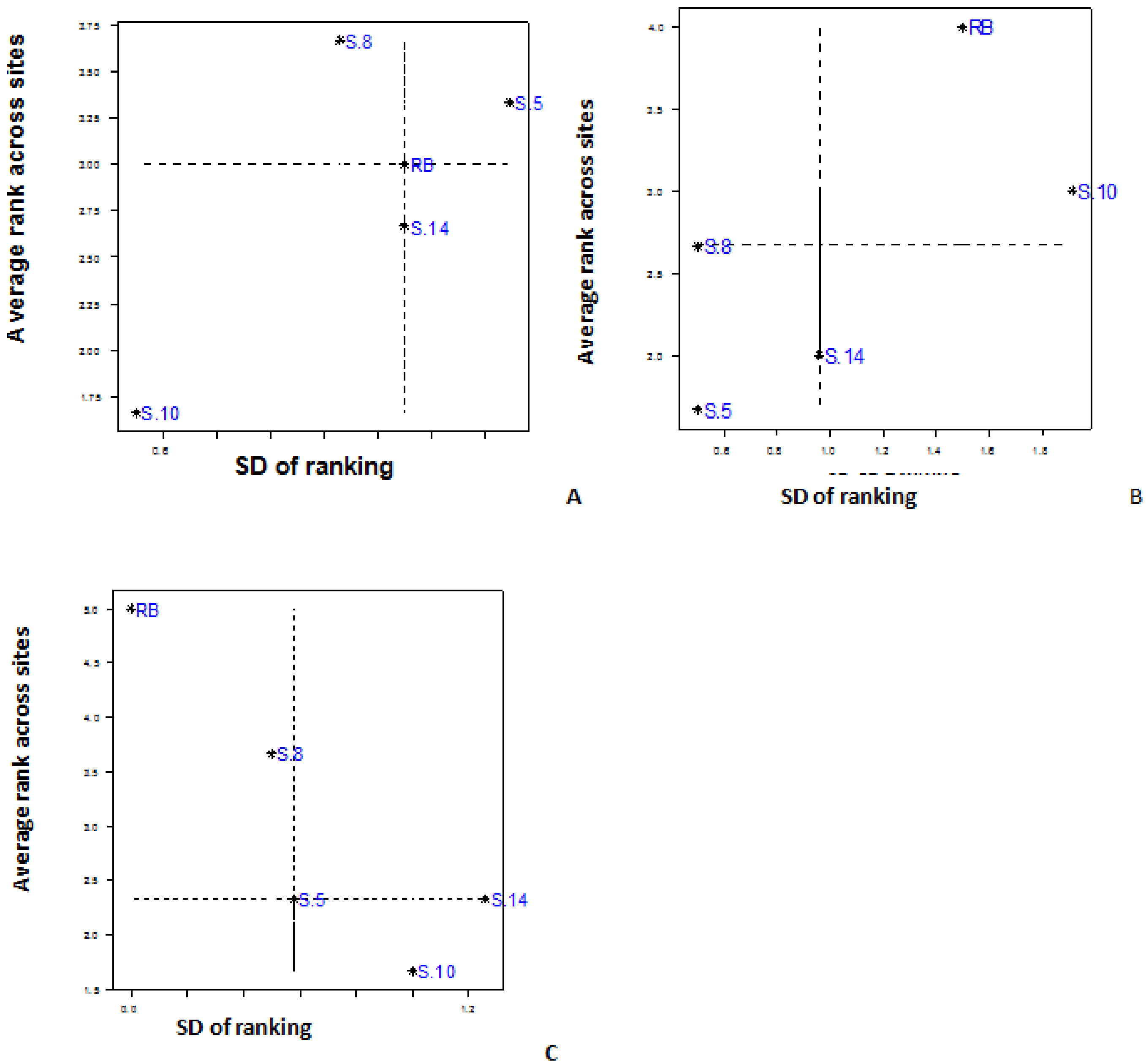

Figure 1. Consistency of genotypic performance based on HSW (A), No. of Pods (B) and Pod Yield (C).

inconsistently inferior, respectively. serenut 14 and Red beauty had average performance across sub-ecologies.

The results based on number of pods/plant indicated that serenut 5 was consistently superior across locations. serenut 10 and red beauty were inconsistently inferior while serenut8 and serenut14 had average performance across sub-ecologies. The results based on overall yield indicated that while serenut10 was inconsistently superior, serenut8 and RED beauty were consistently inferior. Serenut 5 indicated average performance across the sub-ecologies.

Overall, we report that yield and selected yield components classified the genotypes differently. While Serenut 10 was shown to be superior based on hundred seed weight, Serenut 5 was shown to be superior based on number of pods per plant. However, based on overall yield, no genotype was consistently superior. As such, all genotypes were clustered around being inconsistently superior and consistently inferior in terms of performance.

DISCUSSION

This study showed highly significant differences between groundnut genotypes for all traits measured confirming high level of genetic variation in the varieties used in the study. Moreover, the study also revealed that the interaction between variety and ecological area was not significant suggesting that each of these varieties will perform relatively the same way regardless of the growing environment. However, the same analysis also showed that the sub-agro ecological environments where these genotypes were evaluated were indeed variable. This agrees with results from performance ranking for the groundnut genotypes used in the study.

Based on overall yield, no single genotype/variety was consistently superior in terms of performance. As such, all genotypes were clustered around being inconsistently superior and consistently inferior. The above observation is also in agreement with the fact that groundnut yield traits are variable and their response depends not only on the genetic but also largely influenced by the environmental variation (Mothilal et al., 2010; Songsri et al., 2008; Minde et al., 2017).

Therefore, in spite of the lack of statistical significance for interaction between genotypes and sub-agroecologies, and given that the yield performance was found inconsistent, improving agronomic practices or growing conditions through timely planting, timely weeding, sourcing clean seed, and controlling diseases, among others, would have positive implications for the yield of these groundnut varieties in these locations.

Overall, since there are usually no restrictions to varietal movement by the farmers, it is expected that a change in the locality where a farmer chooses to grow any of those improved varieties within LACZ will not significantly affect the expected yield. This finding is consistent with the legal requirement for release of varieties whose performance is stable across various environments (Halewood et al., 2007). It is also consistent with the purpose for which these varieties were released by NaSARRI (Deom and Okello, 2018). Farmers can therefore freely move and grow these varieties in any area of their choice within LACZ and those areas that share similar agro ecological conditions in Uganda.

The results further showed that the seasons over which the experiment was conducted were variable and this was showed to have an effect on overall yield as the interaction of season with either variety or ecology was significant. This study has therefore showed that seasonal differences rather than agro ecological area characteristics will be one of the other limiting factors to the performance of any of the selected improved groundnut variety in LACZ. However, given the fact that weather events can be very unpredictable (Madzwamuse, 2010), future experiments could consider evaluating these varieties over more locations to be able to determine the best adapted SERENUT varieties in LACZ with acceptable performance regardless of the season of cultivation.

Further still, since the involvement of stakeholders in development of new varieties is key for enhancement of their adoption (Woyengo, 2010; Sibiya et al., 2013), sensory evaluation experiments will also need to be conducted on these ecologically adapted varieties in order to compliment cultivar performance and stability with acceptability of these varieties in the zone.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Supplementary Table S1. Mean squares for season 1 (2014A) analysis of selected agronomic attributes for groundnut cultivars tested over different sub-agro-ecologies of LACZ

Source of Variation	DF	Yield	DF	No. pods/plant
Replication	2	3769427	2	101.484
Ecology	1	7911929**	1	145.045*
Variety	3	1033709*	2	15.486NS
Ecology x variety	2	74895NS	2	0.728NS
Error	3	67972	3	8.509
Total	11		10	

*Significant at P ≤ 0.05; **Significant at P≤0.01, **Significant at P≤ 001; NS = Not significant (P>0.05), DF = degrees of freedom; HSD = hundred seed weight

Supplementary Table S2. Mean squares for season 2 (2015A) analysis of selected agronomic attributes for groundnut cultivars tested over different sub-agro-ecologies of LACZ

Source of Variation	DF	Yield	DF	No. pods/plant	DF	HSD
Replication	2	2607813	2	213.750	2	654.6
Ecology	2	3369932**	2	409.204***	2	1811.1*
Variety	3	1260989*	3	93.272**	3	313.7NS
Ecology x variety	3	158065NS	4	8.987NS	2	99.4NS
Error	5	188410	6	4.266	5	228.7
Total	15		17		14	

*Significant at P ≤ 0.05; **Significant at P ≤ 0.01, **Significant at P ≤ 001; NS=Not significant (P > 0.05), DF = degrees of freedom; HSD = hundred seed weight

Supplementary Table S3. Mean squares for season 3 (2015B) analyses of selected agronomic attributes for groundnut cultivars tested over different sub-agro-ecologies of LACZ

Source of Variation	DF	Yield (kg/ha)	DF	No. pods/plant	DF	HSD
Replication	2	2278886	2	39.945	2	400.27
Ecology	3	1618155***	3	28.367***	3	245.54**
Variety	2	4895470*	2	57.148***	2	734.09*
Ecology x variety	6	94610NS	5	8.711*	4	22.03NS
Error	15	285621	14	1.930	11	42.53
Total	28		26		22	

*Significant at P ≤ 0.05; **Significant at P≤0.01, **Significant at P≤ 001; NS = Not significant (P>0.05), DF = degrees of freedom; HSD = hundred seed weight