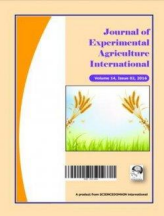

Journal of Experimental Agriculture International

21(5): 1-13, 2018; Article no.JEAI.39912
ISSN: 2457-0591
(Past name: American Journal of Experimental Agriculture, Past ISSN: 2231-0606)

Assessment of Groundnut (*Arachis hypogaea* L.) Genotypes for Yield and Resistance to Late Leaf Spot and Rosette Diseases

Khalid Elsiddig Mohammed[1*], Emmanuel Afutu[2], Thomas L. Odong[1], David K. Okello[3], Ephraim Nuwamanya[4], Olupot Grigon[1], Patrick R. Rubaihayo[1] and Patrick Okori[1]

[1]College of Agriculture and Environmental Sciences, Makerere University, P. O. Box 7062, Kampala, Uganda.
[2]Department of Crop Science, School of Agriculture, College of Agriculture and Natural Sciences, University of Cape Coast, Cape Coast, Ghana.
[3]Department of Groundnut Breeding, National Semi-Arid Research Resources Institute, P. O. Box Soroti, Uganda.
[4]National Crops Resources Research Institute (NaCRRI), P. O. Box 7084, Kampala, Uganda.

Authors' contributions

This work was carried out in collaboration between all authors. Author KEM designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors EA and TLO and DKO managed the analysis of the study. Authors EN and OG managed the literature searches. Authors PO and PRR reviewed the experimental design and all drafts of the manuscript. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/JEAI/2018/39912
Editor(s):
(1) Mohammad Reza Naroui Rad, Department of Seed and Plant improvement, Sistan Agricultural and Natural Resources Research Center, AREEO, Zabol, Iran.
Reviewers:
(1) R. K. Lal, CSIR-CIMAP, India.
(2) Shiamala Devi Ramaiya, Universiti Putra Malaysia Bintulu Campus, Malaysia.
Complete Peer review History: http://www.sciencedomain.org/review-history/23776

Original Research Article

Received 5th January 2018
Accepted 9th March 2018
Published 23rd March 2018

ABSTRACT

Groundnut which is a major staple food crop in Uganda is constrained by late leaf spot (LLS) and groundnut rosette disease (GRD), accounting for major economic yield loss. This study was conducted to identify sources of resistance to LLS and GRD and yield potential of selected groundnut genotypes that could be used in breeding programs. Thirty-eight groundnut genotypes were evaluated at the National Semi Arid Resources Research Institute (NaSARRI)-Serere, Eastern

**Corresponding author: E-mail: khalidelsiddig24@gmail.com;*

Uganda during the first and second seasons of 2015. The experiment was arranged in randomized complete block design with four replications. The results showed highly significant ($P < 0.01$) genotype-by-season interaction for most of the traits studied. There were significant differences among the genotypes for 100 seed weight ($P < 0.01$), and dry pod yield and unshelled sample of 100 pods at $P < 0.05$. Late leaf spot severity (at harvest), GRD incidence (at 12 weeks) and severity (at harvest) were significantly ($P < .01$) different and positively correlated with Area Under Disease Progress Curve (AUDPC). GRD severity at harvest showed highly significant ($P < 0.001$) negative correlation with shelling percentage. Both 100 seed weight and unshelled sample of 100 pod showed highly significant ($P < 0.01$) negative correlations with LLS at harvest, LLS AUDPC, GRD at 12 weeks, GRD AUDPC, and GRD severity. Genotypes susceptible to both LLS and GRD recorded the lowest 100 seed weight. Nine genotypes (Serenut.2, SGV 0001, SGV 0005, SGV 0006, SGV 0019, SGV 0071, SGV 0082, SGV 0083, and SGV 89751T) showed resistance to both diseases with high yield potential. These genotypes could be used to introgress resistance to both diseases in acceptable cultivars which are susceptible.

Keywords: Arachis hypogaea; mycosphaerella berkeleyi; variability; incidence; severity; breeding.

1. INTRODUCTION

Groundnut also knows as peanut (*Arachis hypogaea* L.) is an important oilseed crop belonging to the family Leguminosae. It is an essential crop both in subsistence and commercial farming systems in arid and semi-arid regions of the world [1]. Groundnut is mainly grown as oilseed, cash crop and animal feed [2]. It is the fourth-largest oilseed crop in the world [3]. with major producing countries being China, India, Indonesia, Myanmar and Vietnam in Asia; Nigeria, Sudan, Democratic Republic of Congo, Chad, Mozambique, Zimbabwe, Burkina Faso, Uganda, and Mali in Africa; USA in North America; and Argentina, Brazil and Mexico in Latin America and the Caribbean [4]. Africa contributes about 24.4% of world production of groundnut [5]. Yield per hectare in Eastern and South Central Africa averages 1,604 kg/ha, which is low compared to the 3,393 kg/ha and 3,801 kg/ha recorded in China and the United States of America, respectively [6]. Generally, yields of groundnuts grown by smallholder farmers in Africa are consistently low [7].

In Sub-Saharan Africa (SSA), the crop is grown in many countries by small-scale farmers for direct consumption as a food and as a cash crop [8]. The total production of SSA in 2003 was 8.2 million tons/year from 9.5 million hectares of land [9], which was less than 8% of the world output. Pressure from pests and diseases are among the main reasons behind the low on-farm yields in SSA [10].

Groundnut is a major staple food crop in Uganda, and has the highest return for labour input compared to other food crops [11]. Uganda was ranked number eight in Africa producing 175,000 tons on 236,000 hectares [5]. It is mainly grown in the eastern and northern parts of Uganda, but consumed widely throughout the country [2].

Production of groundnut in Uganda is constrained by various factors, chiefly among them being the late leaf spots (LLS) (*Mycosphaerella berkeleyi*) and groundnut rosette disease (GRD) caused by a virus complex – two viruses (groundnut rosette virus and groundnut rosette assistor virus) and a nucleic acid molecule known as satellite RNA. The two diseases are the most important foliar diseases of groundnuts accounting for major economic yield losses [2].

Yield losses from LLS of over 60% have been reported in Uganda [12]. Besides reducing yield, the disease also has an adverse effect on seed quality characteristics and quality of fodder which renders it unsuitable for use as animal feed. Groundnut rosette disease (GRD) is the most destructive disease to groundnut production and it can cause yield losses of up to 100% depending on the growth stage at which infection occurs [10]. According to Chintu [13], the GRD disease appears to be spreading to most African countries and may reach other parts of the world outside Africa. GRD occurs in fields of all groundnut growing regions of Uganda [14]. GRD usually occurs every growing season and its severity increases mostly in the crops grown late in the season [15]. Early GRD infection especially before flowering results in a severe or total yield loss [16].

Different levels of resistance to both LLS and GRD have been developed in numerous groundnut germplasm [14], however, there is

lack of information on characteristics of germplasm resistant to LLS and GRD and high yield potential. Hence, this study was conducted to identify sources of resistance to LLS, GRD and yield potential that could be introgressed into susceptible but adapted genotypes in the breeding programs.

2. MATERIALS AND METHODS

2.1 Planting Materials

The planting materials used in this study consisted of thirty-eight groundnut genotypes (Table 1), comprising released varieties and inbred lines developed for high yield and resistance to foliar diseases.

2.2 Experimental Sites

The experiment was conducted at the National Semi Arid Resources Research Institute (NaSARRI) in Serere (1°39'N and 33°27'E; 1038 m above sea level), during the first (April-August) and second (September-December) rainy seasons of 2015.

2.3 Experimental Design

All the experiments were carried out in a randomized complete block design (RCBD) with four replications each season. The size of the experimental plot was 3 x 2 m with 45 cm spacing between rows and 15 cm between plants within the rows. Spreader rows technique [17] was used to maximize late leaf spot (LLS) and groundnut rosette diseases (GRD) inoculum pressure under natural conditions using the groundnut line JL 24 which is highly susceptible to LLS and GRD. Spreader rows were planted after every two rows of test materials and at the border of the experiments to maintain the effective inoculum load. These rows were planted two weeks before planting the experimental materials. All recommended cultural practices were followed to ensure good crop stand.

2.4 Data Collection

2.4.1 Late leaf spot severity

Late leaf spot disease severity scoring was done at 28 and 56 days after planting (DAP) and at harvesting based on a rating scale of increasing severity of 1-9. Disease score 1 means 0% foliar infection; 2 for 1–5%; 3 for 6–10%; 4 for 11–20%; 5 for 21–30%; 6 for 31–40%; 7 for 41–60%; 8 for 61–80% and 9 for 81–100% of foliar area infection with plants having almost all leaves defoliated leaving bare stems [18]. Genotypes with a disease score 1-3 = resistant, 4–5= moderate resistance, 6–7 = susceptible and 8-9 = highly susceptible.

2.4.2 Groundnut rosette disease incidence and severity

Groundnut rosette disease incidence was assessed at 4, 8, and 12 weeks after planting and expressed as the percentage of plants infected with GRD over the total number of plants in the plot on a scale based on the percentage of disease incidence (PDI) to interpret genotype response according to Waliyar et al. [15], where; PDI of 0-10 (highly resistant), 11 – 30 PDI (Resistant), 31 – 50 PDI = moderately resistant and more than 50 PDI = susceptible. Disease severity was scored at 12 weeks after planting using a scale of 1-9 based on the intensity of disease attack [14], where 1-3 represented resistant with no or negligible leaf symptoms [where 1= resistant with no symptom, 2 = very slight leaf symptoms and 3 = slight leaf symptoms but still negligible]; 4-6 moderately resistant with leaf symptoms and no stunting [where 4 = showed 50% symptoms on leaves, 5 = all leaves showed symptom of chlorosis and 6 is 25% stunted]; 7-9 = susceptible [where all leaves showed symptom of chlorosis, 7 showed 50% stunted, 8 and 9 severe leaf symptoms with > 50% stunt where 8 = had few pods while 9 = no pod at all expected]. This rating scale was adopted from the Groundnut Improvement Programme at NaSARRI in Serere, Uganda (NaSARRI, unpublished).

2.4.3 Area under the disease progress curve (AUDPC)

The area under the disease progress curve (AUDPC) was calculated from the means of incidence and severity for LLS and GRD. The means were estimated using Microsoft Excel and AUDPC was calculated as described by Campbell and Madden [19] as follows:

$$\mathrm{AUDPC} = \sum_{i=1}^{n-1} \left(\frac{X_{i+1} + X_i}{2} \right) (t_{i+1} - t_i)$$

Where: X*i* = disease incidence at the *i*th observation, T*i* = time (days) at the *i*th observation n = total number of observations.

Table 1. Description of 38 groundnut genotypes screened for yield and resistance to late leaf spot (LLS) and groundnut rosette disease (GRD)

No.	Entry	LLS attribute	GRD attribute	Pedigree	Seed colour	No.	Entry	LLS attribute	GRD attribute	Pedigree	Seed colour
1	Abutalata	R	R	-	Tan	20	SGV 0076	R	MR	GWERINUT TAN X S.2	Tan
2	Erudu Red	MR	MR	86715 X S.2 (9th)	Red	21	SGV 0080	R	MR	GWERINUT TAN X S.2	Tan
3	Gwerinut.T	R	MR	-	Tan	22	SGV 0082	R	R	GWERINUT TAN X S.2	Tan
4	ICGV 01510	MR	MR	SPANISH D.V.T	Tan	23	SGV 0083	R	R	GWERINUT TAN X S.2	Tan
5	ICGV 03590	R	MR	SPANISH D.V.T	Tan	24	SGV 0084	R	MR	GWERINUT TAN X S.2	Tan
6	Serenut.1	R	MR	-	Red	25	SGV 89751T	R	R	-	Tan
7	Serenut.2	R	R	GWERINUT TAN X S.2	Red	26	SGV AW .S6	MR	MR	ACHOLI WHITE D.V.T	Reddish
8	Serenut.3	R	MR	86715 X S.2 (9th)	Red	27	SGV AWI. 0801	MR	MR	ACHOLI WHITE D.V.T	White
9	SGV 0001	R	R	S.1 X 89751	Tan	28	SGV AWI. 0802	MR	MR	ACHOLI WHITE D.V.T	Red
10	SGV 0003	R	R	S.1 X 89751	Tan	29	SGV AWI. 0803	R	MR	ACHOLI WHITE D.V.T	Cracks
11	SGV 0005	R	R	S.1 X 89751	Tan	30	SGV AWI. 0804	R	MR	ACHOLI WHITE D.V.T	Red striped
12	SGV 0006	R	R	S.1 X 89751	Tan	31	SGV ER 10001	R	MR	S.3 X ERUDU RED	Red
13	SGV 0007	MR	R	S.1 X 89751	Tan	32	SGV ER 10002	R	MR	S.3 X ERUDU RED	Red
14	SGV 0019	R	R	S.1 X 89751	Tan	33	SGV ER 10003	R	R	S.3 X ERUDU RED	Red
15	SGV 0023	R	R	S.1 X 89751	Tan	34	SGV ER 10004	MR	R	S.3 X ERUDU RED	Red
16	SGV 0029	R	MR	S.1 X 89751	Tan	35	SGV ER 10005	MR	MR	S.3 X ERUDU RED	Red
17	SGV 0071	R	R	GWERINUT TAN X S.2	Tan	36	SGV ER 10007	R	MR	S.3 X ERUDU RED	Red
18	SGV 0074	MR	R	GWERINUT TAN X S.2	Tan	37	SGV ER 10009	MR	R	S.3 X ERUDU RED	Red
19	SGV 0075	R	MR	GWERINUT TAN X S.2	Tan	38	SGV ER 10010	R	MR	S.3 X ERUDU RED	Red

R: Resistant; MR: Moderately resistant; D.V.T: District variety trials. Source: NaSARRI

2.4.4 Dry pod yield

Pods were collected from each plot at harvest and were weighed in Kg and converted to Kg/ha.

2.4.5 Unshelled sample of 100 pod

A sample of 100 pods was weighed in grams after pods were dried before shelling and data recorded.

2.4.6 Seed weight from 100 pod

Randomly collected 100 pods from each plot were shelled and seeds weighed in grams.

2.4.7 Shelling percentage

Randomly selected 100 g pods from each plot was weighed and recorded. Then the same pods were shelled by hand and kernels weighed and shells were also weighed. The shelling percentage was calculated by using the following formula:

$$\text{Shelling percentage} = \frac{\text{Total pod weight} - \text{shell weight}}{\text{Total pod weight in gram}} \text{ x } 100$$

2.4.8 100 seed weight (g)

Randomly selected 100 kernels from each plot separately was weighed and data recorded.

2.5 Data Analysis

All data were subjected to analysis of variance (ANOVA) using the GenStat computer package (14th edition (PC/windows 7). The mean, standard errors of the mean, as well as coefficients of variations, were calculated from the disease incidence and severity scores at 4, 8, 12 weeks and at harvest and yield component using ANOVA generated from the mGenStat. Where the ANOVA showed significant differences, the means were separated using least significant difference (LSD) at 5% significance level. The analysis used the liner model for RCBD as shown below:

$$y_{ij} = \mu + \tau_i + \beta_j + \epsilon_{ij}$$

Where: yij = Observation from the ith genotype and jth block, μ = Grand means, τ_i = effect of the ith genotype, β_j = jth block effect, ϵ_{ij} = experimental error.

3. RESULTS AND DISCUSSION

3.1 Phenotypic Variability

The results of analysis of variance among the 38 groundnut genotypes for late leaf spot (LLS), groundnut rosette disease (GRD) and yield parameters evaluated in two seasons are presented in Table 2. The results showed highly significant difference ($P < 0.01$) among genotype-by-season interaction for most of the traits studied. Significant differences were recorded for days to flowering, 100 seed weight ($P < 0.01$), dry pod yield and unshelled sample of 100 pod ($P < 0.05$). The genotypes were highly significantly ($P < 0.01$) different for seed weight from 100 pod and shelling percentage. The differences indicated the presence of high genetic variability in the genotypes Wambi, et al. [17] and Mugisa, et al. [20] for these traits.

The highly significant ($P < 0.01$) difference of genotype-by-season interactions for disease incidence, severity and AUDPC among the genotypes for all the yield traits studied and highly significant ($P < 0.01$) difference variance due to seasonal effect for most of the traits, these confirmed the existence of wide variation among genotypes and differential response of genotypes to the seasons. Similar finding were reported by Azharudheen and Gowda [21], who studied late leaf spot disease resistance and productivity traits (pod yield/plant, 100-seed weight and shelling %) in two seasons of 2009 and reported that, genotype x season was significantly ($p < 0.05$) different for LLS at 90 days, 100-seed weight and Shelling %. On the other hand Mugisa et al. [20] studied establishment of the factors influencing the occurrence and severity of GRD in Uganda and found that GRD disease incidence, severity and groundnut yields were significantly ($P < 0.05$) affected by interaction of genotype x season implying that these genotypes consisted of a source of high yielding and resistance to LLS and GRD for use for improvement of existing low yielding and susceptible groundnut varieties currently in use. The results also suggested that for the purpose of breeding, cultivars could be developed for different disease resistances in different seasons.

Table 2. Mean sum of squares for LLS and GRD incidence, severity, AUDPC and yield parameters for 38 groundnut genotypes evaluated in Serere season A and B, 2015

SOV	Df	DTF	LLS 4 Weeks	LLS8W	LLS At harvest	LLS AUDPC	GRD 4Weeks	GRD 8 Weeks	GRD 12 Weeks	GRD AUDPC	GRD severity	Dry pod yield Kg/ha	Unshelled sample of 100 pod	Seed wt from 100 pod	Shelling%	100 seed wt (g)
Rep	3	3.117	0.13	0.09	0.42	1584.1	5.18	6.7	9.51	14153	0.71	109630	30.5	24.9	47.87	17.72
Geno	37	73.059**	0.27**	1.19**	4.40**	10165.7**	36.08**	224.91**	652.14**	699053**	11.07**	5568688**	4547.2**	2135.4**	154.47**	666.7**
Season	1	29.69**	0.8421*	7.58**	13.90**	13932.1**	304**	2495.53**	3120.64**	4212153**	118.75**	18647484**	12572.5**	438ns	6360.15**	3429.1**
Geno. × season	37	4.63**	0.30**	0.63**	0.972**	2656.8**	16.09**	83.21**	305.62**	323890**	2.15**	507122*	340.8*	131.6ns	79.84ns	98.8**
Residual	225	2.41	0.14	0.27	0.31	796.2	4.65	30.28	43.58	45599	0.91	307798	220.2	113.3	74.08	52.4
mean		26.31	1.20	2.45	3.96	216.8	3.47	8.44	14.01	489.3	3.70	1515	109.1	64.71	59.75	42.04
Max		39	3	5	7	378	18	58	75	2212	9	3867	180	110	91.67	75
Min		20	1	1	2	126	1	1	4	140	1	100	40	20	27.27	10
CV%		5.9	30.9	21.1	14.1	13	62.2	65.2	47.1	43.6	25.8	36.6	13.6	16.4	14.4	17.2

*SOV: Source of variation; Df: Degree of freedom; LLS 4 w: Late leaf spot score at four weeks after planting; LLS 8 w: Late leaf spot score at eight weeks after planting; LLS at Harvest: Late leaf spot score at harvest; LLS AUDPC: Late leaf spot-Area under disease progress curve; GRD 4W: Groundnut rosette disease score at four weeks after planting; GRD 8 w: Groundnut rosette disease score at eight weeks after planting; GRD12W: Groundnut rosette disease score at twelve weeks after planting; GRD AUDPC: Groundnut rosette disease-Area under disease progress curve; GRD Severity: Groundnut rosette disease severity at harvest; Max: Maximum value; Min: Minimum value; ** = Significant at .01; * = Significant at .05.*

Table 3. Means and LSD for days to flowering, late leaf spot at 4, 8 weeks, at harvesting, area under disease progress curve and yield of 38 groundnut genotypes grown at NASARRI in season A and B of 2015

No.	Entry	DT50%F	LLS 4 w	LLS 8 w	LLS at Harvest	LLS AUDPC	GRD 4W	GRD 8 w	GRD12W	GRD AUDPC	GRD Severity	Dry Pod Yld kg/ha	Unshelled Sample of 100 pod	Seed Wt 100 pod	Shelling %	100 seed wt
1	Abutalata	37.75	1.00	2.63	3.63	194.20	1.25	2.25	5.88	200	2.88	882.00	54.50	32.94	62.01	42.00
2	Erudu Red	31.13	1.13	3.25	5.25	267.80	9.12	22.88	25.50	970	5.75	1286.00	75.62	47.79	62.67	27.15
3	Gwerinut.t	22.75	1.00	2.50	3.88	204.80	4.75	8.50	11.75	462	4.00	2188.00	126.25	79.04	63.53	50.40
4	ICGV 01510	24.50	1.38	3.00	5.13	273.00	4.12	11.63	30.75	977	5.25	1223.00	84.38	50.19	60.94	34.64
5	ICGV 03590	25.88	1.25	2.38	3.13	183.80	10.38	21.62	31.75	1180	5.13	2239.00	101.25	59.15	60.33	36.96
6	Serenut.1	25.50	1.00	1.75	3.13	173.20	3.50	7.25	31.62	984	4.38	1160.00	113.13	71.24	63.02	44.65
7	Serenut.2	23.63	1.25	2.13	3.13	183.80	2.88	4.38	7.00	277	2.38	1467.00	126.88	80.54	63.52	46.42
8	Serenut.3	30.38	1.25	2.25	3.88	215.20	1.75	7.13	10.13	333	3.75	798.00	93.75	53.16	56.56	32.74
9	SGV 0001	25.63	1.00	2.13	3.50	189.00	1.50	4.50	9.25	301	2.63	1744.00	127.50	66.34	52.44	41.89
10	SGV 0003	26.13	1.25	2.38	3.88	215.20	2.38	4.25	7.38	273	2.38	2821.00	136.25	78.95	58.45	48.84
11	SGV 0005	25.25	1.00	1.75	3.00	168.00	2.38	5.63	9.00	319	2.38	2823.00	137.50	82.74	60.62	50.19
12	SGV 0006	26.50	1.13	2.38	3.88	210.00	3.00	8.50	13.63	466	2.63	1671.00	132.50	81.49	61.65	51.82
13	SGV 0007	27.00	1.75	3.25	5.13	288.80	2.38	5.38	8.50	305	2.38	1588.00	125.62	80.13	64.91	51.56
14	SGV 0019	26.88	1.13	2.25	3.50	194.20	3.12	5.88	10.88	392	2.75	2379.00	136.25	81.56	59.96	48.17
15	SGV 0023	26.13	1.00	2.38	3.50	189.00	2.50	3.88	9.13	326	3.00	2401.00	126.88	75.40	59.86	51.00
16	SGV 0029	25.75	1.25	2.25	3.50	199.50	2.25	8.38	12.25	406	3.75	1326.00	140.00	81.11	58.31	48.99
17	SGV 0071	22.75	1.00	2.25	3.75	199.50	3.62	6.88	10.00	382	3.13	2416.00	121.88	75.36	61.70	48.30
18	SGV 0074	25.13	1.50	2.88	5.00	273.00	4.62	6.00	10.75	431	2.50	2202.00	127.50	81.90	64.91	53.34
19	SGV 0075	24.75	1.13	2.63	3.75	204.80	5.25	8.75	11.63	473	3.75	2394.00	126.88	79.68	62.88	50.56
20	SGV 0076	25.13	1.25	2.63	3.75	210.00	4.38	6.88	10.63	420	3.63	2642.00	126.88	80.78	64.00	47.64
21	SGV 0080	24.38	1.13	2.38	3.63	199.50	4.75	7.13	13.62	515	3.50	2633.00	113.75	70.53	62.34	48.30
22	SGV 0082	24.25	1.13	2.38	3.63	199.50	4.00	5.38	8.50	350	3.13	2111.00	129.38	81.34	63.80	53.67
23	SGV 0083	23.13	1.13	2.38	3.88	210.00	2.88	5.25	8.88	329	3.25	2026.00	135.00	83.76	62.69	52.21
24	SGV 0084	26.38	1.25	2.63	3.88	215.20	2.25	5.63	13.63	445	3.50	2756.00	129.38	78.95	62.02	51.37
25	SGV 89751T	25.13	1.25	2.25	3.63	204.80	2.00	4.88	8.63	298	2.38	2317.00	132.50	86.60	66.01	52.25
26	SGV AW. S6	22.50	1.75	3.00	4.50	262.50	6.12	15.50	32.62	1085	5.75	692.00	105.63	52.50	50.32	42.50
27	SGV AWI. 0801	23.13	1.13	2.75	4.63	241.50	8.00	20.12	36.88	1256	6.25	246.00	70.25	38.75	57.35	28.75
28	SGV AWI. 0802	22.63	1.38	2.75	4.63	252.00	5.75	20.00	34.88	1138	5.13	423.00	83.75	54.38	66.89	30.62
29	SGV AWI. 0803	23.63	1.25	1.88	3.00	178.50	1.88	15.50	34.38	1015	6.00	429.00	88.12	44.38	50.70	31.25

No.	Entry	DT50%F	LLS 4 w	LLS 8 w	LLS at Harvest	LLS AUDPC	GRD 4W	GRD 8 w	GRD12W	GRD AUDPC	GRD Severity	Dry Pod Yld kg/ha	Unshelled Sample of 100 pod	Seed Wt 100 pod	Shelling %	100 seed wt
30	SGV AWI. 0804	24.88	1.00	1.50	2.63	152.20	2.88	7.88	32.50	991	5.75	294.00	88.12	53.75	60.97	34.37
31	SGV ER 10001	28.25	1.38	2.50	4.25	236.20	1.88	5.13	12.88	413	3.50	594.00	96.25	52.39	54.56	36.70
32	SGV ER 10002	29.13	1.25	2.38	3.75	210.00	1.25	4.00	13.25	406	3.75	608.00	101.25	52.10	51.29	37.15
33	SGV ER 10003	28.75	1.13	2.63	3.00	173.20	2.00	5.25	9.50	322	3.00	563.00	94.38	50.74	59.11	34.45
34	SGV ER 10004	28.75	1.25	2.38	5.13	267.80	1.50	4.50	7.00	238	2.63	1117.00	103.13	53.90	52.43	34.96
35	SGV ER 10005	29.38	1.25	3.00	5.50	283.50	3.25	12.88	36.12	1102	4.88	955.00	52.50	31.25	60.02	18.34
36	SGV ER 10007	28.88	1.25	2.38	4.00	220.50	1.63	5.38	12.50	396	3.63	615.00	96.25	53.79	56.62	36.77
37	SGV ER 10009	28.88	1.25	2.75	5.25	273.00	2.50	6.75	10.25	357	2.63	650.00	95.62	50.48	54.95	34.85
38	SGV ER 10010	29.38	1.00	2.38	4.25	220.50	2.12	9.25	11.38	378	3.75	882.00	88.75	50.01	56.23	31.57
	LSD	5.90	0.52	0.72	0.78	39.32	3.00	7.67	8.37	273.1	1.33	773.10	20.68	14.83	11.99	10.09

No: Number; DT50%F: Days to 50% flowering; LLS 4 w: Late leaf spot score at four weeks after planting; LLS 8 w: Late leaf spot score at eight weeks after planting; LLS at Harvest: Late leaf spot score at harvest; LLS AUDPC: Late leaf spot-Area under disease progress curve; GRD 4W: Groundnut rosette disease score at four weeks after planting; GRD 8 w: Groundnut rosette disease score at eight weeks after planting; GRD 12W: Groundnut rosette disease score at twelve weeks after planting; GRD AUDPC: Groundnut rosette disease-Area under disease progress curve; GRD Severity: Groundnut rosette disease severity at harvest.

Table 4. Correlation of diseases incidence, severity, AUDPC and agronomic traits

Traits	DT50% F	LLS 4 w	LLS 8w	LLS At harvest	LLS AUDPC	GRD 4 w	GRD 8 w	GRD 12 w	GRD AUDPC	GRD severity	Seed wt of 100 pod	Shelling%	Unshelled 100 pod wt	100 seed wt	Dry pod yld kg/ha
DT50%F	-														
LLS 4 w	-0.022	-													
LLS 8w	0.050	0.422**	-												
LLS At harvest	0.162*	0.176**	0.468**	-											
LLS AUDPC	0.131*	0.526**	0.563**	0.930**	-										
GRD 4 w	-0.195**	0.022	0.233**	-0.031	-0.019	-									
GRD 8 w	-0.174*	0.036	0.275**	-0.002	0.012	0.716**	-								
GRD 12 w	-0.232**	0.053	0.130*	-0.003	0.018	0.525**	0.758**	-							
GRD AUDPC	-0.244**	0.051	0.164**	-0.009	0.011	0.674**	0.814**	0.983**	-						
GRD severity	-0.182*	0.016	0.177**	-0.089	-0.071	0.511**	0.654**	0.710**	0.728**	-					
Seed wt of 100 pod	-0.346**	0.018	-0.113*	-0.177**	-0.146*	-0.080	-0.289**	-0.406**	-0.370**	-0.418**	-				
Shelling%	-0.079	-0.026	-0.017	0.071	0.052	-0.067	-0.131*	-0.106	-0.107	-0.229**	0.422**	-			
Unshelled 100 pod wt	-0.335**	0.030	-0.109	-0.242**	-0.198**	-0.033	-0.225**	-0.380**	-0.337**	-0.312**	0.827**	-0.123*	-		
100 seed wt	-0.238**	0.074	-0.056	-0.284**	-0.218**	-0.003	-0.210**	-0.341**	-0.297**	-0.278**	0.718**	0.067	0.740**	-	
Dry pod yld kg/ha	-0.169**	-0.106	-0.087	-0.075	-0.105	-0.060	-0.314**	-0.411**	-0.370**	-0.410**	0.600**	0.281**	0.476**	0.419**	-

DT50%F: Days to 50% flowering; LLS 4 w: Late leaf spot score at four weeks after planting; LLS 8 w: Late leaf spot score at eight weeks after planting; LLS at Harvest: Late leaf spot score at harvest; LLS AUDPC: Late leaf spot-Area under disease progress curve; GRD 4W: Groundnut rosette disease score at four weeks after planting; GRD 8 w: Groundnut rosette disease score at eight weeks after planting; GRD12W: Groundnut rosette disease score at twelve weeks after planting; GRD AUDPC: Groundnut rosette disease-Area under disease progress curve; GRD Severity: Groundnut rosette disease severity at harvest; Dry Pod Yld kg/ha: Dry pod yield kilo gram per hectare; Unshelled Sample of 100 pod: Unshelled Sample of hundred pods; Seed Wt 100 pod: Seed weight of hundred pods; Shelling%: Shelling percentage; 100 seed wt: Hundred seed weight

3.2 Disease Intensity, Resistance and Yield Potential

Diseases incidence, severity and AUDPC for LLS and GRD and the yield traits for groundnut genotypes grown at Serere during first and second raining season of 2015 are presented in Table 3. The score of LLS at 4 and 8 weeks ranged between 1 (Abutalata, Gwerinut.T, Serenut. 1, SGV 0001, SGV 0005, SGV 0023, SGV 0071, SGV AWI. 0804 and SGV ER 10010) and 3.25 (Erudu Red and SGV 0007) indicating that these genotypes were resistant [18] at the early stages of growth, suggesting that while the plants are growing up, the pathogen is non-infective and the pathogen becomes aggressive later, in the growth cycle of the crop and then the resistant genotypes will remain healthy and the susceptible cultivars will collapse [22]. LLS disease severity at harvest ranged between 2.63 (SGV AWI. 0804) and 4.00 (SGV ER 10007). The lowest AUDPC (152.20) was recorded for genotype SGV AWI. 0804, while SGV 0007 showed the highest AUDPC (288.80) indicating that the resistant genotypes had low AUDPC which is antithesis to the susceptible ones. Watson et al. [23] in their study of the etiological mechanisms of LLS resistance observed slow disease progress in two resistant genotypes than in susceptible ones.

Significant differences in GRD incidence, severity and AUDPC were recorded for the interaction of the genotype x season (Table 2). All the genotypes were significantly ($P < 0.01$) different and resistant to GRD up to 12 weeks except, ICGV 01510, Serenut.1, ICGV 03590, SGV AWI. 0804, SGV AW .S6, SGV AWI. 0803, SGV AWI. 0802, SGV ER 10005 and SGV AWI. 0801, which were moderately susceptible (Table 3). Shelling percentage was highly significantly ($p < 0.001$) affected by genotypes and seasons but not genotype-by-season interaction. The highest shelling percentage was exhibited by SGV AWI. 0802 (66.89%) while the lowest was exhibited by SGV AW.S6 (50.32%), indicating that high yielding and shelling property potentials were present in these genotypes. Chintu, [13] reported similar results for resistance to rosette disease and its aphid vector in groundnut. Low yield performance was observed on the non-resistant genotypes Table 3. The lowest 100 seed weight (ranging between 18.34 and 30.62) was recorded by SGV ER 10005, Erudu Red, SGV AWI. 0801 and SGV AWI. 0802. These genotypes were moderately susceptible to both LLS and GRD. The reductions may be attributed to the reduced photosynthetic efficiencies due to infection by the two diseases [24]. The diseases were severely aggressive in the field in the two seasons and Serere was considered as a hot spot for the LLS and GRD diseases [14]. Forrest et al. [25], reported that severe infection of Cercospora leaf spot disease significantly reduced the dry weight and greatly reduced the photosynthetic surface of the crop resulting in a serious loss of yield potential. Similarly GRD is known to dramatically reduce the vegetative growth of the plant, thus decrease the yield potential through reduction of dry weight of GRD infected groundnut plant [26]. The results suggested that as the incidence and severity of the diseases increased, the yield decreased significantly through the significant negative effects of the diseases on both the morphological and reproductive growth of the plants [27]. Thirteen genotypes (Abutalata, Serenut.2, SGV 0001, SGV 0003, SGV 0005, SGV 0006, SGV 0019, SGV 0023, SGV 0071, SGV 0082, SGV 0083, SGV 89751T, and SGV ER 10003) showed resistance to both LLS and GRD diseases but five of these cultivars exhibited relatively low yield performance (Table 3) suggesting that this could be attributed to yield penalty associated with resistance to LLS and GRD due to the plants spending energy to express the genes of resistance which makes the plant direct most of its nutrients resources into resistance instead of yield [28].

3.3 Interrelationships among Diseases Indexes, Yield and Yield Traits

The results of correlation analysis among the traits studied are presented in Table 4. AUDPC for LLS and GRD showed highly significant ($P < 0.01$) positive correlation with LLS severity at harvest, GRD incidence up to 12 weeks and GRD severity at harvest. This was expected since LLS and GRD are complex and epidemic diseases [7]. Similar results were obtained by Orondo et al. [29] for AUDPC of crop resistance to rosette and leaf spot.

GRD severity at harvest showed highly significant ($P < 0.01$) negatively weak correlation ($r = -0.229$) with Shelling%, indicating that

GRD severity at harvest affected the shoot growth which reflected on the pods and shelling %. Sylvanus [30] reported similar findings in which there was a reduction in shelling percentage due to complete defoliation of the groundnut leaves at all growth stages. Unshelled sample of 100 pod showed highly significant ($P < 0.01$) negative correlation with LLS at harvest, LLS AUDPC, GRD at 8 and 12 weeks, GRD AUDPC, and GRD severity with values of -0.242, -0.198, -0.225, -0.380, -0.337, and -0.312 respectively. 100 seed weight showed highly significant ($P < 0.01$) negative correlation with the same disease parameters with values of -0.284, -0.218, -0.210, -0.341, -0.297 and -0.278 respectively. On the other hand, dry pod yield kg/ha showed highly significant ($P < 0.001$) negative correlation with GRD at 8 weeks ($r = -0.314$), GRD at 12 weeks ($r = -0.411$), GRD AUDPC ($r = -0.370$), and GRD severity ($r = -0.410$). These results showed that the association between yield traits and diseases were highly significant ($P < 0.01$) negatively correlated indicating that LLS and GRD highly contributed to the yield reduction since the plant leaf area was negatively affected as the diseases developed [31]. The loss of leaf area at any stage of the crop growth resulted in the reduction of net photosynthetic area in which the higher the degree of defoliation the more the loss in seed yield and production [32].

4. CONCLUSION

There was variation in the disease reaction and yield traits among the 38 groundnut genotypes which could be used in selecting parental lines for improving yields and resistance to the late leaf spot and groundnut rosette diseases. Low yield was observed on the non-resistant genotypes which was attributed to the reduced photosynthetic capacity of the plant due to LLS and GRD infection. Nine genotypes (Serenut.2, SGV 0001, SGV 0005, SGV 0006, SGV 0019, SGV 0071, SGV 0082, SGV 0083, and SGV 89751T) displayed resistance to both LLS and GRD diseases and could be used to introgress the diseases resistance into susceptible accepted market class groundnut cultivars.

ACKNOWLEDGEMENTS

We acknowledge the support of the Regional Universities Forum for Capacity Building in Agriculture (RUFORUM), SHARE Intra-ACP, Carnegie Corporation of New York and the groundnut breeding team at the National Semi Arid Resources Research Institute (NaSARRI, Uganda) for the funding and support.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Thakur SB, Ghimire SK, Shrestha SM, Chaudhary NK, Mishra B. Variability in groundnut genotypes for tolerance to drought. Nepal Journal of Science and Technology. 2013;14(1):41–50.
2. Okello DK, Monyo E, Deom CM, Ininda J, Oloka HK. Groundnuts production guide for Uganda, recommended practices for farmers. National Agricultural Research Organization, Entebbe; 2013.
   ISBN: 978-9970-401-06-2
3. Kochert G, Stalker TH, Gimenes M, Galgaro L, Romero Lopes C, Moore K. RFLP and cytogenetic evidence on the origin and evolution of allotetraploid domesticated peanut, *Arachis hypogaea* (*Leguminosae*). American Journal of Botany. 1996;83:1282-1291.
4. Dwivedi SL, Pande S, Rao JN, Nigam SN. Components of resistance to late leaf spot and rust among interspecific derivatives and their significance in a foliar disease resistance breeding in groundnut (*Arachis hypogaea* L.). Euphytica. 2003;125:81–88.
5. FAOSTAT. (Food and Agriculture Organization Statistical Database); 2013.
   Available:http://faostat.fao.org/site/567/default.aspx
6. FAO STAT.
   Available:http://faostat.fao.org/
   (Accessed on 20th April 2014)
7. Richard ADU Amoah. Inheritance of resistance to rosette virus disease in groundnut (*Arachis hypogaea* L.). Thesis. Kwame Nkrumah University of Science and Technology; 2015.
8. Amoah RA. Inheritance of resistance to rosette virus disease in groundnut (*Arachis hypogaea* L.). University of Science and Technology Kumasi, Ghana; 2015.

9. Yussif IJ, Kwoseh C, Mahama O, Kwabena A, Yirzagla J. Farmers' perception and farming practices on the effect of early and late leaf spots on groundnut production in northern Ghana. Journal of Biology, Agriculture and Healthcare. 2014;4(19): 22–29.
10. Okello DK, Biruma M, Deom CD. Overview of groundnut research in Uganda past present and future. Africa Journal Biotechnology. 2010;9:6448-6459.
11. Kassie M, Shiferaw B, Muricho G. Agricultural technology, crop income and poverty alleviation in Uganda. World Development. 2011;39:1784–1795.
12. Mugisha J, Ogwalo R, Ekere W, Ekiyar V. Adoption of IPM groundnut production technologies in eastern Uganda. African Crop Science Journal. 2004;12:383-391.
13. Chintu JMM. Breeding groundnut for resistance to rosette disease and its aphid vector, *Aphis craccivora* Koch in Malawi by. University of Kwa Zulu-Natal Pietermaritzburg Republic of South Africa; 2013.
14. Okello DK, Okori P, Puppala N, Ureta BB, Deom CM, Ininda J, Anguria P, Biruma M, Asekenye C. Groundnuts seed production manual for Uganda. National Agricultural Research Organisation, Entebbe; 2014. ISBN: 978-9970-401-12-3
15. Waliyar F, Kumar PL, Ntare BR, Monyo ES, Nigam SN, Reddy AS, Osiru M, Diallo AT. A century of research on groundnut rosette disease and its management. Information Bulletin no. 75, International Crops Research Institute for the Semi-Arid Tropics, Patancheru. Andhra Pradesh, India. 2007;40.
16. Naidu RA, Kimmins FM. The effect of groundnut rosette assistor virus on the agronomic performance of groundnut (*Arachis hypogaea* L.) genotypes. Journal of Phytopathology. 2007;155:350-356.
17. Wambi W, Tukamuhabwa P, Puppali N, Okello DK, Nalugo RG, Kaaya NA. Narrow sense heritability and gene effects for late leaf spot resistance in valencia groundnuts. African Crop Science Journal. 2014;22:327–336.
18. Subrahmanyam PD, Donald M, Waliyar FR, Nigam LJ, Gibbons SN, Rao RW, Singh VR, Pande AKS, Reddy PM, Rao SPV. Screening methods and sources of resistance of rust and late leaf spot of groundnut. Inf. Bull. ICRISAT, Patancheru, Andhra Pradesh, India. 1995;47:19.
19. Campbell CL, Madden LV. Introduction to plant disease epidemiology. Wiley, New York, USA. 1990;532.
20. Mugisa IO, Karungi J, Akello B, Ochwo-Ssemakula MKN, Biruma M, Okello DK, Otim G. Determinants of groundnut rosette virus disease occurrence in Uganda. Crop Protection. 2016;79:117-123.
21. Azharudheen TPM, Gowda MVC. An assessment of the prospects of developing confectionery grade genotypes with multiple disease resistance in groundnut (*Arachis Hypogaea* L.). 2013;4(4):347-354.
22. Agrios GN. Plant pathology. 5th ed. Elsevier Academic Press. Burlington, MA, USA; 2005.
23. Watson GR. Levels and components of late leaf spot caused by *Cercosporidium personatum* (Berk and Curt.) Dighton in the peanut (*Arachis hypogaea* L.) genotypes Florunner, Southern Runner and UF81206. Dissertation Abstract International, B (Science and Engineering). 1988;48:2171-2178.
24. Funayama S, Sonoike K, Terashima I. Photosynthetic properties of leaves of Eupatorium makinoi infected by a geminivirus. Photosynth. Res. 1997; 53:253-261.
25. Forrest W, Nutter J, Robert H, Littre LL. Relationship between defoliation, canopy reflectance and pod yield in the peanut late leaf spot pathosystem. Crop Protection. 1996;15(2):135- 142.
26. Wilson CR. Applied plant virology. CABI Press, Wallingford, UK; 2014.
27. Usman A. Genetic analysis of resistance to rosette disease of groundnut (*Arachis hypogaea* L.). PhD Thesis. University of Ghana, Legon. Ghana; 2013.
28. Nigam SN, Dwivedi SL, Rao YLC, Gibbons RW. Registration of ICGS-1 peanut cultivar. Crop Science. 1991;31(5):1382-1383.
29. Orondo SGOK, Mudehe M, Rachier GO, Mburu M, Ochebo R. Screening groundnuts groups Virginia, Valencia and Spanish for rosette and leaf spot resistance and yield performance. 2007;9-11.
30. Sylvanus U Joseph. Effect of defoliation on the growth and seed yield of four groundnut (*Arachis hypogaea* l.) cultivars.

Ahmadu bello University, Zaria Nigeria. 2014;15004:10-11.
31. Burdon JJ. Diseases and plant population biology. Cambridge University Press. Cambridge; 1987.
32. Wilkerson GG, Jones JW, Poes SL. Effect of defoliation on peanut plant growth. Journal of Crop Science. 1984;24(3):526-531.

Peer-review history:
The peer review history for this paper can be accessed here:
http://www.sciencedomain.org/review-history/23776