Yield Stability and Resistance to Leaf Spot Diseases and Rosette in Groundnut

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Abstract: Twenty-three advanced groundnut lines were evaluated for yield and resistance to early leaf spot (*Mycosphaerella arachidis* Deighton), late leaf spot (*Mycosphaerella berkeleyi* W.A. Jenkins) and rosette virus in on-station trials in 2001 and 2002. All the early groundnut lines were relatively resistant to rosette virus, early leaf spot and late leaf spot except ICGV-SM-93523 and ICGV-SM-93525, which were susceptible to late leaf spot. The medium maturing lines showed mostly higher levels of diseases, except MS16-791, which performed very well against all three diseases. The late groundnut lines were mostly susceptible to one or more of the diseases, except 49-85A and ICGV-SM-93532. Nine groundnut lines, combining high yield and resistance against all three diseases, were selected for on-farm trials at four locations in 2004 and 2005. In the on-farm trials all the nine selected lines were also resistant or highly resistant to rosette and both early and late leaf spot, while the local check, Makodi, was susceptible to all three diseases in both the on-station and on-farm trials. The analysis of yield data obtained at the eight environments, based on the linear statistical model $y_{ij} = \mu + a_i + e_j + r_{ij}$, estimated the genetic variance about three times higher than the residual variance. Still better results were obtained with the multiplicative model $y_{ij} = \mu a_i b_j + e_j + r_{ij}$, where the genetic variance was more than four times higher than the residual variance and a still better differentiation of cultivars was thus possible. Significant differences in cultivar stability, expressed as the variation coefficient of the a_i estimates (i.e. the variation of Standardised Relative Yields) from the multiplicative model across the eight environments, were observed. The check cultivar Makodi, though quite stable, was the lowest yielding of all tested ones. The groundnut line ICGV-1S-96805 combined very high yielding capacity and outstanding disease resistance with good, though not the highest, yield stability.

Keywords: *Arachis hypogea* L.; yielding capacity; multiplicative model; leaf spot; rosette virus; selection

Groundnut (*Arachis hypogea* L.) is an economically valuable oilseed and cash crop grown extensively in the savannah region of Nigeria. It is cultivated for direct consumption as food and for industrial use. The export of groundnuts accounted for 22% of the national annual export value between 1962 and 1972 (Abalu 1976). This made Kano city famous for its groundnut pyramids. Later on, the production started to decline from peak productions of the 1960s due to severe biotic constraints, which included diseases caused by fungi and viruses.

The leaf spot diseases, caused by early leaf spot (*Mycosphaerella arachidis* Deighton) and late leaf spot (*Mycosphaerella berkeleyi* Jenkins, for many synonyms see Kirk 2004), are economically the most important fungal diseases of groundnut in Nigeria and worldwide. In most areas, both diseases occur together but the incidence and severity of each disease vary with environment and cultivars (Pande & Rao 2001). The leaf spot diseases can cause 30%–70% loss in pod yield and reduction in the kernel quality (Reddy *et al.* 1997). Early leaf spot alone can cause 35%–50% defoliation at the peak flowering stage and yield losses may reach 20%–25% (Mehan & Hong 1994). The relative importance of each disease varies from place to place and from season to season, depending on the cropping system and the environmental conditions.

The rosette is another devastating disease for the productivity of groundnut. Groundnut rosette is caused by the groundnut rosette virus (GRV) and the groundnut rosette assistor virus (GRAV) (Reddy *et al.* 1995; Murant *et al.* 1998). The disease is transmitted by *Aphis craccivora* Koch. Murant *et al.* (1991) showed that the GRV resistant lines they tested were fully susceptible to GRAV. This indicates that the virulence of the two pathogens has a different genetic basis. According to Alegbejo (1997), groundnut rosette virus (GRV) is the most destructive disease of groundnut. The rosette virus disease can cause considerable losses on groundnut. In association with drought, the virus can cause yield losses of up to 100% (Van Der Merwe & Subrahmanyan 1997).

In controlling the two major diseases, leaf spot and rosette, host-plant resistance is considered the most cost-effective control measure. The identification and utilization of stable resistance is of high priority. Therefore, the purpose of the study was to identify groundnut lines with broad-spectrum resistance to leaf spot diseases and rosette combined with high yield and yield stability.

MATERIALS AND METHODS

On-station trials

The on-station trial was sited at the experimental station of the National Cereals Research Institute, Badeggi, Niger state of Nigeria, located at 09°04N and 06°08E, with annual rainfall of 1104 mm. Twenty-three groundnut lines, obtained from the Institute of Agricultural Research at Samaru in Nigeria, were evaluated in the 2001 and 2002 cropping seasons. Farmers' groundnut line (Makodi) was used as a check. The lines were planted on 4-row plots of 5 m × 2.25 m (11.25 m^2), within a randomized complete block design (RCBD) with three replications. The plants were within the rows in groups of two plants, with 20 cm distance between the groups. Weeding (hoeing) and fertilizer application of superphosphate at the rate of 26.22 kg P/ha were done in two and three weeks after planting, respectively.

Data were collected in both years on days to 50% flowering, days to physiological maturity, incidence of early and late leaf spot disease using a 1–9 scale (1 = highly resistant), percentage of rosette-infected plants and yield of dry pods (kg/ha). Since the data from both years were highly correlated, as seen in Table 2, only the mean values from both years will be presented.

On-farm trials

The experiment was conducted at four locations, described in Table 1.

From the 23 lines, tested on-station, nine lines with the lowest incidence of the three diseases and the highest pod yield were selected. Seeds of these genotypes were multiplied and distributed to selected farmers at the four locations in 2004 and 2005 for comparative on-farm evaluation. A plot of the size 10 m × 20.25 m was marked out on each farmer's field. Each groundnut line was planted on four 10 m long ridges with inter-row spacing of 75 cm and intra-row spacing of 20 cm, without replication. Single super phosphate fertilizer was applied at the rate 26.22 kg P/ha during planting. Data were collected on incidence of leaf spot diseases, rosette and dry pod yield.

Statistical analysis

The aim of the analysis was to explore genetically based differences in yielding capacity, yielding sta-

Table 1. Description of sites where on-farm trials were performed

Locality	Ecological savannah zone	Geographic location	Soil type	Annual rainfall (mm)
Jigawa	Sudan	12°20N, 09°40E	Ferruginous	705
Kano	Sudan	11°40N, 08°02E	Ferruginous	900
Kaduna	Northern Guinea	10°26N, 07°38E	Ferruginous	1000
Niger	Southern Guinea	09°05N, 06° 08E	Ferrisols	1104

Table 2. Two year means of earliness, disease scores and yield at on-station trials

Entry	Days to		Rosette (%)	Leaf spot*		Pod yield (kg/ha)
	flowering	maturity		early	late	
Early lines						
ICGV-1S-96801	26.0	90.0	31.5	1.0	1.0	1244.0
ICGV-1S-96806	23.5	87.5	6.5	1.0	1.0	1070.0
ICGV-1S-96802[1)]	**24.5**	**87.0**	**2.0**	**1.0**	**1.0**	**1150.0**
IGCV-1S-93518	25.0	90.5	4.0	2.5	1.0	950.0
IGCV-SM-96805	**25.0**	**88.0**	**0.0**	**1.0**	**1.0**	**1066.5**
IGCV-SM-93534	**25.5**	**91.0**	**1.0**	**1.0**	**4.0**	**1287.5**
IGCV-SM-93523	24.0	90.0	2.0	3.5	5.0	1157.5
IGCV-SM-93528	23.0	89.5	2.5	2.5	1.0	901.0
IGCV-SM-94583	**21.5**	**84.0**	**0.0**	**1.0**	**1.0**	**1293.0**
IGCV-SM-93525	24.0	86.5	3.0	1.0	6.0	1262.5
Medium lines						
IGCV-1S-96803	31.0	95.0	58.5	2.5	7.0	784.5
MS16-791	**33.5**	**98.0**	**0.0**	**2.0**	**1.0**	**1316.0**
MS54-76	32.0	96.5	37.5	2.5	3.5	788.5
ICGV-1S-96844	33.0	98.5	10.0	4.0	5.0	1011.0
ICGV-SM-96846	**30.5**	**95.0**	**7.5**	**3.0**	**1.5**	**1133.8**
UGA-2	32.0	97.0	0.5	2.5	4.0	950.0
Late lines						
ICGV-MS-96701	43.1	105.0	40.5	5.0	1.5	966.5
49-85A	**42.1**	**105.0**	**9.0**	**0.0**	**1.0**	**1102.5**
RMP-12	43.1	104.0	48.0	2.0	4.0	559.0
249-85	**42.1**	**102.0**	**12.5**	**1.5**	**1.0**	**1032.5**
ICGV-SM-93532	**43.1**	**102.0**	**2.5**	**2.0**	**2.5**	**1049.0**
59-85	40.1	110.0	41.5	1.0	4.0	1003.0
Makodi	45.1	114.0	59.5	6.0	5.0	533.5
Mean	31.84	95.91	16.52	2.15	2.74	1026.6
Correlation between 2001 and 2002	0.95	0.99	0.92	0.96	0.87	0.89
Residual variance	0.86	0.74	36.49	0.26	0.68	5609

[1)]Groundnut lines in bold letters were selected for on-farm trials;
*on 1–9 scale (1 = highly resistant)

bility and disease resistance across environments. Since the on-farm trials were non-replicated, all eight combinations of year and location were regarded as different environments. A two-way analysis of variance (ANOVA) was performed and from the expectations of mean squares estimates of variance components were calculated. Two statistical models were used:

(a) the usual linear model $y_{ij} = \mu + a_i + e_j + r_{ij}$,

where:

y_{ij} – actual yield
μ – general mean
a_i – effect of cultivar i
e_j – effect of environment j
r_{ij} – residual effect

(b) the multiplicative model $y_{ij} = \mu a_i b_j + e_j + r_{ij}$,

where:

a_i – multiplicative effect of cultivar i
b_j – multiplicative effect of environment j

The a_i estimates in (b) were calculated as described by Schwarzbach *et al.* (2007), by standardization of the data through division by the local standard deviation, calculation of location effects and subtraction of these from the standardized data. The matrix of the a_i estimates has then zero location effects and their variances within environments are homogeneous. To visualise the multiplicative cultivar effects in practical units familiar to breeders, the a_i estimates were converted to percents of the general mean. Standardised relative yields (SRY) were so obtained, fitting the model (b). Since the residual variance of the raw data, containing all interaction and error effects, was much smaller than the genetic variance and the yield level in all eight environments was similar, the calculation of regression coefficients of cultivar yields to location means would not make sense. Therefore, the variability of the SRY was used as a practical measure of yield stability in understandable units. Because the variance of relative yields is related to the average relative yield (Hühn 1995), the variation coefficient of the SRY across environments was used to express the stability of the tested groundnut lines. For comparison, the residual variance of individual cultivars across environments, known as "stability variance" (Shukla 1972), was calculated from the raw data. To be comparable to the variability of SRY, it was also converted to variation coefficients (see Table 5).

RESULTS AND DISCUSSION

The results of the on-station evaluation of the twenty-three advanced groundnut lines at the National Cereals Research Institute (N.C.R.I.), Badeggi in 2001 and 2002 are presented in Table 2. The groundnut lines were grouped into three maturity classes: early, medium and late. All the early lines were relatively resistant to the three diseases, except ICGV-SM-93523 and ICGV-SM-93525, which were susceptible to late leaf spot. The medium maturing groundnut lines showed mostly higher levels of the diseases infestation, except

Table 3. Disease resistance and mean dry pod yield of nine groundnut lines in on-farm trials

Groundnut line	% Rosette					Early leaf spot*					Late leaf spot*					Mean yield (kg/ha)
	JIG	KAD	KAN	NIG	mean	JIG	KAD	KAN	NIG	mean	JIG	KAD	KAN	NIG	mean	
ICGV-1S-96805	0	0	0	2	0.5	1	1	1	1	1.0	1	2	2	1	1.5	1446.0
ICGV-SM-96846	10	6	20	10	11.5	2	1	3	3	2.3	3	3	2	3	2.8	1421.8
ICGV-SM-94583	0	0	0	0	0.0	1	1	1	2	1.3	1	2	1	2	1.5	1392.3
ICGV-SM-93534	0	0	0	0	0.0	1	1	2	1	1.3	3	3	3	2	2.8	1385.8
MS16-791	0	0	0	1	0.3	1	1	1	1	1.0	3	1	2	1	1.8	1385.8
249-85	0	1	0	8	2.3	1	1	1	1	1.0	1	1	1	1	1.0	1222.3
ICGV-1S-96802	10	8	10	5	8.3	1	1	2	1	1.3	3	1	2	1	1.8	1210.0
49-85A	10	10	10	3	8.3	1	1	1	2	1.3	2	1	0	1	1.0	1151.8
ICGV-SM-93532	8	10	10	5	8.3	3	3	3	3	3.0	3	3	3	2	2.8	1125.8
Makodi (check)	60	52	46	67	56.3	4	5	4	5	4.5	6	7	7	7	6.8	838.1
Mean	9.8	8.7	9.6	10.1	9.6	1.6	1.6	1.9	2	1.8	2.6	2.4	2.3	2.1	2.4	1257.9

Site codes: JIG – Jigawa, KAD – Kaduna, KAN – Kano, NIG – Niger
*on 1–9 scale (1 = highly resistant)

Table 4. Dry pod yield (kg/ha) and ANOVA of nine groundnut lines at eight environments

Groundnut line	Jigawa		Kaduna		Kano		Niger		Mean[1)]	Shukla s^2 stability variance
	2004	2005	2004	2005	2004	2005	2004	2005		
ICGV-1S-96805	1468	1456	1387	1411	1399	1445	1436	1566	1446	2695.9
ICGV-SM-96846	1314	1340	1240	1218	1788	1812	1287	1375	1422	52678.6
ICGV-SM-94583	1500	1568	1334	1384	1385	1281	1365	1321	1392	7519.0
MS16-791	1522	1610	1291	1443	1290	1308	1300	1322	1386	12631.9
ICGV-SM-93534	1354	1390	1397	1425	1351	1375	1429	1365	1386	2132.3
249-85	1303	1163	1209	1241	1210	1252	1190	1210	1222	2174.6
ICGV-SM-96802	1222	1200	1231	1169	1241	1211	1186	1220	1210	1071.9
49-85A	1150	1136	1131	1203	1145	1173	1111	1165	1152	941.7
ICGV-SM-93532	1070	1202	1138	1098	1102	1118	1116	1162	1126	1864.7
Makodi (check)	790	810	799	940	775	745	933	913	838	7716.3
Mean	1269	1288	1216	1253	1269	1272	1235	1262		

[1)]The least significant difference ($p < 0.05$) for pairwise comparison of means is 101

ANOVA of dry pod yields (kg/ha) in on-farm trials

Source	DF	MQ	F	σ^2 estimate	σ^2 (%)
Total	79	41117.1		41117.1	100.0
Groundnut lines	9	285757.3	28.13**	30878.0	75.1
Environments	7	5213.7	0.5 n.s.	0.0	0.0
Residual	63	10157.7		10157.7	24.7

**significant at $p < 0.01$, n.s. – not significant, DF – degree of freedom, MQ –mean square

MS16-791, which performed very well against all three diseases. The late groundnut lines were mostly susceptible to one or more of the diseases, except 49-85A and ICGV-SM-93532, which performed well against the three diseases. The local check, Makodi, was the most susceptible to all three diseases. Based on data on yield and disease incidence, nine groundnut lines (marked bold in Table 2) were intuitively selected as promising and tested for 2 years in on-farm trials.

The reaction of the selected groundnut lines to the three diseases in the on-farm trials at the four locations is presented in Table 3, together with the mean dry pod yield. All the nine groundnut lines showed a similar ranking and level of resistance to the three diseases like in the on-station trials, with the local check, Makodi, being susceptible to the three diseases.

To see the yield performance across the eight environments, a two-way ANOVA was performed, which included also the estimation of variance components and their relative share in the total variance. The results are summarised in Table 4.

The ANOVA of the primary data revealed only one significant factor: groundnut lines, responsible for approx. 75% of the total variability. To obtain an idea about the yield stability, we calculated the "stability variance" of Shukla (1972), which is the interaction variance of each cultivar across the environments. Since the on-farm trials did not have any replications, it was not possible to separate the error variance from the interaction variance. The residual variance contains both. The stability variance therefore indicates here the residual variance of each line. It is shown as the last column in Table 4. We are aware that stability

Table 5. Standardized relative yields (SRY) and ANOVA of nine groundnut lines at eight environments; standardized to equal variance within columns and zero column effects

Groundnut line	Jigawa		Kaduna		Kano		Niger		Mean[1)]	s^2 SRY	s SRY	$s_{\%}$ SRY	$s_{\%}$ Shukla
	2004	2005	2004	2005	2004	2005	2004	2005					
ICGV-1S-96805	114.0	111.3	115.7	115.3	108.0	110.2	120.0	127.9	115.3	39.7	6.3	5.5	3.6
ICGV-SM-96846	106.0	106.9	116.6	116.6	105.1	106.1	119.3	109.5	110.7	33.7	5.8	5.2	16.1
ICGV-SM-94583	103.2	103.5	102.2	96.6	131.9	131.9	105.2	110.4	110.6	186.7	13.7	12.4	6.2
MS16-791	116.3	118.7	110.8	112.7	107.2	100.5	112.9	105.4	110.6	35.5	6.0	5.4	8.1
ICGV-SM-93534	117.8	121.5	106.9	118.4	101.3	102.1	106.5	105.5	110.0	63.6	8.0	7.3	3.3
249-85	102.4	91.7	99.4	98.8	96.4	98.8	95.5	95.2	97.3	10.7	3.3	3.4	3.8
ICGV-SM-96802	96.7	94.2	101.4	91.9	98.3	96.4	95.1	96.2	96.3	8.0	2.8	2.9	2.7
49-85A	91.6	89.9	92.3	95.1	92.4	94.2	87.6	91.1	91.8	5.6	2.4	2.6	2.7
ICGV-SM-93532	85.9	94.3	92.9	85.0	89.8	90.9	88.1	90.8	89.7	10.5	3.2	3.6	3.8
Makodi (check)	66.2	68.1	61.9	69.7	69.7	68.9	69.9	68.0	67.8	7.2	2.7	4.0	10.5
Column effect	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0			mean	5.2	6.1

[1)]the least significant difference ($p < 0.05$) for pairwise comparison of means is 6.7

ANOVA of standardized relative yields

Source	DF	MQ	F	σ^2 estimate	σ^2 %
Total	79	228.6		228.6	100.0
Groundnut lines	9	1694.4	38.9**	187.5	82.0
Environments	7	0.0	0 n.s.	0.0	0.0
Residual	63	44.6		44.6	19.5

**significant at $p < 0.01$, n.s. – not significant, DF – degree of freedom, MQ –mean square

parameters, calculated from a limited number of environments, are subjected to enormous errors (Piepho 1998), are difficult to reproduce (Eagles & Frey 1977) and may be partly artefacts of inappropriate models (Schwarzbach *et al.* 2007). Therefore we tried also the multiplicative model, which fits the natural behaviour of some crops better than the additive model. We converted the yield data to standardized relative yields (SRY) as mentioned above and performed an ANOVA on the SRY. The results are summarized in Table 5.

Standardization of the data considerably reduced the proportion of residual variance on the total from 24.7% to 19.5% and increased the proportion of genetic variance from 75.1% to 82.0%. The multiplicative model provided therefore a better differentiation of the lines than the linear model.

Although the yield stability expressed as variation coefficients of the SRY are based on a similar principle like the variation coefficient of "Shukla's stability variance", the ranking of the lines is not the same. The only difference between both approaches is that Shukla's criterion is based on non-standardized raw data, while the variation of SRY is based on standardized data. Obviously, the "stability variance" is more influenced by environmental factors, while the variation of SRY expresses the genetic properties of the tested lines to a slightly higher degree. We preferred therefore the variation of the SRY as a simple and easy to understand measure of yield stability.

For pairwise comparisons of the variance of the SRY, the F-test can be used. If variation coefficients are compared, then the square root of F may be used. The critical F value for the given degrees of

Table 6. Summary of disease resistance, standardized relative yield (SRY) and yield stability of nine groundnut lines in on-farm trials

Groundnut line	Resistance against			SRY[1)] %	Stability $s_{\%}$ of SRY
	ROS	ELS*	LLS*		
ICGV-1S-96805	0.5	1.0	1.5	115.3	5.5
ICGV-SM-96846	11.5	2.3	2.8	110.7	5.2
ICGV-SM-94583	0.0	1.3	1.5	110.6	12.4
ICGV-SM-93534	0.0	1.3	2.8	110.6	5.4
MS16-791	0.3	1.0	1.8	110.0	7.3
249-85	2.3	1.0	1.0	97.3	3.4
ICGV-1S-96802	8.3	1.3	1.8	96.3	2.9
49-85A	8.3	1.3	1.0	91.8	2.6
ICGV-SM-93532	8.3	3.0	2.8	89.7	3.6
Makodi (check)	56.3	4.5	6.8	67.8	4.0
Mean	9.6	1.8	2.4	100.0	5.2

[1)]least significant difference for pairwise comparisons at $p < 0.05$ is 6.7%

*on 1–9 scale (1 = highly resistant)

ROS – Rosette virus, ELS – early leaf spot, LLS – late leaf spot

freedom at $p < 0.05$ is 3.50. Its square root is 1.87. Based on this, three distinct levels of stability can be observed among the nine selected groundnut lines (Table 6), represented by the very stable 49-85A (vc = 2.6%), stable ICGV-SM-96846 (5.2%) and the less stable ICGV-SM-94583 (12.4%).

From the combined performance in all evaluated traits (Table 6) it can be seen that among the nine selected groundnut lines there are lines combining high pod yield, resistance to the rosette virus, early leaf spot, late leaf spot and yield stability. The best groundnut line in this respect was ICGV-1S-96805, followed by ICGV-SM-93534.

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