



Estimates of Combining Ability and Gene Action in Groundnut (*Arachis hypogaea* L.) for Resistance to Aphis (*Aphis craccivora* Koch)

Bashir, Y.R.¹, Umar, U.U.², Usman, H.¹ and Sani, Z.R.¹

¹Department of Biological Sciences, Federal University Gusau,

²Department of Biological Sciences, Kaduna State University, Kaduna

Corresponding Author: yusufbashir32@yahoo.com

Received: October, 2016

Revised and Accepted: December, 2016

Abstract

Nine groundnut genotypes, consisting of three male testers and six female lines were crossed in a line x tester mating design to develop 18 hybrids in 2010. The resultant hybrids, parents and three checks were evaluated using a completely randomized design in the screen house of Institute for Agricultural Research (IAR) located at Samaru (11°11'N, 7°38' E) in 2012 to obtain information on combining ability and gene action for resistance to aphid and other quantitative traits in groundnut. Results of the combining ability analysis revealed that both additive and non-additive gene actions were responsible for the control of the traits studied. However, the values of dominance genetic variance were greater than additive genetic variance for all traits which depicts the importance of non-additive gene action for controlling these traits. Narrow sense heritability was low for all the traits studied except shelling percentage (74.00%) which was high and ranged from 1.60% (number of pods per plant) to 74.00% (shelling percentage) also indicating non-additive gene action. Significant effects among female parents were observed in their General Combining Ability for pod yield, 100-seed weight, and number of pods per plant and among male parents for 100-seed weight and days to maturity. SCA effects for ICGX-SM 00020/5/P4/P1 x ICGV IS 07890, ICGX-SM 00017/5/P10/P1 x KWANKWASO and ICGX-SM 00017/5/P10/P1 x SAMNUT 14 revealed maximum positive result for pod weight. Lower negative SCA effects were observed among most of the hybrids for the characters studied.

Keywords: Groundnut; Aphid; Gene; Estimates; *Aphis craccivora* Koch.

1.0 INTRODUCTION

Groundnut (*Arachis hypogaea* L.) is an annual leguminous crop. It is a self-pollinated allotetraploid ($2n=4x=40$), with a genome size of 2891 Mbp. The genus *Arachis* belongs to the family fabaceae and sub-family papilanoceae (Nigam and Bock, 1990). Groundnut is grown on nearly 23.95 million ha worldwide with the total production of 36.45 million tons and an average yield of 1520 kg/ha in 2009 (FAOSTAT, 2011). China, India, Nigeria, and USA are the major groundnut growing countries. Developing

countries in Asia, Africa and South America account for over 97% of world groundnut area and 95% of total production. Production is concentrated in Asia (50% of global area and 64% of global production) and Africa (46% of global area and 28% of global production), where the crop is grown mostly by smallholder farmers under rain-fed conditions with limited inputs (Bock, 1990). Nigeria currently produces about two million metric tons representing 5% of world production. Groundnut constitutes a major source of

foreign exchange as an export commodity as well as generating local income to Farmers.

Groundnut is rich in protein (2534%) and oils (44-56%); it is used in the manufacture of cooking oil as well as making a paste for the preparation of groundnut sauce in many African communities. It is also eaten boiled, fried or roasted, and its by-products can be used as animal feed. As a legume, groundnut improves soil fertility by fixing nitrogen and thereby increases productivity of other crops in the semi-arid cereal cropping systems. Groundnut requires little in-put, making it appropriate for cultivation in low in put agriculture by smallholding farmers. *Aphis craccivora* Koch is a major pest of groundnut causing losses by feeding on phloem sap and through transmission of virus disease (Padgham *et al.*, 1990). It is a vector of at least seven viruses that attack groundnut, the most important of which is groundnut rosette virus (GRV) in Africa. Rosette is the most destructive virus disease of groundnut in Africa. In 1975 rosette affected about 0.7 million hectares of groundnut in Nigeria and caused yield losses estimated at over 0.5 million tons, with a value estimated at US\$250 million (Yayock *et al.*, 1976). Rosette disease is caused by a complex of groundnut rosette virus (GRV), together with an associated satellite RNA, and a helper virus, Groundnut Rosette Assistor Virus (GRAV), on which the other two components depend for transmission by the Aphid.

Aphids are the most prevalent insect vectors of virus disease with over 200 species known to transmit plant pathogenic viruses. They are responsible for the transmission of 50% of the insect vectored viruses (Ng and Perry, 2004). It is clear that the intense selection pressure placed on aphids through insecticide use is enough to result in the continued development of resistance. Hence, it is vital that alternative methods of control are developed for contingency before there is a significant build-up of neonicotinoid resistance in natural aphid populations. To achieve this, a greater understanding of natural plant resistance mechanisms is required with the goal of implementing this knowledge in protecting crop species from aphids and subsequent virus infection. Host-plant resistance to *Aphis craccivora* in groundnut is recognised as the most effective, economic and sustainable

method of limiting both the spread of the aphid and the viruses (Padgham *et al.*, 1990). Screening germplasm for aphid resistance led to the discovery of resistant accession in several crop species against various aphid species. However, sources of aphid resistance are limited and usually scarce. More often, aphid resistance have been identified in unimproved landraces, in wild accessions or even in related species, thus requiring a long breeding process to introduce the resistance into cultivated varieties.

As a result of increased demands on food production from escalating population growth and environmental degradation, interest in improved breeding strategies for agricultural crops is growing (Wang, D. 2008). The main aim of any plant breeding programme is to develop special high yielding hybrids that are resistance to insect, pest and diseases. To accomplish this, the breeding programme can efficiently be planned with prior knowledge of the genetic makeup of complex quantitative characters like yield and its attributes. It is therefore, necessary to examine the genetic architecture of various quantitative characters in relation to breeding behavior of the genetic material available. The knowledge of combining ability provides a useful clue for selection of desirable parents for the development of superior hybrids that are resistant to insect, pest and diseases. Thus, the information regarding combining ability and nature of gene action are the basic requirements for a thorough understanding of genetic architecture of aphid resistance, yield, and its components. The present study therefore, was undertaken to study the genetics of eight quantitative traits in six lines (females) and three testers (males) using line \times tester analysis as well as to determine the relative importance of general and specific combining abilities for resistance to *Aphis craccivora* using line \times tester analysis.

2.0 MATERIALS AND METHODS

The Research was carried out at Institute for Agricultural Research (IAR), Samaru (11°11'N and 07°38'E, 686m above sea level) in the northern Guinea Savannah ecological zone of Nigeria. The plant materials for the study comprised three Aphid resistant male parents (testers) and six aphid susceptible female parents (lines) which were crossed by hand

pollination in a line x tester scheme to develop 18 hybrids in 2010. The 18 F₁ hybrids, 9 parents and 3 checks were evaluated in a Completely Randomized Design (CRD) with two repetitions in 2012 at the IAR screen-house to study their performance and reaction to *Aphis craccivora* infestation. Each genotype was assigned two soil filled plastic pots of 25cm in diameter with three seeds per pot. The pots were watered once daily and hand weeding was carried out four and eight weeks after planting.

Aphis craccivora were isolated from an infected groundnut plant variety and were cultured on a susceptible groundnut variety (ICGV IS 07890). Thirty days after sowing, five aphids from a culture maintained on a susceptible groundnut variety (ICGV IS 07890) were introduced onto the tender leaf of each seedling using a paint brush. After confirming that each aphid was moving about on the area of placement, each pot was covered with a crisp bag and secured in place. Aphids were left to move freely along plants and feed. Aphid resistance was visually rated for each plant, 3 and 4 weeks after infestation using a scale of 0–4 developed by Mensah *et al.* (2008). Care was taken to avoid disturbance of the aphid.

Data for the following agronomic characters were obtained: Plant height (cm), Days to 50% flowering, Days to maturity, Number of mature pod per plant, Pod yield (g), 100 seed weight (g), and Shelling percentage. Aphid damage index (D.I) for each line was calculated according to Mensah *et al.* (2008) using the following formula:

$$DI = \sum (\text{Scale value} \times \text{no. of aphids in the category}) / (4 \times \text{total no. of plants}) \times 100.$$

Data collected were subjected to Analysis of variance (ANOVA) using the generalized linear model (GLM) procedure of the Statistical Analysis System (SAS) version 9.1 (SAS Institute, 2004). The general Combining Ability (GCA) and Specific Combining Ability (SCA) effects were estimated according to Singh and Chaudhary (1985). The estimates of variances due to GCA and SCA were also computed from mean squares according to Singh and Chaudhary (1985).

3.0 RESULTS AND DISCUSSION

3.1 Analysis of Variance for Combining ability and Variances

The experimental data on combining ability for groundnut evaluated for resistance to aphid is presented in Table 1. Genotypes mean squares exhibited highly significant ($P < 0.01$) difference for days to maturity, seed weight per plant, 100 seed weight, number of pods per plant, pod yield per plant, D.I except plant height which was significant at $P < 0.05$ and was not significant for shelling percentage. The significant difference observed for most of traits among the genotypes showed that the characters studied can be selected for genetic improvement. Mean squares due male showed highly significant ($P < 0.01$) difference only for number of pods per plant and D.I and were non-significant for other traits. Female mean squares were highly significant ($P < 0.01$) only for days to maturity and D.I and were non-significant for other traits. This indicated insufficient variability among parents. Interestingly, this was observed (Narayanan, S.L. 2000).

The female x male interaction mean squares were highly significant ($P < 0.01$) for days to maturity, seed weight per plant, 100 seed weight, number of pods per plant and D.I and were non-significant for plant height and pod yield per plant. This indicated that non-additive gene action was important and responsible in the genetic expression of this traits and this shows the existence of tremendous variability among the crosses, which is pre-requisite for any crop improvement programme.

Estimates of genetic components of variance and narrow sense heritability for groundnut evaluated for resistance to aphid are presented Table 2. The estimates of SCA variances were higher than the GCA variances for all the traits and all the GCA/SCA ratios were less than unity. This depicts that variance due to specific combining ability was more important than the variance due to general combining ability for all the traits and that the hybrids in general were superior to parents for all the traits studied. It is evident from that the variance due to SCA wherein dominance variance was more important for all traits. Narrow sense heritability was low for all the traits studied except shelling percentage (74.00%) which was high and ranged from 1.60% (number of

Pods per plant) to 74.00% (shelling percentage). This also indicates that the studied traits are mainly controlled by non-additive genes.

Proportional contributions of lines, testers, and their interaction to total variance for groundnut evaluated for resistance to aphid Table 3. The contribution of line x tester interaction was very high for all traits studied. This revealed the preponderance of paternal and maternal interaction (line x tester) for all the traits studied.

3.2 General Combining Ability Effects of Parents

The results of general combining ability effects of lines and testers evaluated for resistance to aphids are presented in Tables 4. Negative GCA effect were exhibited by lines ICGV IS 07890 (-1.33), SAMNUT 14 (-0.83) and MANIPENTA (-1.00) for days to maturity. Female parents KWANKWASO, revealed positive and significant GCA effect for 100 seeds weight, number of pods per plant and pod yield while male parent ICGX-SM 00020/5/P4/P1 depicted positive and significant GCA effect for these traits. Lines with high positive GCA estimates for seeds weight, and pod yield are good candidates to be used as parents for the development of desirable hybrids. Among the testers ICGX-SM 00020/5/9 for 100 seed weight and days to maturity exhibited negative GCA effect and such was desirable male parent for earliness. Male parents ICGX-SM 00020/5/P4/P1 demonstrated positive and significant GCA effect for seeds weight, number of pods per plant and pod yield as well as for D.I. All the lines and testers show significantly higher positive GCA except lines; KWANKWASO (-273.27), MANIPENTA (-609.11) and tester ICGX-SM0020/5/P4P1 (-235.31) which show significantly higher negative GCA.

Variation in general combining ability effect was estimated among lines and tester for indicated plant traits to identify the best parent for subsequent hybrid development programmed. Farmers need short duration groundnut hybrids because it reduces the incidence of insect-pest and disease attack due to early maturity. Minimum number of days to 50% flowering is preferred to reduce the crop growth period. Negative GCA effect was exhibited by parents (lines) ICGVIS07890 and

MANIPENTA for days to maturity and D.I. ICGVIS07890 and MANIPENTA having significant negative GCA effects can be considered for selection due to shorter number of days to maturity. Female parent KWANKWASO revealed positive and significant GCA effects for 100 seeds weight, number of pods per plant and pod yield. Lines with high positive GCA estimates for seeds weight, and pod yield are good candidates to be used as parents for the development of desirable hybrids. These results are in accordance to Naiket *et al.* (1999) and Ashok *et al.*, (2000) who observed significant and positive GCA effects for these traits in their respective studies.

3.3 Specific Combining Ability of Crosses

Estimates of Specific Combining Ability effects for groundnut crosses evaluated for resistance to aphid are presented in Table 5. Cross combination ICGX-SM 00020/5/P4/P1 X ICGV IS 07890, ICGX-SM 00017/5/P10/P1 X KWANKWASO and ICGX-SM 00017/5/P10/P1 X SAMNUT 14 revealed maximum positive and significant SCA effects for higher seed weight per plant. Similarly, potential crosses showing significantly high positive SCA effects for number of pods per plant were six. However all the potential crosses show lower negative SCA, for Aphid infestation index (D.I) except six of the crosses which show significantly higher positive SCA effects.

Higher pod yield per plant and lower D.I is an ultimate objective of groundnut breeding and hybrid development programs. Positive and highly significant specific combining ability effects for pod yield were revealed by four crosses (ICGX-SM 00017/5/P10/P1 x KWANKWASO, ICGX-SM 0020/5/P4/P1 x ICGV IS 07890, ICGX SM 00020/5/9 x ICGV IS 07890, and ICGX-SM 00020/5/9 x ICGV IS 07899). The hybrids having negative and significant SCA effects for plant height, D.I and days maturity showed their ability to contribute genes for earliness and reduced level of damage by the aphids. These results are in line with the finding of Ashok *et al.* (2000) who found significant and negative SCA effects for maturity in sunflower hybrids. For 100-seed weight, significantly positive SCA effects were demonstrated by 6 crosses. Higher seed yield is an ultimate objective of

groundnut breeding and hybrid development programmers. Positive and highly significant

specific combining ability effects for pod yield were revealed by 6 crosses.

Table 1 Analysis of variance for combining ability for groundnut evaluated for resistance to aphid

Source of variation	df	Mean squares							
		DTM	PH	SW	HSW	SP	NPD	PY	D.I
Replication	1	0.00	15.34*	5.64	42.61	438.84	0.53	1.26	65.16**
Genotypes(G)	29	40.54**	14.35*	41.92**	427.12**	291.98	120.35**	92.94**	136.45**
Parents (P)	8	16.00*	22.49*	6.50	72.00	94.03	36.81	19.80	154.26**
P vs crosses	1	65.33**	5.64	381.57**	4243.79**	4.36	42.39**	954.08**	78.62**
Crosses	17	33.45**	8.31	37.48*	421.99*	325.79	83.89**	78.95	148.69**
Line (L)	5	10.47	3.39	24.23	269.96	458.15	81.71**	89.56	170.14**
Tester (T)	2	56.33**	6.13	18.11	209.03	485.76	30.11	83.36	11.87**
L x T	10	40.60**	10.49	51.94**	585.33**	227.86	94.61**	73.09	165.34**
Error	17	6.46	11.45	16.30	184.84	248.59	27.68	40.67	5.18

*, ** Significant at P<0.05) and <0.01, respectively NS = non-significant

DTM (days) = days to maturity, PHT (cm) = Plant height, SW (g) = Seed weight per plant, HSW (%) = 100 seed weight, SP (%) = Shelling percentage, NPD (no) Number of pods per plant, PY (g) = Pod yield per plant, DI (%) =Aphid damage index.

Table 2: Estimates of genetic components of variance and narrow sense heritability for groundnut evaluated for resistance to aphid.

Traits	σ_{GCA}^2	σ_{SCA}^2	$\sigma_{GCA}^2 / \sigma_{SCA}^2$	h_n^2 (%)
Days to maturity	5.05	273.09	0.02	1.90
Plant height (cm)	-1.88	-7.67	0.25	19.60
Seed weight (g)	8.73	285.11	0.03	3.20
100 seed weight	98.60	3203.93	0.03	3.20
Shelling percentage	70.57	165.84	0.43	74.00
Number of pods per plant	8.19	535.41	0.02	1.60
Pod yield per plant	4.35	259.36	0.02	6.30
Aphid damage index	172304.74	5324434.53	0.03	11.50

σ_{GCA}^2 = GCA variance, σ_{SCA}^2 = SCA variance, h_n^2 = narrow sense heritability.

Table 3: Proportional contributions of lines, testers, and their interaction to total variance for groundnut evaluated for resistance to aphid

Traits	Contribution of lines (%)	Contribution of testers (%)	Contribution of line x tester (%)
Days to maturity	9.20	19.81	71.39
Plant height (cm)	12.00	8.68	74.23
Seed weight (g)	19.01	5.68	81.52
100 seed weight	18.82	5.83	81.59
Shelling percentage	41.14	17.54	41.36
Number of pods per plant	28.64	4.22	66.33
Pod yield per plant	33.37	12.42	54.46
Aphid damage index	47.83	5.37	46.79

Table 4: Estimates of General Combining Ability effects for 9 groundnut parents evaluated for resistance to aphid

Parents	DTM	PHT	SW	HSW	SP	NPD	PY	D.I
Female parent(Lines)								
ICGV IS 07890	-1.33	0.90	0.03	0.19	2.53	-0.94	-2.47	635.36
ICGV IS 07899	0.33	-0.18	-0.97	-3.47	-7.39	-4.44	-2.31	369.23
ICIAR-19BT IS 07899	0.67	-1.01	0.19	0.69	-3.73	1.89	-0.64	760.89
SAMNUT 14	-0.83	-0.68	0.19	0.69	12.31	1.89	0.86	428.14
KWANKWASO	2.17	0.40	3.36	11.19	-10.48	5.22	7.36	-273.27
MANIPENTA	-1.00	0.57	-2.81	-9.31	6.76	5.22	-2.81	-609.11
Male parents (testers)								
ICGX – SM 00020/5/9	-1.17	0.65	-1.39	-4.72	3.28	-1.61	-2.14	228.21
ICGX – SM 00017/5/P10/P1	-1.33	-0.76	0.44	1.53	-7.33	1.56	-0.81	52.88
ICGX – SM 00020/5/P4/P1	2.50	0.11	0.94	3.19	4.05	0.06	2.94	-235.31
SE(GCA for lines)	1.04	1.38	1.65	5.55	6.44	2.15	2.61	109.08
SE (gi-gj) for lines	1.47	1.95	2.33	7.85	9.10	3.04	3.68	109.08
SE (GCA for testers)	0.73	0.98	1.17	3.93	4.55	1.52	1.84	82.46
SE(gi-gj)for testers	1.04	1.38	1.65	5.55	6.44	2.15	2.61	116.61

DTM (days) = days to maturity, PHT (cm) = Plant height, SW (g) = Seed weight per plant, HSW (%) = 100 seed weight, SP (%) = Shelling percentage, NPD (no) = Number of pods per plant, PY (g) = Pod yield per plant, DI (%) =Aphid damage index.

Table 5: Estimates of Specific Combining Ability effects for groundnut crosses evaluated for resistance to aphid

Crosses	DTM	PHT	SW	HSW	SP	NPD	PY	D.I
ICGX-SM 00020/5/9 X ICGV IS 07890	5.83	-0.82	3.72	12.72	9.38	9.61	3.14	1.79
ICGX-SM 00020/5/9 X ICGV IS 07899	1.17	-3.49	0.72	2.39	5.90	3.11	2.97	-249.46
ICGX-SM 00020/5/9 X ICIAR-19BT IS 07899	-0.17	0.85	1.56	5.22	-13.67	-1.22	0.81	117.87
ICGX-SM 00020/5/9 X SAMNUT 14	-2.67	1.76	-0.94	-3.28	-11.20	-3.72	-2.19	-174.71
ICGX-SM 00020/5/9 X KWANKWASO	-1.67	2.18	-6.61	-22.28	4.43	-11.06	-6.69	497.04
ICGX-SM 00020/5/9 X MANIPENTA	-2.50	-0.49	1.56	5.22	5.15	3.28	1.97	-224.46
ICGX-SM 00017/5/P10/P1X ICGV IS 07890	-2.00	1.59	-9.11	-30.53	-7.50	-10.06	-10.19	31.95
ICGX-SM 00017/5/P10/P1 X ICGV IS 07899	-3.67	1.18	-1.11	-3.86	-7.38	-1.06	-1.86	70.45
ICGX-SM 00017/5/P10/P1X ICIAR-19BT IS 07899	-2.00	-2.74	-0.78	-2.53	6.15	5.11	0.97	212.54
ICGX-SM 00017/5/P10/P X SAMNUT 14	-2.00	-1.07	4.72	15.97	2.27	2.61	1.97	-2.79
ICGX-SM 00017/5/P10/P1X KWANKWASO	7.50	-0.90	6.56	21.97	10.70	5.28	10.47	792.95
ICGX-SM 00017/5/P10/P X MANIPENTA	0.67	1.93	-0.28,	-1.03	-4.23	-1.89	-1.36	-36.96
ICGX-SM 00020/5/P4/P X ICGV IS 07890	-3.83	-0.78	5.39	17.81	-1.88	0.44	7.06	-394.79
ICGX-SM 00020/5/P4/P X ICGV IS 07899	2.50	2.31	0.39	1.47	1.48	-2.06	-1.11	-641.38
ICGX-SM 00020/5/P4/P X ICIAR-19BT IS 07899	2.17	1.89	-0.78	-2.69	7.52	-3.89	-1.78	-215.69
ICGX-SM 00020/5/P4/P X SAMNUT 14	3.17	-0.69	-3.78	-12.69	8.93	1.11	0.22	-120.94
ICGX-SM 00020/5/P4/P X KWANKWASO	-5.83	-1.28	0.06	0.31	-15.13	5.78	-3.78	-325.94
ICGX-SM 00020/5/P4/P1 X MANIPENTA	1.83	-1.44	-1.28	-4.19	-0.92	-1.39	-0.61	-900.86
SE (SCA effect)	1.79	2.39	2.86	9.61	11.15	3.72	4.51	218.17
SE (Sij-Sk1)	2.54	3.38	4.04	13.59	15.77	5.26	6.38	308.53

DTM (days) = days to maturity, PHT (cm) = Plant height, SW (g) = Seed weight per plant, HSW (%) = 100 seed weight, SP (%) = Shelling percentage, NPD (no) Number of pods per plant, PY (g) = Pod yield per plant, DI (%) =Aphid damage index.

4.0 CONCLUSION

Among the lines, KWANKWASO and SAMNUT 14 were best combiners for all the traits studied, while MANIPENTA also performed best for number of pods per plant and D.I. Lines ICGV IS 07890, SAMNUT 14 and MANIPENTA were the best general combiner for early maturity. KWANKWASO was the best line for seed weight. Among testers, ICGX-SM 0002/5/9 was the best general combiner for early maturity. Tester ICGX-SM 00020/5/P4/P1 was the best general combiner for seed weight, D.I and seed yield. For shelling percentage ICGX-SM 00017/5/P10/P1 was found to be the best general combiner. In terms of specific combining ability effects, the best groundnut hybrids were ICGX-SM 00020/5/P4/P1 X KWANKWASO for early maturity, and ICGX-SM 00017/5/P10/P1 X KWANKWASO for pod yield. ICGX-SM 00020/5/9 X ICGV IS 07899 for number of pods per plant and ICGX-SM 00020/5/P4/P1 X MANIPENTA for D.I. Parental lines with high GCA effects for yield and yield components may result in resistant hybrids with better performance for yield and its components. High SCA effects resulting from crosses between higher general combiners can be improved through early selection. High SCA effects resulting from low GCA combiners suggest that such crosses may be utilized for further improvement through single plant selection in the later generations. Higher SCA variances than GCA variances show that the characters were under the control of dominance gene action.

5.0 ACKNOWLEDGEMENT

I thank the management of the Institute for Agricultural research (IAR), A.B.U, Samaru and the International Crop Research Institute for Semi-Arid Tropics (ICRISAT), Kano, for supplying the seeds of the female and male groundnut lines, respectively.

6.0 REFERENCES

Ashok, S., Muhammad, S.N. and Narayanan, S.L. (2000). Combining ability studies in sunflower (*Helianthus annuus* L.). *Crop Research Hisar.*, 20(3): 457-462.

FAOSTAT (2011). Food and Agricultural organization. *Statistics*

Mensah, C., Difonzo, C. and Wang, D. (2008) Inheritance of soybean aphid resistance in P567541B and PI 567598B. *Crop Science*, 48: 1759-1763.

Naik, V.R., Hiremath, S.R. and Giriraj, K. (1999). Gene action in sunflower. *Karnataka Journal Agricultural Science*, 12(1/4): 43-47.

Ng, J.C.K. and Perry, K.L. (2004). Transmission of plant viruses by aphid vectors. *Molecular Plant Pathology*, 5:505-511.

Nigam, S.N. and Bock, K.R. (1990). Inheritance of resistance to groundnut rosette virus in groundnut (*Arachis hypogaea* L.). *Annals of Applied Biology*, 117:553-560.

Padgham, D.E., Kimmins, F.M. and Ranga Rao, G.V. (1990). Resistance in groundnut (*Arachis hypogaea* L.) to *Aphis craccivora* Koch. *Annals of Applied Biology*, 117:285-294.

SAS Institute Inc. (2004). SAS/STAT 9.1 user's guide. SAS Institute Inc., Cary, 5121 p.

Singh, R.K. and Chaudhary, B.D. (1985). Analysis in Biometrical Genetics. Kalyani publishers, New Delhi. pp.211-214.

Yayock, J.Y., Rossel, H.W. and Harkness, C. (1975). A review of the 1975 groundnut rosette epidemic in Nigeria. *Samaru Conference Paper 9*. Institute of Agricultural Research, Ahmadu Bello University, Zaria, Nigeria.