African Crop Science Journal, Vol. 24, No. 4, pp. 389 - 395
Printed in Uganda. All rights reserved
ISSN 1021-9730/2016 $4.00



DOI: http://dx.doi.org/10.4314/acsj.v24i4.5

# NATURE OF RESISTANCE OF COWPEA *ALECTRA VOGELII* INFESTATION

A. MBWANDO[1,2], D.M. LUNGU[1], G.M. TRYPHONE[3] and L. TEMBO[1]
[1]Department of Plant Science, School of Agricultural Science, University of Zambia, P. O. Box 32379, Lusaka, Zambia
[2]Ilonga Agriculture Research Institute, P. O. Box 33, Kilosa- Morogoro, Tanzania
[3]Department of Crop Science and Production, Faculty of Agriculture, Sokoine University of Agriculture, P. O. Box 3005, Chuo Kikuu, Morogoro, Tanzania
**Corresponding author:** mbwandoally@yahoo.com

*(Received 28 September, 2015; accepted 18 November, 2016)*

## ABSTRACT

*Alectra vogelii* (benth) is parasitic weed which causes significant yield reductions in cowpea (*Vigna unguiculata* Walp) in Africa. The objective of this study was to identify the type of gene action controlling the trait for resistance to *Alectra vogelii* in cowpea and estimate the heritability of the trait. Seven genotypes of cowpea were mated in half diallel and their $F_2$ progeny, including parents, were evaluated for reaction to *Alectra vogelii* infection in the field in two locations at Ilonga and Hombolo Agriculture Research Stations. Highly significant ($P < 0.001$) differences were found for *Alectra* emergency and infestation at Ilonga. General combining ability (GCA) and specific combining ability (SCA) effects for *Alectra* shoot emergency and infestation were significant ($P < 0.05$). The estimate of Baker's ratio for *Alectra* shoot emergency and infestation were 0.62 and 0.66, respectively. This indicates that both additive and non-additive gene actions influenced the trait for resistance to *Alectra* emergency and infestation. Narrow sense heritability estimates were 41.28 and 44.39 for shoot and emergency, respectively. These results imply that introgression of a desirable trait in an elite genotype would involve careful crossing with a resistance genotype, accompanied by selection in the advanced population.

*Key Words*: *Alectra vogelii*, gene action, *Vigna unguiculata*

## RÉSUMÉ

*Alectra vogelii* (benth) est une herbe parasite qui engender des reductions significatives dans les rendements du niébé (*Vigna unguiculata* Walp) en Afrique. L'objectif de la présente étude était d'identifier le type d'action de gène controllant la résistance à *Alectra vogelii* chez le niébé et d'estimer les valeurs d'héritabilité. Sept génotypes de niébé ont été croisés selon le mode half diallel et leurs descendants F2, ainsi que les parents, ont été évalués pour leur reaction face à 'linfestation en plein champs du *Alectra vogelii* dans les stations de recherché agricole de Ilonga et Hombolo. Des differences très significatives ($P < 0{,}001$) ont été observées pour l'émergence, la croissance végétative et l'infestation de *Alectra* à Ilonga. L'habileté à la combinaison générale (GCA) et spécifique (SCA) pour l'émergence, la croissance végétative et infestation de *Alectra* étaient significative ($P < 0{,}05$). les valeurs du ratio de Baker pour l'émergence, la croissance végétative et l'infestation de *Alectra* étaient respectivement de 0,62 et 0,66. Ceci indique que les deux effets de gène; additif et non-additif sont responsables de la résistance à l'émergence, la croissance végétative et à l'infestation de *Alectra*. Les valeurs de l'héritabilité au sens strict étaient respectivement de 41,28 et 44,39 pour la croissance végétative et l'émergence. Ces résultats indiquent que l'introgression d'un caractère désirable dans un génotype élite nécessiterait des croisements avec un genotype résistant, suivi de selection au cours des générations avancées.

*Mots Clés*: *Alectra vogelii*, action de gène, *Vigna unguiculata*

## INTRODUCTION

Cowpea (*Vigna unguiculata* (L) Walp) is one of the most important pulse (grain legume) crop which is grown in environmental conditions ranging from arid to humid tropics. It does not require highly fertile soils and it is tolerant to high temperatures and drought (Dugje *et al.*, 2009). It is one of the important source of quality protein for human and animal nutrition and hence serves both dietary function and source of income to peasant farmers in sub-Saharan Africa (Stahley *et al.*, 2012). Cowpea also has high ability of associating with different species of *Rhizobia* bacteria within the soil to fix atmospheric nitrogen that increases and improves the soil fertility for sustainable crop production.

Yields on farmers' managed fields in Tanzania are generally low compared to potential yield almost in all cowpeas growing areas due to a numbers of observed constraints. A major constraint to cowpea production in is a parasitic weed *Alectra vogelii*, which attaches to the roots of plants and diverts assimilate from roots and, hence cause the reduction in production of the total biomass of the plant and yield (Singh and Emechebe, 1997; Mbwaga *et al.*, 2010). The problem of *Alectra vogelii* appears to be widely spread in Southern and Eastern Africa, and a serious cowpea yield loss has been reported in the areas infested by this parasitic weed (Bagnall-Oakley *et al.*, 1991; Karanja *et al.*, 2010; Mbwaga *et al.*, 2007; 2010); Different control measures have been proposed, thus include hand weeding, chemical control, crop rotation and trapping crop but with little success (Bouker *et al.*, 2004). However, use of host plant resistance is an alternative approach that is most effective economically and environmentally friendly in controlling *A. vogelii* (Mainjeni, 1999; Rubiales *et al.*, 2006).

High yielding cowpea germplasm with resistance to emergency of *A. vogelii* and those that show resistance by delaying the emergence of *A. vogelii* exist in Tanzania (Mbwaga *et al.*, 2010). These can be employed in breeding programmes as parents. To plant breeders, the concern of developing resistant cowpea genotypes to *A. vogelii* is the most important task. However, in order to effectively use the germplasm for this purpose, the nature of gene action conditioning the resistance to *A. vogelii* needs to be fully understood. The objective of this study was therefore to determine the nature of gene action conditioning resistance to *A. vogelii* in cowpeas and to estimate heritability of the trait.

## MATERIALS AND METHODS

Field and screen house experiments were conducted at Ilonga Research Station (ARI-Ilonga), in Morogoro ( 06° S, 37° E, Altitude 506 m) and Hombolo research station (ARI-Hombolo), in Dodoma (5° 52' S, 35° E, Altitude1100 m) Tanzania during the 2014/ 2015 and 2015/2016 cropping season. Rainfall at Ilonga station is monomodal with a tendency to bimodalism with a mean annual of 1000- 1064 mm. The soil type is sandy clay loams, well drained, friable and dark colored soil. Rainfall at Hombolo is mono-modal; with mean annual rainfall of 655 mm. It has reddish, loamy sandy soils with good and high drainage. The average annual temperature at Ilonga is 28.64- 30.37 ÚC while that of Hombolo is 22.4- 27.13 ÚC.

A total of seven cowpea genotypes (Table 1) with varying reaction to *Alectra vogelii* infestation were collected from the International Institute of Tropical Agriculture (IITA) and Ilonga Agriculture Research Institute (ARI- Ilonga) in Tanzania.

Seven inbred lines were mated in a 7 x 7 half diallel (Method II and Model I by Griffing (1956) at Ilonga Station. Crossing procedures used were according to Rachie *et al.* (1975). The 21 progenies produced were advanced to $F_2$ in the screen house. The $F_2$ families together with their parents were evaluated for reaction to *A. vogelii* in the field in 2015/2016 cropping season using a randomised complete block design with 3 replications and in two locations of Ilonga and Hombolo. Fields used for evaluation were naturally infested by *Alectra* seeds though additional artificial inoculation to increase the pressure of infestation. *Alectra* was infested in the soil by planting putting a full spoon of *Alectra* seeds per hill calibrated to deliver about 1000 seeds per hill at planting time.

Seeds were sown in a single row plot of 5.0 m length, and the spacing between and within rows maintained at 0.75 and 0.3 m, respectively. All plots were kept free of weeds by hoe weeding for the first five weeks and then by hand weeding thereafter.

Data on number of cowpea plants infested per plot and number of *Alectra* shoots emerged per plot at 10 weeks after planting were recorded (Geleta, 2010). Inspection of the plot for residues (Data not shown) revealed violation of the ANOVA preconditions. Transformation using square root method "(X+1), where "X" is the number of emerged *Alectra* shoots per plot or number of cowpea plants infested by *Alectra* normalised the situation (Rugare *et al*., 2013).

Genotypic responses on *Alectra* shoots count and number of cowpea plant infested by *Alectra* were analysed using Analysis of variances (ANOVA) and Regression analysis approaches in GenStat Discovery Edition 15$^{th}$ (Payne *et al*., 2012). Diallel analysis was performed using Griffings (1956) method II fixed model I. The relative contributions of GCA to SCA were analysed using bakers ratio (Baker's, 1978) computed as $2V_{gca} / (2V_{gca} + V_{sca})$. Where; $V_{gca}$ and $V_{sca}$ are variance component due to GCA and SCA, respectively. Narrow-sense heritability ($h^2$) which measures the proportion of additive variance in the overall variance was estimated as follows:

$$h^2 = V_A / (V_A + V_D + V_E)$$

While, broad-sense heritability ($H^2$) which measures the proportion of both additive and dominance variances in the overall variance, was estimated as follows (Acquaah, 2007):

$$H^2 = V_A + V_D / (V_A + V_D + V_E)$$

Where:
$V_D$ = Variance component due to SCA;

$V_A$ = Variance component due to GCA; and

$V_E$ = environmental or error variance.

## RESULTS AND DISCUSSION

High significant differences ($P< 0.001$) were found for number of *Alectra* shoots emerged and number of cowpea plant infested by *Alectra* among genotypes at Ilonga site (Table 2). No significant differences in reaction to *A. vogelii* at Hombolo site in Dodoma were found (Table 2). This was probably due to prolonged drought that affected both crop stand and *Alectra vogelii's* degree of virulence at Hombolo site (Mbwaga *et al*., 2010).

The general combining ability (GCA) and specific combining ability (SCA) effects for both *Alectra* emergency and its infestation were significant ($P < 0.05$) (Table 2). Likewise, Baker's ratio, for number of *Alectra* shoots emerged and number of cowpea plant infested were observed to be 0.62 and 0.66 respectively (Table 3). This signifies that both additive and non- additive gene action effects are important components in controlling trait for resistance to *Alectra vogelii* in cowpea. Further analysis of genetic component of variation (Table 3) shows that broad sense heritability of 66.48 and 66.78% were estimated for number of *Alectra* shoots emerged and

TABLE 1. Materials used in 7x7 half diallel analysis experiment to determine inheritance for resistance of *Alectra vogelii* at Ilonga and Hombolo Agriculture stations in Tanzania

| Parental identity | Genotype | Reaction to *A. vogelii* | Source |
|---|---|---|---|
| $P_1$ | B301 | Resistant | IITA |
| $P_2$ | IT99K-7-21-2-2-1 | Resistant | ARI-Ilonga |
| $P_3$ | IT99K-573-1 | Resistant | ARI-Ilonga |
| $P_4$ | IT99K-1122 | Tolerant | ARI-Ilonga |
| $P_5$ | VULI-1 | Susceptible | ARI-Ilonga |
| $P_6$ | VULI-2 | Susceptible | ARI-Ilonga |
| $P_7$ | TUMAINI | Susceptible | ARI-Ilonga |

TABLE 2. Mean squares for 7x7 half diallel for cowpea genotypes and their parents evaluated for their reaction to *Alectra vogelii*

| Source of variation | d.f | Ilonga Location | | Hombolo Location | |
|---|---|---|---|---|---|
| | | No. *Alectra* shoot | No. plant infested | No. *Alectra* shoots | No. plant infested |
| Replication | 2 | 2.13 | 0.56 | 0.66 | 0.05 |
| Genotypes | 27 | 1.07*** | 0.25*** | 1.12 | 0.16 |
| GCA | 6 | 2.48*** | 0.61*** | | |
| SCA | 21 | 0.66* | 0.15* | | |
| Error | 54 | 0.38 | 0.09 | 1.29 | 0.15 |

*and *** significantly different at 0.5 and 0.001 probability levels respectively

TALE 3. Estimates of genetic parameters and their ratios in the genotypes of 7x7 half diallel and their parent observed for trait of resistance to *Alectra vogelii* in cowpea evaluated at Ilonga in Tanzania

| Parameter | Number of *Alectra* shoot emerge | Number of plant infested per plot per plot |
|---|---|---|
| $h^2_{ns}$ (%) | 41.28 | 44.39 |
| $H^2_{bs}$ (%) | 66.48 | 66.78 |
| Ratio 2Vgca/(2Vgca+Vsca) | 0.62 | 0.66 |

$h^2$, Narrow sense heritability; $H^2$, Broad sense heritability; ratio 2Vgca/(2Vgca+Vsca), Baker's ratio; Vgca, variances for general combining ability; Vsca, variance for specific combining ability

number of cowpea plant infested, respectively; while narrow sense heritability of 41.28 and 44.39% were observed for number of *Alectra* shoots emerged and number of cowpea plant infested respectively. The results suggest that, there will be a response to selection when breeding or improving for resistance trait to *Alectra vogelii* in cowpea (Facloner, 1989). Therefore, this study suggests that there will be genetic gain from selection for the trait of resistance of cowpea to *A. vogelii* infestation when visual phenotypic selection is done. High heritability ensures the possibility for early generation testing (Acquaah, 2007; Karademir *et al*., 2007). On the other hand, high heritability observed for this trait in this study implies that resistance for *Alectra* in cowpea is conditioned by few major genes, with minor effect of partial dominance (Falconer and Mackay, 1996; Faurie *et al*., 2011). This finding is in agreement with Singh *et al*. (1993) and Atokple *et al*. (1995), who found that dominant genes condition the resistance to *Alectra vogelii* in cowpea.

In terms of GCA, parent IT99K-7-21-2-2-1 and IT99K-573-1 exhibited significance (P < 0.05) negative effects to both number of *Alectra* shoots emerged and number of cowpea plant infested (Table 4). The negative effect is desirable and important because it indicates the presence of a high gene frequency for *Alectra* resistance in the materials. Therefore, parents IT99K-27-2-2-1 and IT99K-573-1 were the best general combiners in the hybridisation for genetic improvement for this trait. Mbwaga *et al.* (2010), while working on developing and promoting *Alectra* resistant cowpea cultivars for smallholder farmers in Malawi and Tanzania recommended the same parents as the best source of *Alectra* resistance in cowpea. Likewise, parent VULI-2 showed a significant positive GCA effects (P < 0.001) in both number of *Alectra* shoots emerged and number of cowpea plants infested (Table 4); while VULI-1 showed a significant (P < 0.05) positive GCA effects in number of cowpea infested implying that they were transmitting susceptibility genes to progenies.

TABLE 4. Estimate of general combining ability (GCA) for number of *Alectra* shoots emerged and number of cowpea plant infested by *Alectra* among seven parents used for evaluation for reaction of cowpea to *Alectra vogelii* at Ilonga site in Tanzania

| Parent | Code | Number of *Alectra* emerge per plot | Number of plant infested per plot |
|---|---|---|---|
| B301 | $P_1$ | -0.25 | -0.08 |
| IT99K-7-21-2-2-1 | $P_2$ | -0.56* | -0.27* |
| IT99K-573-1 | $P_3$ | -0.49* | -0.30* |
| 1T99K-1122 | $P_4$ | -0.19 | -0.09 |
| VULI-1 | $P_5$ | 0.47 | 0.28* |
| VULI-2 | $P_6$ | 0.88*** | 0.39*** |
| TUMAINI | $P_7$ | 0.14 | 0.07 |
| Standard error | | 0.23 | 0.11 |

* and *** significantly different at P < 0.5 and P < 0.001 probability levels, respectively

TABLE 5. Estimates of specific combining ability (SCA) effects for number of *Alectra* shoots emerged and number of cowpea plant infested by *Alectra* among 21 $F_2$ genotypes of 7x7 half diallel evaluated for their reaction to *Alectra vogelii* in cowpea at Ilonga site in Tanzania

| Parent/Crosses | No. of *Alectra* emerge per plot | No. of plant infested per plot |
|---|---|---|
| $P_1xP_2$ | 0.46 | 0.34 |
| $P_1xP_3$ | 0.75 | 0.33 |
| $P_1xP_4$ | -0.13 | 0.08 |
| $P_1xP_5$ | -0.37 | 0.04 |
| $P_1xP_6$ | -0.41 | -0.23 |
| $P_1xP_7$ | -0.01 | -0.10 |
| $P_2xP_3$ | 0.78 | 0.62* |
| $P_2xP_4$ | 0.29 | 0.07 |
| $P_2xP_5$ | -0.44 | -0.26 |
| $P_2xP_6$ | -0.64 | -0.30 |
| $P_2xP_7$ | -0.39 | -0.22 |
| $P_3xP_4$ | -0.47 | -0.28 |
| $P_3xP_5$ | -0.38 | -0.17 |
| $P_3xP_6$ | -0.42 | -0.34 |
| $P_3xP_7$ | 0.07 | -0.02 |
| $P_4xP_5$ | -0.60 | -0.09 |
| $P_4xP_6$ | 0.70* | 0.72** |
| $P_4xP_7$ | 0.47 | 0.21 |
| $P_5xP_6$ | 1.86** | 0.75** |
| $P_5xP_7$ | -1.20* | -0.54* |
| $P_6xP_7$ | 0.33 | 0.28 |
| Standard error | 0.55 | 0.26 |

*, ** and *** significantly different at P < 0.05, P < 0.01 and P < 0.001 probability levels respectively

A negative significance (P < 0.05) SCA effects in number of *Alectra* shoots emerged and number of cowpea plant infested by *Alectra* was observed in VULI-1xVULI-2 (Table 5). This suggests that, cross VULI-1 x VULI-2 was significantly more resistant compared to other crosses with one parent in common. The cross between VULI-1 and VULI-2, which was identified as best specific combiner derived from parents that has proved to be poor general combiners for resistance trait, signifies the presence of non-additivity influence for this trait. This non additive gene action can be best exploited by multiple crosses, followed by inter-mating among desirable segregates and selection (Singh *et al.*, 2006). Generally, the best breeding method for improving this trait should be based in hybridisation and or followed by selection in order to exploit both additivity and non-additivity effect of the trait and early generation testing can be done for the advanced generation with maximum success.

The fact that there were no significant differences in shoot emergency and number of plants infected evaluated at Hombolo (Table 2), implies that this trait is dependent on the environment. Therefore, use of molecular markers, which are independent of the environment, in selecting for resistance to *A. vogelii* infestation can be most helpful. In this regard, a mapping population for use in detecting associated molecular markers can be created by crossing two genotypes with significant positive GCA effects and negative GCA effect (Collard *et al.*, 2005;

Tembo *et al.,* 2014). No of plant infested From our work a suitable cross can be between VULI-2 x IT99K-573-1 or IT99K-7-21-2-2-1.

## CONCLUSION

The nature of gene action conditioning resistance to *A. vogelii* in cowpea was estimated to be both additive and non- additive, with additivity being more important. Therefore it is important that hybridisation method followed by selection be considered in cowpea breeding programmes that involve breeding for resistance to *Alectra vogelii* in cowpea. The narrow sense heritability of 41.28 and 44.39% were observed for number of *Alectra* shoots emerged and number of cowpea plant infested implies that there will be genetic gain from selection for the resistance trait of cowpea to *A. vogelii* infestation when visual phenotypic selection is done.

## ACKNOWLEDGEMENT

The authors are very grateful to Initiative Agriculture Research Innovative (iAGRI) project based at Sokoine University of Agriculture (SUA) in collaboration with Regional Universities Forum for Capacity Building in Agriculture (RUFORUM) at Makerere University for their full grant support channelled through the University of Zambia (UNZA).

## REFERENCES

Acquaah, G. 2007. Introduction to quantitative genetics In: Principles of plant genetics and breeding. Black well Publisher, Carlton Australia. pp. 126-144.

Atokple, I. D. K., Singh, B.B. and Emechebe, A.M. 1995. Genetics of resistance to *Striga* and *Alectra* in cowpea. *Journal of Heredity*. pp 86: 45-49.

Bagnall-Oakley, H., Gibberd, V. and Nyongesa, T.E. 1991. The incidence and control of *A. vogelii,* in Embu district, Kenya. In: Ransom, J. K., Mussleman, L. J., Worsham, A. D and Parker, C. (Eds.), Proceedings of the 5th International Symposium on Parasitic Weeds, CYMMIT, Nairobi, Kenya.

Baker, R. J. 1978. Issues in diallel analysis. *Crop Science* 18:533-536

Berner, D. K and Williams, O. A. 1998.Germination Stimulation of *Striga gesnorioides* seed by host and non-host.Plant Disease. 82:1242-1247.

Dugje, I. Y., Omoigui, L. O., Ekeleme, F., Kamara, A. Y and Ajeigbe, H. 2009. Farmers guide to cowpea production in West Africa. International Institute of Tropical Agriculture (IITA) 2009, Ibadan Nigeria. pp. 125-148.

Falconer, D. S. 1989. Introduction to quantitative genetics. 3rd edition. Longman Group, New York. 438pp.

Falconer, D.S and Mackay, T.F.C. 1996. Introduction to quantitative genetics, 4th edition. Essex, UK: Longman.

FAOSTAT. 2008. Statistics of cowpea production. Available on http://FAOSTAT.fao.org. Accessed on 20/08/2010.

Geleta, L.F. 2010. Cowpea landraces of Botswana: A potential resistance source for *Alectra vogelii*. Aspect of Applied Biology. 96.

Griffings, B. 1956. Concept of general and specific combining ability in relation to diallel crossing systems. *Australia Journal of Biological Science*. 9:463-93.

Kabambe, V.H., Nambuzi, S., Kauwa, A.E and Ngwira, A.R. 2005. Role of cowpea and silver leaf intercropping on witch weed (*Striga asiatica*L. Kuntze) in maize in Malawi. In: Safalaoh, A.C.L, Gowela, J.P., Mtethiwa, A.H. (Eds). Proceedings of the Second Bunda College Research Dissemination Conference Lilongwe, Malawi. pp. 22-27.

Karademir, C., Gencer, O andKarademir, E. 2007. Heterosis and combining ability for yield and fiber properties in cotton (*Gossypium hirsutum* L.) under drought stress conditions. *Asian Journal of Plant Science* 6:667-72.

Karanja, J.K., Nguluu, S.N and Gatheru, M. 2010. Farm yard manure reduces the virulence of *Alectra vogelii* (Benth) on cowpea (*Vigna unguiculata)*. Unpublished paper presented at Bondo University College conference, February, 2010.

Mainjeni, C.E. 1999. The host range of *Alectra vogelii* Benth.From Malawi and resistance in common bean and cowpea.MSc. Thesis, University of Bath, UK. 83pp.

Mbwaga, A., Hella, J., Mligo, J., Kabambe, V. and Bokos, J. 2007. Development and promotion of *Alectra* resistant cowpea cultivars for smallholder farmers in Malawi and Tanzania. McKnight Foundation Collaborative Crops Research Project No: 06741

Mbwaga, A., Hella, J., Mligo, J., Kabambe, V and Bokos, J. 2010. Development and promotion of *Alectra* resistant cowpea cultivars for smallholder farmers in Malawi and Tanzania. McKnight Foundation Collaborative Crops Research Project No: 06741.

Payne, R.W., Murray, D. A., Harding, S. A., Baird, D.B. and Soutar, D.M. 2012. An Introduction to GenStat for Windows 17th Edition. VSN International, Hemel Hempstead, UK.

Rachie, K.O., Rawal, K.M and Franckowiak, J.D. 1975. A rapid method of handling cowpeas. Technical bulletin No.2, IITA, Ibadan, Nigeria. 18pp.

Rubiales, D., Perez de Luque, A., Fernandez-Aparica, M., Sillero, J. C., Roman, B., Kharrat, M., Khalil, S., Joel, D.M. and Riches, C.R. 2006. Screening techniques and sources of resistance to parasitic weeds in grain legumes. Euphytica 147:187-199

Rugare, J.T., Mbwasa, S. and Tsekenedza, S. 2013. Response of cowpea (*Vigna unguiculata* L.) Genotypes to witch weed (*Alectra vogelii* Benth) Infection. *Asian Journal of Agricultural and Rural Development* 3(9):667-673.

Singh, I., Badaga, S.N and Tikka, S.B.S. 2006.Combining ability for yield over environments in cowpea (*Vigna unguiculata* L. Walp). *Indian Journal of Crop Science*, 1 (1-2) :205-206.

Singh, B.B., Ehlers, J.D., Sharma, B. and Freire Filho, F.R.2002. Recent progress in cowpea breeding. In: Fatokun, C.A., Tarawali, S.A., Singh, B.B., Kormawa, P.M. and Tamo, M. (Eds.). Challenges and opportunities for Enhancing Sustainable Cowpea Production, IITA, Ibadan, Nigeria. pp. 22-40.

Singh, B.B. and Emechebe, A.M. 1997. Advances in research on cowpea *Striga* and *Alectra*. In: Advances in cowpea research. Singh, B.B., Mohan, R., Dashiell, K.E. and Jackai, L.E.N. pp. 215-224. IITA-Jirca, Ibadan, Nigeria.

Singh, B.B., Emechebe, A.M. and Atopke, I.D.K. 1993. Inheritance of *Alectra* resistance in cowpea genotype B301. Crop Science 33:70-72 IITA (1983). Research highlights. International Institute of Tropical Agriculture, Ibadan, Nigeria.

Stahley, K., Slakie, E., Derksen-Schrock, K., Gugerty, M.K. and Anderson, C.I. 2012. LSMS integrated surveys on agriculture, United Republic of Tanzania: Legumes. EPAR Brief No. 189. Washington: Evans School Policy Analysis and Research – University of Washington.

Tarawali, S.A., Singh, B.B., Gupta, S.C., Tabo, R., Harris, F., Nokoe, S., Ferna´ndez-Rivera,S., Bationo, A., Manyong, V. M., Makinde, K. and Odion, E. C. 2002. Cowpea as a key factor for a new approach to integrated crop–livestock systems research in the dry savannas of West Africa. In: Fatokun, C.A., Tarawali, S., Singh, B.B., Kormawa, PM. and Tamo M. (Eds.). Challenges and opportunities for enhancing sustainable cowpea production. International Institute of Tropical Agriculture, Ibadan, Nigeria. pp. 233-251.

Timko, M.P and Singh, B.B. 2008. Cowpea, a multifunctional legume. In: Genomics of tropical crop plants. Moore, P.H. and Ming, R. (Eds.), Springer, New York. pp. 227-257.