Reviewing Striga, its economic importance and management practices

Assoc. Prof. Dr. Evans Jimmy Kenyi, PhD

Dean, College of Agriculture, Dr. John Garang University, Bor, South Sudan

E-mail: nyaliga53@gmail.com

Prof. Dr. Sampson A-Koi Binyason, PhD

Director-General, Yambio Polytechnic Institute of Agriculture

E-mail: sampsonaliai@gmail.com

Assoc. Prof. Dr. Deng Manasseh Mach, PhD

Vice-Chancellor, University of Rumbek, Rumbek, South Sudan

E-mail: dengmanasseh@yahoo.uk.co

Assoc. Prof. Dr. Akim Ajieth Buny, PhD

College of Management Sciences, Dr. John Garang University, Bor, South Sudan. E-mail: akim.bunny@gmail.com

Prof. Dr. Wani Marcello D'raga, PhD

College of Natural Resources, University of Juba

E-mail: drwani49@gmail.com

Abstract

Previous research identified over 4,000 species of angiosperms able to directly invade and parasitize other plants. Few of these are weeds and parasitize cultivated plants with almost no satisfactory control. These weedy parasites belong to various families and attach to host roots, shoots, or branches. The most damaging weedy root parasite belongs to family Orobanchaceae (formerly Scrophulariaceae). Two genera of this family are of economic importance. The findings of this study revealed that to alleviate hunger and reduce food insecurity especially in Sub-Saharan Africa, the scorch of *Striga* on cereals are be tackled vigorously. Therefore, objective of this review is to show areas where research on *Striga* has been done so that avenues for further and new research initiatives in the management of parasite could be directed.

Keywords: Striga, species of economic importance, striga management practices

Introduction

Most cereals are vulnerable to the parasite *Striga* resulting in low crop yield. In Sub-Saharan Africa, more than 50% of cereals- pearl millet (*Pennisetum glaucum* [L.] R. Br and *Pennisetum americum* [L.] K. Schum, maize (*Zea mays* [L.] and sorghum (*Sorghum bicolor* [L.] Moench are estimated to be infested with *Striga* (Sauerborn, 1991). Sorghum according to ICRISAT (1992) ranked the second most important cereal in Africa, globally the 5th in cereals (see cereal statistics) and according to Khidir (1983) the most consumed grain in the Sudan. The crop is used in human food, while grain is ground for making porridge and bread. In some African countries including parts of the Sudan, it is brewed for making local beer. The grain is also used as feed for animals and stalks provide fodder, fuel, shelter and sugar.

Sorghum yield losses due to *Striga* are usually high and varying depending on the crop genotype and level of infestation. Annual crop losses due to *Striga* have been estimated at 40% (Lagoke et al, 1991) but in some countries like the Sudan and Ethiopia, 65-100% has been experienced in the field frequently.

Review

The Plant, *Striga*

Nickrent et al. (1998) identified over 4,000 species of angiosperms able to directly invade and parasitize other plants. Few of these are weeds and parasitize cultivated plants with almost no control (Joel et al, 2007a; Gressel et al. 2004; Parker and Riches, 1993a). These weedy parasites belong to various families and attach to host roots, shoots, or branches. According to Joel et al. (2007b), the most damaging weedy root parasite belongs to family Orobanchaceae (formerly Scrophulariaceae). Two genera of this family are of economic importance – Orobanche and *Striga* (S.).

Striga is an obligate root parasite that includes 50 to 60 species though only about a quarter of these parasitize crops (Joel et al. 2007c). It is most damaging to grain grasses and legumes endangering food security in many developing countries (Parker and Riches, 1993b). The name "witchweed" given to *Striga* was coined from the debilitating effects it inflicts on its host even before emergence.

The genus *Striga* has many species parasitizing many crops and weeds in different regions of similar agro-climatic zones. The most destructive species on cereals are *S. hermonthica* (Del.) Benth, *S. asiatica* (L.) Kuntze, *S. densiflora* Benth, *S. angustifolia* Sadanha and *S. aspera* (Willd)

Striga has tiny seeds measuring 0.15-0.31 mm and weighs 3-15µg (Stump, 2007; Parker and Riches, 1993c). The number of seeds per capsule varies from 700 in *S. hermonthica* to 800 in *S. asiatica* and number of capsules per plant differs with an average of 60-70 in *S. hermonthica* and *S. asiatica* (Parker and Riches, 1993d). For successful host attachment, germination must take place within 3-4 mm of the host root since *Striga* radicles can only manage 2-4 mm (Ramaiah et al. 1991). To compensate for this biological restriction, *Striga* produces up to 450,000 seeds per plant which persist in the soil for up to 10 years (Eplee, 1992). Well-grown *Striga* plant may produce up to 500,000 seeds which under specific soil conditions may remain viable for 14 years (Parker and Riches, 1993e).

Species of economic importance

Four parasitic species of the genus *Striga* are of economic importance because of their impact as yield reducers (Parker and Riches, 1993f). Joel et al. (2007d) described the distribution and biology of these four *Striga* species as follows:

(i) *S. hermonthica* (Del.) Benth

S. hermonthica (Del.) Benth has the largest geographical distribution. It spreads in Africa between latitudes 5° N and 20° S. It is also found in South-East Asia. The plant is erect 50 to 100 cm high with pink flowers, five ribs on the calyx and bracts below each flower fringed with hairs. It is a parasite of a number of cereal crops in Africa and Arabia and most destructive to sorghum, maize, (*Zea mays* L.) and millet (*Pennisetum glaucum* L.)

(ii) *S. asiatica* (L.) Kuntze

S. asiatica (L) Kuntze is found in East, Central/Southern and West Africa. It is also found in India, the U.S. and Australia. The plant is slender with erect stems 15 to 30 cm in height. It is distinct in that the calyx has 10 ribs.

It parasitizes the same crops as *S. hermonthica.* In India, *S. asiatica* (L.) Kuntze together with *S. densiflora* Benth and *S. angustifolia* Saldanha are serious parasites of the new sorghum hybrids.

(iii) *S. forbesii* Benth

S. forbesii Benth is wide spread in Africa and India. It favours wet soil conditions and is predominantly found in Zimbabwe, Tanzania and Madagascar. Size of this parasite is between *S. hermonthica* and *S. asiatica* -30 to 40 cm high. It differs from both species in the shape of leaves. Its flowers are large, comparable to those of *S. hermonthica* but are pale pink with occasional white flowers. It is similar to *S. asiatica* in that both are self-pollinated. *S. forbesii* parasitizes sorghum, maize and millet.

(iv) *S. gesnerioides* (Willd) Vatke

This root parasite occurs in Africa, Arabian Peninsula and the Indian Sub-continent and was introduced to USA (Parker.1991a). It is succulent in appearance, about 15-30 cm in height and is broad from above the ground. The plant is pale green or purple with leaves reduced to scales. Flowers are pink to purple with 2-3 flowers open on each plant at peak flowering and turn dark blue as they wither. It has large tuberous haustorium that may reach 3cm in diameter. It is mainly a parasite of cowpea, tobacco and sweet potatoes.

Lifecycle of *Striga*

Joel et al. (1995) pointed out that *Striga* exhibited two main life phases: independent and parasitic. The independent phase begins with seed imbibition and germination and lasts a few days until the germinated parasite finds a host and attaches to it. The parasitic phase during which the parasite becomes dependent on nutrients derived from the host starts as soon as the haustorium invades the host root eventually forming a physiological bridge between the vascular system of the host and parasite (Joel, 2000). The following are the developmental stages of the parasite:

Seed dormancy and after - ripening.

Joel et al. (2007e) stated that when seeds of *Striga* from a mature fruit are released, they enter a period of dormancy or after – ripening during which seeds complete preparation for later germination. He suggested that this period is influenced by temperature and seems to limit germination of freshly shed seeds in the field at the end of the growing season ensuring germination only in the next season when host plants are able to support the whole life cycle of the parasite.

Wet dormancy

Alternatively, even after being imbibed and environmentally primed for germination, when seeds failed to find a suitable host, they can re-enter a low energy dormant state or “Wet dormancy”

(Vallance, 1950). This ensures seed longevity and is reversible with desiccation (Joel, et al. 2007f).

Seed germination

A chemical stimulus is needed to trigger germination of root parasites

(Press and Graves, 1995) Before a chemical stimulus was needed to trigger germination of the parasite, some metabolic processes must occur in order for the seed to become responsive to stimuli and germinate.

Conditioning

Joel et al. (1995) discovered that *Striga* seeds are conditioned after exposure to moist environment, imbibition of water and suitable temperature before they respond to germination stimulus in order to germinate. Conditioning lasts for 10 to 21 days within a temperature range between 20 and 40ºC but optimum temperature is between 25 and 35ºC. After this, seeds respond to stimuli in order to germinate.

Germination stimulation

Joel, (2000) found that parasitic plants of Orobanchaceae are capable to perceive the presence of adjacent living host roots by sensing strigolactones from other the plant roots even at extremely low concentrations. Several strigolactones from various plant species proved to stimulate plants of Orobanchaceae (Yasuda et al. 2003). Conditioned *Striga* seeds germinated under influence of strigolactones produced by sorghum. Another *Striga* seed also germinated as a result of a stimulant produced by sorgoleone- a plant growth inhibitor from sorghum roots (Czarnota et al, 2003; Hejl and Koster, 2004). After germination, the radicle grows towards the host root.

Haustorial initiation

In order for *Striga* to attach to its host, a haustorium is formed through which the parasite acquires host substances vital throughout its life. As it occurs to germination, the parasite uses host-derived signals like kinetin, simple phenolic compounds and quinones to trigger haustorium initiation (Riopel and Timko. 1995). The remaining *Striga* seed food reserves are rapidly consumed once newly germinated *Striga* are exposed to haustorium initiation factors (Chang and Lynn, 1987).

Attachment and penetration

Hair – like projections cover the haustorium that develops on the radicle of *Striga*. Baird and Riopel (1983) discovered that these projections secrete adhesive that fixes the parasite to host root. After attachment, the host root is penetrated and continuity channel is formed with the host xylem through which the root parasite withdraws nutrients from the host roots (Kuijt, 1969).

Host parasite interaction

After the vascular connections have been established, *Striga* reduces growth and photosynthesis of its host though phytotoxic effects induced by enzymes and plant hormone changes (Gurney et al, 1995; Ransom et al, 1996).

Seed Production and Dispersal

Stewart, (1987) found that, young *Striga* shoots emerged above ground after six weeks, flowered after six weeks of emergence and is day neutral. Some *Striga* and *Orobanche* spp are self – pollinated while others are cross pollinated (Musselman et al, 1981).

The parasite (*Striga*) completes its life cycle within 7 to 16 weeks and fruits contain mature seeds two weeks after pollination depending on host phenology (Stewart, 1987). Seed production by a healthy *S. hermonthica* plant may exceed 200,000 and in exceptional cases successful parasites may reach half a million (Joel et al. 1995). Large quantities of long-lived seeds assure the parasite genetic adaptability to changes in host resistance and cultural practices. Joel et al. (2007g) suggested that since *Striga* seeds are minute, they are easily transferred from place to place by cultivation, water, wind, animals, vehicles and farm machinery.

***Striga* management practices developed**

The practices of *Striga* management developed are as follows:

Containment

Preventing movement of *Striga* into uninfected areas is described as containment. It is a key element in the eradication program in the U.S. (Sand and Manley, 1990). Spread of *Striga* seed involve human aided movement to new uninfected areas e.g. trade in crops, movement of agricultural implements.

Containment in the U.S. was done through regulatory program that include strict quarantine of all land that is infested by *Striga* (Sand and Manley, 1990). In Africa and Asia implementation of containment may prove effective through education, use of clean seed, avoiding use of tools from infested areas.

Host resistant/tolerant/immunity to *Striga*

Ejeta and Butler, (1993) defined *Striga* resistant sorghum as that which support significantly fewer *Striga* plants and produce high yield in the presence of *Striga* than a susceptible one whereas tolerant sorghum support as many *Striga* plants as do susceptible hosts but without a proportionate reduction in productivity. Immune sorghum genotypes, free of *Striga* when grown under varying infestation levels, are yet to be found.

Crops with resistance to *Striga* have been advocated as a cost effective method of reducing *Striga*- related losses compatible with the low - input system of African farmers (Joel et al. 2007h). Completely resistant cereal crops have yet to be found. However, partially resistant and tolerant cultivars had been reported with several mechanisms including rooting patterns that allow avoidance (Ransom and Odhiambo,1995); reduced levels of *Striga* germination stimulants (Ejeta and Butler 1993g); increased photosynthetic rate (Gurney et al. 2001); growth and delayed development that delay attachment (Gurney et al. 1999). Cultivars with improved resistance/tolerance to *Striga* have not yet been widely cultivated because they are poorly adapted, have low yield potential (Oswald and Ransom, 2004) or do not possess other required traits such as plant height and grain characters (Ezeaku and Gupta, 2004).

Conventional breeding for *Striga* resistance has been frustrating because plant breeding methods that work well for improving other desirable crop characteristics have not operated at the same efficiency for *Striga* resistance (Ejeta and Butler, 1993). Biotechnology is offering new approaches and tools such as molecular markers for mechanical resistance, incorporation of genes from wild relatives and mutation to improve levels of resistance (Haussmann et al, 2004; Gurney et al, 2003).

Cultural management practices

Several cultural management practices in *Striga* parasitized crops have been developed which include the following:

Crop rotation

Rotating *Striga* susceptible cereal crops with none susceptible crops particularly false hosts had long been advocated as a simple way of reducing *Striga* seed bank in the soil. Odhiambo and Ransom, (1994); Carsky et al. (2000); Sauerborn et al. (2000); Hess and Dodo (2004) demonstrated that rotations effectively reduce *Striga* numbers and increase yield in subsequent cereal crops. Berner et al. (1995) suggested that selected crops for rotations should be of high efficacy in germinating *Striga* seeds. Ransom (2000), Oswald and Ransom (2001) added that selection of rotational crops must be based on socioeconomic considerations (market value and availability). Development of ready and steady market for alternative crops may have a greater impact on adoption of rotations than biological effectiveness.

Managed or planted fallows with fast growing nitrogen fixing non- crop species, are grown to help subsequent crop productivity. Kwesiga, et al. (1999) found that *Sesbania sesban* (Linn.) Merrill. *Senna sianea* Irwin and Barnaby and *Leucaena leucocaphala* (Lam.) de Wit used in managed fallow system nearly eliminated *S. asiatica* development in a subsequent maize crop. Adoption of this system may be constrained by lack of seed, increased labor requirement and difficulties of crop harvest during fallow period.

Transplanting

Mature crop plants were found to be resistant to or minimize maize damage by *Striga* than young seedlings (Cechin and Press, 1993; Dawoud et al. 1996). Oswald and Ramson (2002) found increased maize yield and reduced *Striga* parasitism in transplanted maize seedlings compared to direct seeding. Late maturing maize cultivars benefited more from transplanting than earlier maturing ones (Oswald and Ransom, 2002). Transplanting sorghum was found more difficult than maize (Oswald et al. 2001). This system is constrained by high costs of labour and nursery requirement.

Drought, soil fertility and fertilizers

It has long been established that Striga is most problematic on soils of low fertility especially nitrogen (Joel et al. 2007i). Parker and Riches (1993f) reported that crop damage by *Striga* was most severe where drought and low soil fertility already limit crop productivity. Mumera, (1983) found that low nitrogen resulted in more *Striga* but high nitrogen levels suppressed it. Pesch and Pieterse (1982) demonstrated that there was direct toxic effect of urea on germination and vigor of Striga seedlings. However, Pieterse and Verklaij (1991) argued that *Striga* and soil fertility problems should be tackled concurrently. Ransom (1999) found dramatic increase in maize yield resulted after *Striga* was hand weeded or nitrogen fertilizer applied or when both treatments were applied. Parker, (1991b) pointed out that no consistent rate of nitrogen fertilizer has been established while Dawoud et al. (2007) found that *Striga* was reduced by about 56 % when urea was applied at 190 kg/ha.

Planting

Bebawi (1987) found that widely spaced sorghum reduced number of *Striga* per hectare. However, number of *S. hermonthica* per plant was reduced at high planting density.

Land preparation

This includes deep ploughing and zero or minimum tillage. Hess and Ejeta (1987) found that zero tillage reduced infestation of *S. hermonthica*.

Mixed or intercropping/shading

Mixed or intercropping has been adopted by farmers to avert risks of crop failure. In addition it is selectively used with trap crops to control *Striga*. Salle et al. (1987) reduced *S. hermonthica* in pearl millet by intercropping four rows of groundnuts and one row of millet. Carson (1989) also reduced *Striga* incidence by planting groundnuts within sorghum rows rather than in alternating rows with sorghum. It was suggested that reduction of *Striga* by intercropping was due to both low temperature and shading (Parker, 1991c).

Mechanical/hand-pulling

Sarwala is a form of mechanical removal of *Striga* from a dense population of sorghum 30-40 days after crop emergence. This operation results in reduced number of *Striga* and increased sorghum yield (Yousif, 2001). On the other hand, hand-pulling has been practiced by small scale farmers for the control of *Striga* as well as other weeds. There are conflicting reports about benefit of hand-pulling of *Striga*. However, Ramaiah (1985) found that hand-pulling of *Striga* once at flowering was beneficial in millet.

Chemical control

Cheap, safe and effective herbicides are an important option in the control of *Striga* in crops. Herbicides 2, 4-D (2, 4-dichloro-phenoxy acetic acid) and its derivatives are growth regulators and relatively cheap herbicides with plant hormone disruption action. It has been reported by Kasasian and Parker (1971), Dowler and Robinson (1990) and Langston and English (1990) that 2, 4-D showed high suppression activity at the germination stage of *Striga*. There was no progress in exploiting this finding for the control of *Striga* in the field. However, it has been effectively used in the control of emerged *Striga* in crops at the rate of 0.5-1 kg.a.e./ha but proved ineffective in reducing related *Striga* yield losses (Parker, 1991d and Joel et al. 2007j). Odhiambo and Ransom (1993) found that Dicamba provide protection to maize when applied before *Striga* emergence but timing of application is critical to crop safety and *Striga* control. Aliyu et al. (2004) reported that maize yield improved in *Striga* infested fields with a pre-emergence application of metolachlor and prometryne followed by acifluorfen applied post-emergence.

Germination stimulants

Ethylene was found to induce germination of conditioned *Striga* seeds (Egley and Dale, 1970). This became a key treatment in the successful eradication programmer of S. asiatica in the US (Egley et al. 1990). In Africa, results of the application of ethylene were disappointing due perhaps, to soil properties and lower sensivity of the parasite to stimulation by ethylene (Bebawi and Eplee, 1986; Odhiambo and Ransom 1996). Ethephon had been tested as an alternative to ethylene for easy application but its activity might have been restricted by moisture and soil pH (Egley et al. 1990; Babiker and Hamdoun, 1983).

Strigol is a natural stimulant isolated from cotton (Cook et al. 1972). Hopes that analogues of Strigol would be of practical value were not realized (Johnson, et al. 1976). There were reports of partial success with selected compounds including GR-7 and GR-24 on S. asiatica and *S. hermonthica* control (Norris and Eplee, 1983; Babiker and Hamdoun, 1982). Because of costs and limited market only GR-24 is one of the few compounds that can be synthesized in large quantities in a cheaper way and is mostly used by researchers as germination stimulant (Kuiper, 1997).

Seed dressing

This technique is effective when selectivity exists between crop and parasite. Imazapyr and pyrthiobac as seed dressings to maize seeds showed considerable activity against *Striga*. This system provided early season control of *S. asiatica* and *S. hermonthica* and increased yield by threefold in heavily infested field and permitted intercropping (Kanampiu et al. 2002).

Seed hardening. Alternate wetting and drying of host seeds in solutions of phenolic acids was reported to induce resistance to *S. asiatica* (Bharathalakshimi and Jayachandra, 1980). Awad (1989), however, failed to confirm this finding.

Anti transpirants

It was discovered that emerged *S. hermonthica* can be killed by preventing its transpiration under hot conditions. Shah, et al. (1987) confirmed that *S. hermonthica* stomata remain open under extreme heat and under darkness. This indicates that it has poor tolerance to heat and has to depend on the cooling effect of transpiration under hot conditions.

Biological control

Berner, et al (2003) defined biological control as the number of insects and diseases that can affect growth and reproduction of *Striga* species. Biological control with insects has been tested with limited success. Nevertheless, *Smicronyx albovariegatus* Faust and *Junonia orithya* Burgess and Trimboli were reported to have reduced the amount of new *Striga* seeds being produced in some locations and years (Kroschel et al.1995, 1999; Traore et al. 1996). The fungus *Fusarium oxysporum* (Schltdl.) was identified as highly pathogenic to all developing stages of *Striga* (Ciotola et al. 1995; Kroschel et al. 1996). Selected strains of this fungus have been formulated as mycoherbicides which effectively controlled *Striga* and increased crop yields (Ciotola et al. 2000; Marley et al. 2004). *Fusarium nygamai* and *F. oxysporum* were reported to have reduced *S. hermonthica* emergence by over 90 % (Abbasher and Sauerborn 1992; Ciotola et al. 1995). A major challenge to this technology is lack of delivery to the farming community and lack of the commercial backing. The bacterium *Pseudomonas syringae* p.v. glycinea Coerper produces sufficient ethylene to induce suicidal germination of *Striga* seeds (Berner et al.1999). Research on this is still in the infancy stage.

Integrated *Striga* management

There is general agreement that the control of parasitic weeds requires an integrated approach and many different combinations of approach have been tested and recommended (Parker, 1991e). The various *Striga* management practices reviewed above offer varying levels of *Striga* control depending on environment. None can provide complete control. An integrated *Striga* management approach may offer the best possibility for impact at the farm level. Berner et al. (1995) suggested rotation and trap crops that reduce seed bank, Schulz et al. (2003) suggested resistant maize genotypes with trap crops, Kanampiu et al (2003) and Marley et al. (2004) suggested combination of mycoherbicides and imazapyr with resistant maize cultivars and Aliyu et al. (2004) suggested combining of herbicides with high yielding tolerant maize as some integrated *Striga* control options. These options may not work elsewhere due to environmental factors, agricultural systems and other factors (Joel et al. 2007k).

Conclusion

This review covers a variety of knowledge about the plant *Striga*, its life cycle and management options attempted while at the same time it opens new opportunities to study the parasite further and to improve or device other methods for its management.

References

Abbasher, A. A., and J. Sauerborn (1992) *Fusarium nygamai* a potential bioherbicide for *Striga hermonthica* control in sorghum *Biological Control* 2:291–296.

Aliyu, L., S. T. O. Lagoke, R. J. Carsky, J. Kling, O. Omotayo, and J Y Shebayan (2004a, b) Technical and economic evaluation of some *Striga* control packages in maize in the Nigerian Guinea Savanna *Crop Protection* 23: 65-69.

Awad, A. E. (1989). Effects of Dicamba, Nitrogen and Pre-sowing Hardening of Host seeds with Phenolic Acids on Witchweed control in Sorghum. *PhD thesis. North Carolina State University* Raleigh USA

Babiker, A.G.T., A.M. Hamdoun. (1982) Factors affecting the activity of GR-7 in stimulating germination of *Striga hermonthica* (Del) Benth *Weed Research* 22, 111-115

Babiker, A.G.T., A.M. Hamdoun. (1983). Factors affecting activity of Ethephon in stimulating germination of *Striga hermonthica* (Del) Benth *Weed Research* .23. 125 - 131.

Baird, W. V., and J. L Riopel (1983) Experimental studies of the attachment of the parasite angiosperm *Agalinus purpurea* to a host. *Protoplasm* 118: 206-218.

Bebawi, F.F. (1987). Cultural practices in witchweed management. In: *Parasitic weeds in Agriculture*. *Striga* Vol.1 pp.159-171 (ed.by L .J Musselman) Boca Raton CRC Press.

Bebawi, F.F., and R.E. Eplee (1986) Efficacy of ethylene as germination Stimulant of *Striga hermonthica* seed *Weed Science*. 34. 694-698.

Berner, D. K., J. G. Kling, and B. B Singh (1995) *Striga* research and control: A perspective from Africa. *Plant Diseases* 79: 652-660.

Berner, D. K., J. Sauerborn, D. E. Hess, and A. M Emechebe (2003) The role of biological control in integrated management of *Striga* species in Africa. In: P. Neuenschwander, C. Borgemeister, and J. Langewald (eds.). *Biological Control in IPM Systems in Africa*. p. 559-576. CABI Publishing Wallingford UK

Berner, D. K., N. W Schaad, and B. Volksch (1999) Use of ethylene- producing bacteria for stimulating *Striga* spp. seed germination *Biological Control* 15: 274-282.

Bharathalakshimi and Jayachandra, (1980) Presowing hardening of the host with Phenolic acids reduces induction of seed germination in the root parasite *Striga asiatica*. *Tropical Pest Management* 26 309 – 312.

Carsky, R. J., D. K. Berner, J. G. Kling, A. Melake-Berhan, and S. Schulz (2000). Reduction of *Striga hermonthica* parasitism on maize using soybean rotation *International Journal of Pest Management* 46: 115-120.

Carson, A.G. (1989). Effects of intercropping sorghum and groundnuts on density

of *Striga hermonthica* in The Gambia *Tropical Pest Management* 35 130-132

Cechin, I., and M. C Press (1993) Nitrogen relations of the sorghum-*Striga hermonthica* host-parasite association: growth and photosynthesis. *Plant Cell Environment* 16:237–247.

Chang, M. and D.G. Lynn (1987) Plant-plant recognition: chemistry- mediating host identification in the Scrophulariaceae root parasites In: G.R.Walker (Ed) Allelochemicals: Role in Agriculture and Forestry *American Chemistry Society* Washington DC pp. 551-561

Ciotola, M., A. Di'Tommaso, and A. K. Watson (2000) Chlamydospore production,

inoculation methods and pathogenicity of *Fusarium oxysporum* M12-4A. A mycoherbicide of *Striga hermonthica Biocontrol of Science and Technology* 10: 129-145.

Ciotola, M., A. K. Watson, and S. G Hallett (1995a, b) Discovery of an isolate of

Fusarum oxysporum with potential to control *Striga hermonthica* in Africa *Weed Research* 35: 303-309.

Cook C.E., L.P. Whichard, M.E. Wall, G.H. Egley, P Coggon, and P.A Luhan, and A.T. MacPhail (1972) Germination Stimulants Π the structure of Strigol- A potent seed germination stimulant for witchweed (*Striga lutea* Lour.). *Journal of American Chemistry Society* 94: 6198-6199.

Czarnota, M. A., A M Rimando, and L.A Weston (2003) Evaluation of root exudates of seven sorghum accessions *Journal of Chemical Ecolology* 29: 2073-2083.

Dawoud, A.D., E.A.Ahmed, N.K.Abdalla, J.Sauerborn, A.G.T.Babiker (2007) Influence of intercropping of sorghum (*Sorghum bicolor* [L.] Moench) with hyacinth bean (*Lablab purpureous* L.) on *Striga hermonthica* control and sorghum growth and yield *Sudan Journal of Agricultural Research* Special Issue 10: 101-106

Dawoud, D. A., J Sauerborn, and J Kroschel (1996) Transplanting of sorghum: A method to reduce yield losses caused by the parasitic weed *Striga*. p. 777–785. In: M. T. Moreno, J. I. Cubero, D. Berner, D. Joel, L. J. Musselman, and C. Parker (eds.), Advances in parasitic plant research—*Proceedings of 6th Parasitic Weed Symposium*. Junta de Andalucía, Córdoba, Spain

Dowler, C. C and E.L. Robinson (1990) Early herbicide evaluation for control of witchweed from 1957 through 1964 pp.91-98 In: Witchweed Research and Control in the United States of America. P.F. Sand, R.E. Eplee and R.A. Westbrook (Eds.) *Weed Science Society of America* Champaign.

Egley, G. H., and J. D. Dale (1970) Ethylene, 2-chloroethylphosphonic acid and witchweed germination *Weed Science* 18:586–589.

Egley, G. H., R. E. Eplee, and R. S Norris (1990a, b) Discovery and development of ethylene as a witchweed seed germination stimulant. p. 56-67. In: P.F. Sand, R.F. Eplee and R.G.Wesbooks (eds.) *Witchweed Research and Control in the United States.* WSSA. Champaign.

Ejeta, G., and L. G Butler (1993a, b, c) Host-parasite interactions throughout the *Striga* life cycle, their contributions to *Striga* and resistance *African Crop Science Journal* 1: 75-80.

Eplee, R. E. (1992). Witchweed (*Striga asiatica*.): an overview of management strategies in the USA. *Crop Protection* 1: 3-7.

Ezeaku, I. E., and S. C. Gupta (2004) Development of sorghum populations for resistance to *Striga hermonthica* in the Nigerian Sudan Savanna *African Journal of Biotechnology* 3:324–329.

Gressel, J., A., Hana., G. Head., W. Marasas, B. Obilana, J Ochanda, T. Souissi, and G.Tzotzos. (2004). Major heretofore intractable biotic constraints to African food security that may be amendable to novel technological solutions *Crop Protection* 23: 661-689.

Gurney, A L., M.C. Press and J K Ransom (1995) The parasitic angiosperm *Striga hermonthica* can reduce photosynthesis of its sorghum and maize hosts in the field. *Journal of Experimental Botany* 46: 1817-1823.

Gurney, A. L., M. C. Press, and J. D. Scholes (1999) Infection time and density influence the response of sorghum to the parasitic angiosperm *Striga hermonthica*. *New Phytology*.143:573–580.

Gurney, A., A. Taylor, A. Mbwaga, J. D. Scholes, and M C Press (2001) Do maize cultivars demonstrate tolerance to parasitic weed *Striga asiatica*? *Weed Research*. 42: 299-306.

Gurney, A.L., D. Grimanelli, F.Kanampiu, D Hoisington, J.D. Scholes and M.C. Press (2003) Novel sources of resistance to *Striga hermonthica* in *Tripsacum dactyloides* a wild relative of maize. *New Phytology* 160: 557-568.

Haussmann, B.I.G., D.E. Hess, G.O, Omanya, R.T. Felkertsma, B.V.S. Reddy, M. Kayentao, H.G. Welz and H. H. Geiger. (2004) Genomic regions influencing resistance to parasitic weed *Striga hermonthica* in two recombinant inbred populations of sorghum. *Theoretical and Applied Genetics* 109: 1005-1016.

Hess, D. E., and H. Dodo (2004) Potential for sesame to contribute to integrated control of *Striga hermonthica* in the West African Sahel. *Crop Protection* 23:515–522.

Hess, D.E. and G. Ejeta (1987) Effects of cultural treatments on infestation of *Striga hermonthica* (Del.) Benth (Scrophulariaceae) In: *Proceedings of the 4th International Symposium of Parasitic Flowering Plants*, Marburg, Germany. pp. 361 -375 (ed. by H.C. Weber and W. Forsteuter) Marburg: Philipps Universität.

ICRISAT, (1992) ICRISAT Report 1991. Patancheru, India. pp. 2-12.

Joel, D.M. (2000a, b). The long term approach to parasitic weed control: Manipulation of specific developmental mechanisms of the parasite: *Crop Protection*. 19: 753-758.

Joel, D.M., G. Ejeta P.J. Rich, J.K. Ransom and D. Rubiales (2007a, b, c, d, e, f, g, h, i, j, k) Biology and Management of Weedy Root Parasites *Horticultural Reviews*, Vol. 33. Edited by Jules Janik ISBN 0-471-73214-1 ©2007 John Wiley and Sons.

Joel, D.M., C Steffens and D.E. Metthews (1995a, b, c) Germination of weedy root parasites In: J.Kigel and D. Galili (eds.) *Seed development and germination.* Marcel Dekker. New York. p. 567-597.

Johnson, A.W., G. Roseberry and C Parker (1976) A novel approach to *Striga* and *Orobanche* control using synthetic germination stimulants. *Weed Research*.16. 223 – 227.

Kanampiu, F.K., J.K. Ramson, D.Friesen, and J.Gessel (2002) Imazapyr and pyrthiobac movement in soil and from maize seed coats to control *Striga* in legume intercropping *Crop Protection* 21. 611-619.

Kanampiu, F. K. ,V. Kabambe, C. Massawe, L. Jasi, D. Friesen, J. K. Ransom, and J. Gressel. (2003). Multi-site, multi-season field tests demonstrate that herbicide seed-coating herbicide- resistance maize controls *Striga* spp and increases yields in several African countries. *Crop Protection* 22: 697-706.

Kasasian, L and C Parker (1971) The effect of numerous herbicides on germination of *Orobanche aegyptiaca* and *Striga hermonthica PANS* 17: 471-481.

Khidir, M. O. (1983). *Technical Progress Report No. 3 on Striga Research in the Sudan.* Agricultural Research Corporation, Wad Medani and Faculty of Agriculture, Shambat Sudan Pages 1-2

Kroschel, J., A. A. Abbasher, and J Sauerborn (1995) Herbivores of *Striga hermonthica* in northern Ghana and approaches to their use as biocontrol agents *Biocontrol and Science Technology* 5:163–164.

Kroschel, J., A. Hundt, A. A. Abbasher, and J. Sauerborn.(1996). Pathogenicity of fungi collected in Northern Ghana to *Striga hermonthica*. *Weed Research*. 36:515–520.

Kroschel, J., A. Jost, and J Sauerborn (1999) Insects for *Striga* control: Possibilities and constraints. p. 117–132. In: J. Kroschel, H. Mercer-Quarshie, and J. Sauerborn (Eds). *Advances in parasitic weed control at on-farm level.* Vol. I. Joint Action to Control *Striga* in Africa Margraf Verlag, Weikersheim, Germany

Kuijt, J. (1969). *Biology of parasitic flowering plants* Univ. California Press Berkeley.

Kuiper, E. (1997). Comparative studies on the parasitism of *Striga aspera* and *Striga hermonthica* on tropical grasses *PhD- Thesis, Vrije Universiteit, and Amsterdam*

Kwesiga, F. R., S. Franzel, F. Place, D. Phiri, and C. P Simwanza (1999) *Sesbania sesban* improved fallows in eastern Zambia: Their inception, development and farmer enthusiasm. *Agroforestry Systems* 47:49–66.

Lagoke, S.T., V Parkinson and R.M. Agunbiade (1991) Parasitic weeds and control methods in Africa In S.K. Kim (eds.) *Combating Striga in Africa* P 3-15.

Langston, M.A and English, T.J. (1990) Vegetative control of witchweed and herbicide evaluation and techniques In: *Witchweed Research and Control in the USA*. Champaign. pp. 107-125. In P.F. Sand R.E. Eplee and R.G Westbrook (Eds.)

Marley, P. S., D. A. Aba, J. A. Y Shebayan, R Musa, and A Sanni (2004a, b) Integrated management of *Striga hermonthica* in sorghum using a mycoherbicide and host plant resistance in the Nigerian Sudano-Sahelian Savannna *Weed Research* 44: 157-162.

Mumera, L. (1983). *Striga* infestation in maize and sorghum relative to cultivar herbicidal activity and nitrate *Proceedings of 9th East African Weed Science Conference,* Nairobi pp. 82 – 104 Nairobi: EAWSS.

Musselman, L.J., C. Parker, and N. Dixon. (1981). Notes on autogamy and flower structure in agronomically important species of *Striga* (Scrophulariaceae) and Orobanchace (Orobancheceae) *Beitrage Biologie Pflanzen* 56: 329-343.

Nickrent, D. L., R. J. Duff, A. E. Colwell, A. D. Wolfe, N. D. Young, K. E. Steiner and C.W. dePamphilis.(1998). Molecular phylogenetic and evolutionary studies of parasitic plants p 211-241 In: D.E.Soltis. P.S.Soltis and J.J. Doyle (Eds) *Molecular systematics of plants II-DNA sequencing* Kluwer Academic Publ. Boston

Norris, R.S. and R.E. Eplee (1983) Effect of stimulant plus herbicide on *Striga* germination In: *Proceedings of the 2nd International.Workshop on Striga.* Ouagadougou. 1981. pp. 43 - 46 (ed. by K.V. Ramaiah and M.J. Vasudara Rao) Patancheru. ICRISAT

Odhiambo, G. D., and J K Ransom (1993) Effect of Dicamba on the control of *Striga hermonthica* in maize in western Kenya. *African Crop Science Journal*.1:105–110.

Odhiambo, G. D., and J. K Ransom (1994) Preliminary evaluation of long- term effects of trap cropping on *Striga* p. 505–512. In: A. H. Pieterse, J. A. C. Verkleij, and S. J. ter Borg (Eds). Biology and management of *Orobanche Proceedings of the 3rd International Workshop on Orobanche and Related Striga Research* Royal Trop. Inst Amsterdam the Netherlands

Odhiambo, G. D., and J. K Ransom (1996) Effect of continuous cropping with trap crops and maize under varying management systems on restoration of land infested with *Striga hermonthica* p. 834–842. In: M. T. Moreno, J. I. Cubero, D. Berner, D. Joel, L. J. Musselman, and C. Parker (eds.), Advances in parasitic plant research. *Proceedings of the 6th International Parasitic Weed Symposium* Cordoba, Spain

Oswald, A., and J. K. Ransom (2001) *Striga* control and improved farm productivity using crop rotation. *Crop Protection* 20: 113-120.

Oswald, A., and J K Ransom (2002) Response of maize varieties to transplanting in *Striga* infested fields. *Weed Science*. 50:392-396.

Oswald, A., and J. K. Ransom (2004) Response of maize varieties to *Striga* infestation *Crop Protection* 23:89–94

Oswald, A. J.K. Ransom, J. Kroschel, and J. Sauerborn (2001) Transplanting maize and sorghum reduce *Striga hermonthica* damage. *Weed Science*. 49: 346 – 353.

Parker, C (1991a, b, c, d, e) Protection of crops against parasitic weeds In: *Crop Protection.* Vol. 10 pp. 6-8

Parker, C., and C. R. Riches (1993a, b, c, d, e, f, g) *Parasitic Weeds of the World*: *Biology and Control*. Pp. 1-74.

Pesch, C, and A.H. Pieterse (1982) Inhibition of germination in *Striga* by means of urea *Experientia* 38 559 – 560

Pieterse, A. H., and J. A C Verkleij (1991) Effect of soil conditions on *Striga* development a review p.329–339 In: J. K. Ransom, L. J. Musselman, A. D. Worsham, and C. Parker. (Eds.). *Proceedings of the 5th International Symposium of Parasitic Weed*s CIMMYT, Nairobi, Kenya

Press, M.C. and J.D. Graves (1995) *Parasitic plants* Chapman and Hall London. Pages 295

Ramaiah, K. V., V. L. Chidley, and L.R. House. (1991) A time – course study of early establishment stages of parasitic angiosperm *Striga asiatica* on susceptible sorghum roots *Annals of Applied Biology* 118: 403-410.

Ramaiah, K.V. (1985). Hand pulling of *Striga hermonthica* in pearl millet *Tropical Pest Management* 31 326 – 327

Ransom, J. K. (1999). The status quo of *Striga* control: Cultural, chemical and integrated aspects. Vol. I. 133–143. In: J. Kroschel, H. Mercer-Quarshie, and J. Sauerborn (Eds). *Advances in parasitic weed control at on-farm level*. Joint Action to Control *Striga* in Africa Margraf Verlag, Weikersheim, Germany

Ransom, J. K., and G. D Odhiambo (1995) Effect of corn (*Zea mays*) genotypes which vary in maturity length on *Striga hermonthica* parasitism *Weed Technology*. 9:63–67.

Ransom, J.K., G.D. Odhiambo, R.E Eplee, and A.O. Diallo (1996) Estimates from field studies of the phytotoxic effects of *Striga* spp. on corn.p. 327-333. In: M.T. Moreno. J.I. Cubero, D Berner, D.M. Joel, L.J. Musselman and C Parker (Eds) *Advances in parasitic weed research* Junta de Audalucia Cordaba, Spain.

Ransom, J.K. (2000). Long term approaches for the control of *Striga* in

Cereals: Field management options. *Crop Protection* 19 759-763

Riopel, J.L., and M.P. Timko (1995) Haustorial initiation and differentiation p 39-79 In: M.C. Press and J.D. Graves (Eds.). *Parasitic plants* Chapman and Hall London

Sand, P. F., and J. D. Manley (1990a, b) The witchweed eradication program:

Survey, regulatory and control p. 141-150. In: P.F. Sand. R.E. Eplee and R.G. Westbrooks (Eds) *Witchweed research and control in the United States.* WSSA Champaign

Salle, G., B. Dembele, A.Raynal-Roques, M. F. Hallais, and C. Tuquet (1987) Biological aspects of *Striga* species, pest of food crops In: *Proceedings of the 4th International Symposium of Parasitic Flowering Plants*. Marburg. Germany. 1987. pp. 367 (ed. By H.C. Weber and W. Forstreuter) Marburg: Philipps Universität.

Sauerborn, J. H. Sprich, and H Mercer-Quarshie (2000) Crop rotation to improve agricultural production in Sub Saharan Africa *Journal of Agricultural Crop Science* 184:67-72.

Schulz, S., M A. Hussaini, J. G. Kling, D.K. Berner and F.O. Ikie (2003) Evaluation of integrated *Striga hermonthica* control technologies under farmer management *Experimental Agriculture* 39: 99 – 108.

Shah, N. N Smirnoff, and G.R.Stewart (1987) Photosynthesis and stomatal characteristics of *Striga hermonthica* in relation to its parasitic habit *Physiologia* Pl 69 699- 703.

Stewart, G. R. (1987). Physiological biochemistry of *Striga* p 77–88 In: L. J. Musselman (Ed) *Parasitic weeds in agriculture*, Vol. 1 *Striga* CRC Press, Boca Raton, FL

Stump, W. (2007). Host Recognition Strategies of *Striga*–A parasitic Angiosperm.http://www.colostate.edu/Depts/Entomology/courses/en570/papers_1994/stump.html 8/13/2007

Traore, D., C. Vincent, and R. K Stewart (1996) Association and synchrony of *Symicronyx guineanus* Voss *S. umbrinus* Hustache (Coleoptera: Cucunionidae) and the parasitic weed *Striga hermonthica* (Del.) Benth (Scrophulariaceae).*Biological Control*. 7: 307-315.

Vallance, K.B. (1950). Studies on the germination of the seeds of *Striga hermonthica* (Del.) Benth 1.The influence of moisture treatment, stimulant- dilution and after – ripening on germination. *Annals of Botany,* 14: 347 – 363.

Yasuda, N., Y. Sugimoto, M. Kato. S. Imanaga and K. Yoneyama. (2003) (+)–Strigol, a witchweed seed germination stimulant from *Menispermum dauricum* root culture *Phytochemistry* 62: 1115 – 1119.

Yousif, I.A. (2001). Evaluation and Optimization of Sarwala Operation for *Striga* control on Rain fed sorghum. *MSc. Thesis. University of Gezira, Wad Medani, Sudan* Pages 162