Advances in Cowpea *Striga* Control

N. MULEBA*, J.T. OUEDRAOGO†, I. DRABO† AND T. BEZUNEH§

Organization of African Unity/ Sientific, Technical and Research Commission : Semi-Arid Food Grain Researc and Development (OAU/STRC-SAFGRAD), 01 B.P. 1783, Ouagadougou 01, Burkina Faso

Summary

Research based on genetic and environmental manipulations were conducted in Burkina Faso and West and Central Africa from 1981 to 1993 for controlling and/or mitigating *Striga* damages in cowpea (*Vigna unguiculata* (L.) Walp.) production. Resistant and tolerant cultivars were developed. Some resistant cultivars have good adaptation and high yielding ability combined with a single dominant gene controlling *Striga* either in a wide or a narrow geographical area. The resistance in cultivar Suvita-2 and its progenies, in spite of controlling *Striga* only in a narrow geographical area, have proven to be highly stable in time in its area of origin since 1981 when it was first discovered up to date. Agronomic practices: prevention of *Striga* seed dispersal, soil fertilization with phosphorus, optimum sowing dates, scouting of fields grown with resistant cultivars for removal of any *Striga* plants and crop rotation, are proposed for use with either resistant or tolerant cultivars. These technologies not only minimize cowpea yield losses under *Striga* infestations, but also ensure the sustainability of the *Striga* control and are accessible and affordable to the farmers regardless of their resource.

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* Consultant, OAU/STRC-SAFGRAD, 01 B.P. 1783, Ouagadougou 01; Burkina Faso (* Corresponding author)

† Cowpea breeders, Programme Protéagineux INERA, 01 B.P. 7192, Ouagadougou 01, Burkina Faso.

§ Director of Research, OAU/STRC-SAFGRAD, 01 B.P. 1783, Ouagadougou 01; Burkina Faso.

INTRODUCTION

In Semi-Arid West and Central Africa, cowpea (*Vigna unguiculata* (L.) Walp.) is consumed as pulse and/or pot herb; it thus supplements, in daily diets, staples such as cereal, root and tuber foods with good quality protein rich in lysine, an essential amino acid deficient in cereal grains (Bressani 1985). As forage, cowpea fodder are fed to livestock, mainly ruminants, in the Sahel and Sudan Savannah regions, for meat and milk production; milk being a major component of diets of nomadic peoples in the region. In rotation and/or association with cereals and/or root and tuber crops, cowpea boosts the productivity of these crops in the subsequent year. This, as a result of its soil improvement attributes, i.e., enrichment of soil with nitrogen biologically fixed and phosphorus and other essential nutrients mobilized through double associative symbioses with *Rhizobium* bacteria and Vesicular Arbuscular Mycorrhizae, respectively (Sanni 1976; Nnadi 1978; Barea *et al.* 1980; Islam *et al.* 1980; Kang 1983). Cowpea plays, therefore, a very crucial role in the welfare of the peoples particularly the resource poor ones.

Cowpea crop is subject to a witchweed (*Striga gesnerioides* (Willd.) Vatke) parasitism in Africa, particularly in West and Central Africa (Musselman & Parker 1982; Ramaiah *et al.* 1983; RENACO 1990). There exist, at least, three areas where cowpea suffers from severe *Striga* damages in West Africa, i.e., in the triangle between Lokossa, Bohicon and Save in southern Benin; Congo near Bolgatanga in northern Ghana; and Cinzana in Mali. Cowpea fields in these regions are being abandoned. Elsewhere, in northern Nigeria, *Striga* may cause cowpea yield losses varying from few kg/ha to total crop failure (Obilana 1987). This had also led to the abandonment of *Striga* infested fields for cowpea production (Emechebe & Leleji 1988). Recent reports also suggest that the productivity of new, improved cowpea cultivars is being reduced under farming conditions in *Striga* infested regions of Ghana, Mali and Nigeria (Sanders *et al.* 1994).

Yield losses due to *Striga* parasitism in cowpea production have been estimated to average 30% in susceptible cultivars (Aggarwal & Ouédraogo 1988; Muleba *et al.*

1997). Cowpea being grown, in West and Central Africa, mostly (80%) in association with cereals, particularly sorghum and millet which acreage covered 8.5 and 10 million ha, respectively, in 1993 (Sanders *et al.* 1994), its total growing area may be estimated to approximate 14.8 million ha in 1993 of which about 60% is infested with *Striga*. With an average yield of 0.1 to 0.4 t/ha (Muleba & Ezumah 1985), current yields losses inflicted by *Striga* on cowpea production in the subregion may be estimated to vary between 0.44 to 1.78 million tons, which represents a loss of incomes by farmers of about 88 to 356 million US Dollars per year.

To limit *Striga* damages in cowpea production, research were conducted from 1981 to 1993 in Burkina Faso and West and Central Africa under the Semi-Arid Food Grain Research and Development (SAFGRAD), a joint project of the Organization of African Unity (OAU) and the United State Agency for International Development (USAID) of the United States of America (USA). The technical assistance was provided by the International Institute of Tropical Agriculture (IITA). The objectives of the research consisted of controlling and/or mitigating *Striga* damages in cowpea production and boosting the cowpea productivity for increased food security for the peoples of the region. New technologies to be developed under this research were to be simple, easily accessible and affordable to low income as well as resource rich farmers. Progresses made under this research are herein reviewed and discussed.

Biology of *Striga*

Taxonomy and Morphology

The genus *Striga* belongs to the family Scrophulariaceae, subfamily Rhinanthoideae and has 30 species inventoried so far (Musselman 1987). It is characterized by a corolla divided into tube with a definite bend, spreading lobes, herbaceous habit, tiny dust-like seeds, and parasitism. Taxonomically, *Striga* species are differentiated by the number of ribs on the calyx, the way flowers are borne, corolla colour, dentation of leaves, and size characteristics (Musselman 1987). Wettstein (1893), cited by Musselman & Ayensu (1984), divided the genus into two sections: the Pentapleurae with a five-ribbed calyx, and the Polypleurae with five to ten ribs. The number of ribs was, however, found recently inconsistent for use in taxonomic classification (Saldanha 1963). This, nevertheless, did not preclude for *S. gesnerioides* to belong to the Pentapleurae section.

The aerial parts of *S. gesnerioides* consist of primarily floral axes 15-20 cm high (Ba 1984). The main axis is extremely branched in its lower half where it bears many secondary axes. The floral axes bear chlorophyllous scale-chapped leaves, 0.5 to 0.7 cm long, thick, and covered with white, stiff hairs. The inflorescence, flowers, pollination mechanism, fruits and grains have been described elsewhere (Musselman *et al.* 1982; Ba 1984; Musselman & Ayensu 1984). It is, however, important to note that: the species is strongly autogamous, each capsule contains 400-500 wrinkled grains that are 0.20-0.35 mm long and 0.15 mm wide. A single plant can produce an estimated 50,000-500,000 seeds.

The underground parts of *S. gesnerioides* consist of three colourless section: the stem, the roots and the parasitic system referred to as haustorium. The stem bears scale-leaves. The roots system is highly variable dependent on the hosts; it has, however, primary and secondary roots with the latter being adventitious roots emerging from the base of the underground leaves. The primary haustorium develops at the point of attachment of the *Striga* seedling radicle to the host root. It is a tuber-shaped organ reaching up to 150 g at full maturity (Ba 1984). Secondary roots emerging above the haustorium may form secondary haustoria where they contact the host roots. Unlike most of *Striga* species including *S. hermontica*, which have only xylem, *S. gesnerioides* has both xylem and phloem present in the haustorium. This coupled with its chlorophyllous leaves makes it a hemiparasite of small size (Ba 1984).

Origin

Twenty three out of the 30 *Striga* species inventoried by Musselman (1987) are of African origin. *S. gesnerioides*, like *S. asiatica* (L.) and *S. hermontica* (Del.), is among these species; and is found in two distinct regions: the Mediterranean and the Sudano-Zambesian. It has migrated to the Middle East, India and United States of

America (USA). It is adapted to the grasslands in the tropics and semitropics where it has several morphotypes each differing in corolla colour, branching, pubescence, and host specificity.

Host specificity

S. gesnerioides is highly variable with different morphotypes or strains exhibiting host specificity (Saldanha 1963; Musselman & Parker 1981). Specific hosts include broadleaf species such as *Indigofera hirsuta*, *Tephrosia pedicellata*, *Convolvulaceae* ssp., *Euphorbiaceae* spp., and some *Gramineae* spp. (Parker & Reid 1979; Ramaiah *et al.* 1983). Most economic damages in agriculture are found in cowpea production in West Africa, tobacco (*Nicotians tobacum* L.) in East Africa and in sweet potato (*Ipomea batatas* L.) (Musselman 1980). No across host species parasitism has been observed with a given *Striga* strain except probably for sweet potato and *Jacquemontia tamimifolia* both Convolvulaceae (Parker & Reid 1979). Cowpea has been, however, observed to stimulate the germination of the strain that parasitizes tobacco; for that reason, it is used a trap crop in tobacco production (Wild 1948).

Striga parasitism

Though hemiparasite because of its chlorophyllous leaves and the presence of xylem and phloem in the haustorium (Ba 1984), *S. gesnerioides* is an obligate parasite particularly in its early growth stage, before emergence. Its seeds must receive some physical and chemical stimulants from, respectively, the environment and the host plant for them to initiate and complete the germination process (Cook *et al.* 1972; Parker 1984a). After germination, another chemical stimulus, from the host root which must be in a close proximity of 2 to 4 mm with the *Striga* radicle, is required for the seedling to switch from a germinating mode to the parasitizing mode with the formation of the haustorium at the point of contact with the host root (Okonkwo & Nwoke 1975; Parker 1984a). The successful penetration of host roots and the establishment of connections with its vascular system enable the seedling to parasitize the host, i.e., withdrawal by

Striga from the host of water and inorganic and organic solutes to sustain its growth and development.

The conditions required for *S. gesnerioides* seeds to establish a successful parasitism on a susceptible cowpea is summarised below according to Parker (1984a):

- After-Ripening or post-harvest ripening of *Striga* seeds: 4 to 6 months, after seed shed, required before germination would occur;
- Conditioning requirement: 2 to 3 weeks of exposure of ripen seeds to moist conditions at 27 to 35 C;
- *Striga* radicle in 2 to 4 mm proximity with the root of a suitable host and production by the host of appropriate root exudates;
- Germination, attachment to the host root system and formation of haustorium; and
- Penetration of the host root tissues, connection with the host conductive tissues, withdrawal of the necessary nutrients, and growth and development of *Striga* and its emergence.

Thus, under field conditions, the emergence of a *Striga* shoot signals the establishment of a successful parasitism. Failure to do so is an expression by the host of resistance to *Striga* infestation (Singh & Emechebe 1990; Emechebe *et al.* 1991) and could result from one of the following mechanisms or any combination of them:

- *Striga* seed germinates, after receiving an appropriate stimulus from the host, the seedling attach itself to the host root system and further growth is inhibited by a hypersensitive reaction resulting in the necrosis of host tissue around the point of attachment;
- In the absence of hypersensitivity, the initial infection is successful and connections are established with the host vascular system, but small tubercles 1 to 2 mm in length develop in the conductive tissues and thereby inhibit further *Striga* growth;
- Successful infection and establishment of connections with the host vascular system, but *Striga* seedlings either exhibit some limited growth and fail to emerge or if occasionally few plants emerge they are so very weak and die out before reproductive maturity; and finally

- The emergence of *Striga* plant is delayed; and the emerged parasite causes only little damage to the host plant.

In the Sudan savannah region of Burkina Faso, the number of days from cowpea sowing to *Striga* emergence is about 32 days regardless of sowing dates under no soil moisture stress as shown in Table 1. It can, however, be delayed for few days to indefinitely depending on the degree of resistance of cultivars as compared to the highly susceptible ones; or several days up to 50 or more by dry spells occurring within one to two weeks after cowpea sowing (Muleba & Mosarwe 1994). *Striga* control can, therefore, be effected through either genetic and environmental manipulations or both. These aspects are hereafter examined.

Genetic Control of *Striga* Infestations

Genetics of resistance

Several cowpea cultivars resistant to *Striga* have been identified (Aggarwal *et al.* 1984; Singh & Emechebe 1990; Aggarwal 1991; Lane *et al.* 1994; Atokple *et al.* 1995). The genetics of resistance in cultivars Suvita-2 (Gorom local), B301, and IT82D-849 have also been studied by, respectively, Aggarwal *et al.* (1984), Singh & Emechebe (1990), Atokple *et al.* (1995). The resistance was found to be controlled by a single dominant gene but at a different locus in each cultivar; and gene symbols Rsg_1, Rsg_2 and Rsg_3 were proposed for resistance to *S. gesnerioides* in B301, IT82D-849 and Suvita-2, respectively (Atokple *et al.* 1995). Other resistant cultivars for which the genetics of resistance have not been elucidated include: 58-57, IT81D-994, TN93-80, TN121-80 and many more.

Different strains of *S. gesnerioides* have been identified. They include: the Burkina, the Mali and the Niger-Nigeria strains (Parker & Poliaszek 1990), and recently the Zakpota (Benin) strain (Lane *et al.* 1994). Suvita-2 and 58-57 are resistant only to the Burkina, Mali and Zakpota strains; and B301, IT82D-849 and IT81D-994 have been reported resistant to all four strains except the Zakpota strain for the first two cultivars (Parker & Poliaszek 1990; Lane *et al.* 1994).

Development of Striga resistant cultivars

The breeding efforts under the SAFGRAD's collaborative research in controlling the cowpea *Striga* damages consisted of crossing Suvita-2 to susceptible cultivars and the same cultivar or its resistant progenies, to B301 from, respectively, 1981 to 1986 and 1986 to 1993. The latter crosses were made in attempts to broaden the resistance of new selections by taking advantage of the combination of resistant genes: Rsg_1 and Rsg_3 from, respectively, B301 and Suvita-2.

Progenies were advanced, in Burkina Faso, from F_2 to F_7 in *Striga* free artificial media consisting of wooden boxes: 0.75 m^2, 20 cm deep, using a single seed descendent approach. F_8 progenies were screened for resistance in naturally *Striga* infested fields at the Kamboinse Experiment Station. To ensure uniform *Striga* infestation, the fields were supplemented with 1-year-old *Striga* plant materials (seeds and plant debris, at a rate of 10 g/m^2) mixed with wet sand, broadcast and ploughed under with a hand-hoe prior to sowing cowpea lines. Each line was grown in a single row plot bordered by a susceptible control using at least two sowing dates: optimum and late sowing. And dependent on the availability of seeds, trials were replicated at least twice. Only high yielding and *Striga* free lines, across sowing dates, were selected and advanced in the next generation through best plants which resistance was reconfirmed in pot culture during the off-season.

Resistant lines, so selected, were further tested in *Striga* infested fields in Burkina Faso: first, in preliminary yield trials for one or two seasons and later on in advanced yield trials. The most promising lines along with the best *Striga* resistant cultivars, identified or bred in the region by national and/or international research institutions, were subsequently evaluated in regional yield trials in *Striga* infested plots in West and Central Africa under the supervision of the SAFGRAD's cowpea network, known as RENACO. The regional *Striga* resistance trials were conducted yearly from 1987 to 1992 and covered over 20 *Striga* infested sites throughout in the region.

Striga free cultivars were identified among resistant cultivars at each tested location except at Gabougoura, Niger. Nevertheless, none of resistant cultivar was immune from *Striga* infestation at all locations as shown in Table 2 for the 1992's regional trial. Also not a single couple of cultivars exhibited a similar pattern of resistance across locations in the region (Muleba *et al.* 1996). This implied the existence of several strains, more than the four identified so far (Lane *et al.* 1994), in the region and/or different genetic mechanisms used by resistant cultivars in controlling *Striga* parasitism.

Indeed, because the *Striga* density of the susceptible cultivar IT82E-32 increased positively with increasing degree of field plot infestations (Table 2), $\beta>1$, contrasting, thus, with the high stability, $\beta<1$, of the least infested resistant cultivars, this inferred that the *Striga* population was not homogenous at different locations. The major or the most frequent genotype or strain in the population was, however, the same at all locations; its parasitism was, therefore, successfully controlled by resistant cultivars. Whereas the minor or the least frequent genotypes differed with the locations; their control required different genetic mechanisms in resistant cultivars as Lane *et al.* (1994) showed at Zakpota, Benin, for the Zakpota *Striga* strain.

The requirement of different genetic mechanisms for the control of minor *Striga* strains is well illustrated by the reaction of cultivars KVx164-65-5, KVx404-19-5 and B301 to *Striga* infestations in the region (Table 2). Indeed, the first cultivar is a progeny of Suvita-2; whereas the second one is the best resistant, recombinant line derived from a cross of a progeny of Suvita-2 with B301. Because B301 is purported to be resistant to a wide spectrum of *Striga* strains than Suvita-2 (Parker & Poliaszek 1990; Lane *et al.* 1994), KVx404-19-5 is, therefore, expected to control *Striga* infestations better than Suvita-2 or its progenies and comparably to, if not better than, B301. Since this was not the case at Dourum and Maroua in Cameroon (Table 2), a genetic environment in KVx404-19-5 appears thus to prevent genes Rsg_1 and/or Rsg_3 from expressing their full potential. This could result from either nonallelic interactions, i.e., epistasis, or pleiotropy or both.

At Gabougoura, Niger, in 1991, all genotypes were heavily infested with *Striga* (Table 3). Only the susceptible control, IT82E-32, and two resistant cultivars, KVx291-47-222 and IT81D-994, were less infested than others. Since the field at this location was an old orchard infested with a soil born disease charcoal rot or ashy stem blight caused by (*Rhizoctonia bataticola* Copr.) and the three cultivars were less affected than others by the disease, it can be inferred that, in addition to soil infertility discussed later on, the sanitary conditions of a field may influence the resistance of a genotype.

Striga resistance stability in time

Unlike the *Striga* resistance stability in space, described in the preceding section, that of resistance in time was studied only in Burkina Faso with Suvita-2 and its progenies. Starting in 1980, Suvita-2 including its progenies, in spite of its resistance covering only a narrow geographical area (Parker & Poliaszek 1990; Lane *et al.* 1994), has not shown any breakdown in resistance to *Striga* in Burkina Faso up to date (Aggarwal *et al.* 1984; Aggarwal 1991; Muleba & Mosarwe 1994; Muleba *et al.* 1996; Muleba *et al.* 1997). This could be ascribed to the soil borne nature of *S. gesnerioides* infestation and its apparently low mutation rate. The strong autogamy of this *Striga* (Musselman *et al.* 1982; Ba 1984) and the ineffectiveness of *Striga* seed dispersal by wind and runoff water (Berner *et al.* 1994) might also not be conducive to a rapid build up of population of new virulent strains in a given area such is the case for *S. hermontica* (Ramaiah 1986, cited by Lagoke *et al.* 1991). As a consequence, cowpea scientists should feel confident to promote for commercial production the best resistant cultivars even though such cultivars do not exhibit a stable resistance in space, but instead meet the needs and requirements of local farmers and consumers.

Development of Striga tolerant cultivars

Tolerant cultivars sustain heavy *Striga* infestations, but suffer less severe yield losses than the susceptible cultivars. They, therefore, yield comparably to or sometimes better than resistant cultivars under *Striga* infestations (Muleba *et al.* 1997). They should be promoted for commercial production where suitable resistant cultivars cannot be found.

Such cultivars have been developed under the SAFGRAD's collaborative research efforts as shown in Table 4.

Environmental Manipulations

The effectiveness of *Striga* control in cowpea production in a given area requires for a number of measures to be put together and carried out concomitantly. Measures such as used in *S. asiatica* control in the USA (Eplee 1981; Sand & Manley 1990) can also be adapted to the circumstances of resource poor farmers as discussed herein. They include (i) prevention of influx of *Striga* seeds; (ii) eradication of *Striga* seeds in the soil; (iii) prevention of reproduction of *Striga* plants; and (iv) reduction of cowpea yield losses.

Prevention of influx of Striga seeds

Striga seeds may be disseminated by: wind, runoff, livestock, agricultural machinery and implements, and contaminated seed crops (Bebawi 1987; Berner *et al.* 1994). In West Africa, Berner *et al.* (1994) found wind, runoff and livestock relatively ineffective in long-distance *Striga* seed dispersal. According to these workers, livestock accounted for a dispersion of only 8% of *Striga* ssp. seeds ingested and to a distance of less than 0.5 km; and most of *Striga* dispersal was effected through contaminated seeds of crops such as cowpea, sorghum, millet and maize sold in the markets. They, therefore, recommended for seeds of these crops to be produced in *Striga* free plots and/or treated with the pesticide imazaquin, an acetolactate synthase (ALS) inhibitor, to prevent *Striga* dissemination (Berner *et al.* 1995). This herbicide interferes with parasitism through inhibition of amino acid biosynthesis by the *Striga* seedlings.

The ineffectiveness of wind and runoff in *Striga* seed dispersal appears justifiable by the very short plant height of *S. gesnerioides*, not exceeding 25 cm utmost, and by the presence of other plant materials in the fields after cowpea ripening -- these constitute obstacles that may impair the movement of *Striga* seeds --. It is also evidenced in fields by attacks of cowpea plants in patches, often not exceeding 1-1.5 m diameter, by a different *Striga* strain thereby implying the incapacity of *Striga* seeds to be spread in long distance from the mother plant.

Although consistent with the traditional practice of mitigating *Striga* damages on crops by stocking fields with livestock to improve soil fertility by increasing soil organic matter with animal wastes (Lagoke *et al.* 1991), the ineffectiveness of livestock in *Striga* dispersal reported by Berner *et al.* (1994) needs, however, to be taken cautiously. It may only reflect, as discussed later on, the extremely low soil fertility of soils under the isohyperthermic regime prevailing in West and Central Africa. In any case, it contrasts with the findings made elsewhere: Bebawi & Elhag (1983) reported up to 80% of *Striga* seeds passed through the digestive tract of sheep without loosing germinability; Farquhar (1937), cited by Bebawi (1987), observed *Striga* infestation increased the season after the fields were stocked with cattle that came from infested fields; and in Zimbabwe, an increase in livestock has been associated with an enhancement of *Striga* dissemination (Bebawi 1987).

Thus, since food ingested by ruminant animals may take up to four days to pass through the digestive tract, the *Striga* seed dispersal, including the long-distance one, by livestock should not be underestimated particularly in areas where livestock transhumance is commonly practised. Such areas, like the Sahel and Sudan savannah regions in West and Central Africa, are heavily infested with *Striga*. The same is occurring now in the northern Guinea Savannah, sub-humid and humid regions in Benin, Togo, Sierra Leone and Ghana (RENACO 1990) where *Striga* parasitism is expanding along the paths used for exportation of livestock from Sahelian to coastal countries and in ecosystems subjected to anthropological disturbance and where livestock raising is becoming more important than ever before. Livestock should, therefore, be put in at least a 1-week quarantine before moving from infested to uninfested areas to prevent *Striga* seed dispersal.

Farm machinery and implements, also involved in *Striga* dispersal (Bebawi 1987), must be washed with water and soap before moving them from *Striga* infested to uninfested fields; also the movement of workers should be restricted from infested to uninfested fields. The implementation of these control measures at Kamboinse, Burkina

Faso, has enabled a successfully confinement of *Striga* infestations only to specified field plots for over 15 years. Finally in the absence of resistant cultivars, cowpea seed contamination can be averted by harvesting pods as they ripen, before *Striga* reproductive maturity, and drying them at the compound away from infested fields.

Eradication of Striga seeds in the soil

Infested soils can be ridded of *Striga* seeds directly by use of fumigation and seed stimulant technologies developed in USA to control *S. asiatica* in maize production (Eplee & Norris 1987; Eplee *et al.* 1991). The fumigants include methyl bromide or sodium *N*-methyldithiocarbamate, Metham and Dazomet. Whereas the seed germination stimulants include the gas ethylene (C_2H_2) and nongaseous compounds, strigalogs. Strigalogs are analogs of strigol, a natural stimulant, released by a susceptible cultivar, that trigger the germination of *Striga* seeds. The most stable and effective strigalogs in *Striga* control are designated as GR7 and GR24. The transfer of these technologies from USA to many developing countries are, however, not only very costly, but also high skill demanding. Also their accessibility as well as their adoption by farmers is highly problematic at this point in time.

Prevention of reproduction of Striga plants

In infested soils, *Striga* plants can be prevented from reproducing by use of: (i) resistant cultivars; (ii) trap crops in rotation; (iii) weeding out *Striga* plants before reproductive maturity; and (iv) herbicides.

Resistant cultivars

Resistant cultivars, particularly those that stimulate *Striga* germination but inhibit further growth and development (Singh & Emechebe 1990; Emechebe *et al.* 1991) are highly valuable in cowpea *Striga* control by resource poor farmers. They not only prevent *Striga* reproduction but also contribute at low cost to *Striga* eradication by depleting the soil's seed load. Resistant cultivars with good agronomic attributes have been developed; they are now available for commercial production in most cowpea growing regions in West and Central Africa (Tables 2, 5).

Use of trap crops in rotation

Trap crops or non-host species release the germination stimulant which triggers *Striga* seed germination; the germinated seedling dies thereafter as it cannot attach to the host roots for parasitism. Traditionally farmers used natural non-host species to control *Striga* epidemics by leaving their fields fallow for up to 12-15 years or more after 3-5 years of cultivation. Since in Semi-Arid West and Central Africa, the duration of the fallow has been significantly curtailed to less than 6 years, also because of the restricted number of major crops, and owing to the tediousness of screening crop cultivars for their non-host relationship to *S. gesnerioides* and the possibility of their non acceptation by farmers thereafter, the use of trap crop to control *Striga* infestation has not been extensively explored.

Weeding out *Striga* plants before reproductive maturity

Weeding out of *Striga* plants before flowering or slightly thereafter can significantly contribute to reducing the soil's load of *Striga* seeds while preventing its replenishment. Owing to the tediousness of this practice, its efficiency may be improved by combining it with other technologies such as the use of resistant cultivars or cereal-cowpea inter-cropping or relay-cropping systems as follow:

- A yearly scouting of cowpea fields grown with resistant cultivars and weeding out of any *Striga* plant would not only eradicate the soils with any new virulent strains, should it appears, but also prevent the build up of their seeds and the subsequent epidemics.
- Cowpea used as catch crop in cereals-cowpea intercropping or relay-cropping systems. Since cowpea is traditionally grown in mixture with cereals, which are the dominant crops (Andrews 1972a, b; Muleba & Ezumah 1985), susceptible or tolerant cowpea cultivars may, thus, be sown three weeks or later after cereals in

inter-cropping or relay-cropping systems with early cereal cultivars. They should be harvested at the podding growth stage, but before or slightly after *Striga* flowering, and fed to livestock as fodder. The fields can then be ploughed under immediately after cereal and cowpea fodder and *Striga* plants harvesting or the *Striga* plants weeded out by hand-hoeing and burnt to prevent their seed set and maturation.

Herbicides

Pre- and post-emergence herbicides developed in USA and currently used in *S. asiatica* control (Eplee & Norris 1987; Eplee *et al.* 1991) are also highly valuable in minimizing cowpea yield losses inflicted by *Striga* in many developing countris. Some of them, particularly the Phenoxy herbicides 2,4-D, and Paraquat and Glyphosate have been proven successful in *S. gesnerioide* control in Nigeria (Lagoke *et al.* 1991).

The post-emergence herbicides may also be used in a *Striga* eradication programme consisting of cereal-cowpea relay-cropping system. Towards this end, cowpea is sown late under cereals such as to enable harvesting cereals while *Striga* plants have emerged. Cowpea haulms are then harvested and the entire field is treated with the herbicides to kill *Striga* before flowering. The advantage of this practice is: the farmer will harvest the full cereal crop and cowpea haulm, and controls *Striga* for the next cowpea crop, but he or she will not harvest cowpea grains.

Minimization of cowpea yield losses

In *Striga* infested field plots, cowpea yield losses can be minimized in the absence of resistant cultivars by (i) proper choice of sowing date, and (ii) weakening of *Striga* infestation and vigour.

Use of sowing date

A long duration of *Striga* parasitism in the cowpea vegetative growth stage -- such as happens for daylength sensitive (DS) cultivars sown more than 40-45 days prior to their critical photoperiod -- as well as the occurrence of moisture stress, i.e., dry, hot spells, particularly in the generative growth stages of *Striga* parasitized cowpea crops result in severe yield losses (Muleba & Mosarwe 1994; Muleba *et al.* 1996). Thus, proper choice of sowing dates is highly conducive to mitigating the severity of yield losses in susceptible cultivars in infested soils (Table 6). This since *Striga* has a high rate of transpiration for supplying itself with water and inorganic and organic solutes from the host and also for cooling itself -- *Striga* leaf temperature can be as low as 7°C when ambient temperature is about 40°C --; and it also may cause a metabolic dysfunction which is detrimental to the host photosynthetic capacity as observed in sorghum-*Striga* parasitism (Stewart *et al.* 1991). *Striga* parasitism, therefore, imposes strong moisture and nutrient stresses on the host.

For West Africa where critical photoperiods occur in late August, throughout September and early-October; and rains end in mid to late September in the *Striga* infested Sudan savannah regions, the optimum sowing date for DS cowpea cultivars is mid- to late July (Muleba & Mosarwe 1994). These cultivars, particularly those with the critical photoperiod in late August and up to mid-September, sown in mid-July or later would spend only a short vegetative growth duration with *Striga* parasitism; their flowering, pod set, grain fill and the subsequent grain yield would, therefore, be less damaged than when sown earlier (Tables 1, 6). For daylength insensitive (DI) cultivars, the optimum sowing date is mid-July or earlier (Muleba & Mosarwe 1994; Muleba *et al.* 1996). These cultivars sown in late July in infested field plots become highly sensitive to the end-of-season drought, i.e., dry spells occurring in mid- to late September, with the resulting severe yield losses (Table 6).

Weakening of *Striga* infestation and vigour

Continuous cultivation of susceptible cultivars may reduce *Striga* infestation and vigour in cowpea production. Indeed, Muleba *et al.* (1996) observed *Striga* density and vigour declining instead of increasing, as expected, at Kamboinse, Burkina Faso, from 1984 to 1986 (Table 7). The correlation coefficients (r) of cowpea yields on *Striga* density also decreased over the years: r = -0.36** in 1984, r = -0.26* in 1985 and r = -0.12 in 1986, at Kamboinse. Whereas at Gampela "r" was -0.56** in 1987, the first year of growing susceptible cultivars. It should be noted that 1984 was the third year of cultivation of susceptible cultivars at Kamboinse.

Similar observations have been made in Mali; a pathogenic fungus was believed to infect *Striga* plants parasitizing cowpea (B. Dembele and A. Konate' 1988, cowpea pathology, IER, Sotuba/Bamako, Mali; personal communication). The fungus was identified as *Macrophomina phaseolina* and its pathogenicity, demonstrated in England (J. A. Irvine 1993, Botany Department, University College London, England; UK unpublished data).

Since the Kamboinse field plot was yearly fertilized with 21.8 kg P/ha from phosphorus (P) soluble sources (Muleba *et al.* 1996), it is possible that soil fertility build up might have weakened the *Striga* parasitism ill effect on the host-cowpea physiology and thereby enabled cowpea to withstand and/or tolerate *Striga* parasitism as observed in cereals: *Striga* parasitism alters the hormonal balance in cereals characterized by a 90% reduction of gibberellins and cytokinins and an almost doubling of growth inhibitors abscic acid and farnesol in the xylem sap of the host (Drennan & El Hiweris 1979); it also induces a metabolic dysfunction resulting from the release by the parasite of toxic or pathologic substances (Parker 1984a), which impair the photosynthetic capacity of the host; maize being more damaged than sorghum (Stewart *et al.* 1991). The overall *Striga* parasitism results in markedly reduced dry matter accumulation and poor partitioning and low yields (Graves *et al.* 1989), particularly in infertile soils (Lagoke *et al.* 1991).

Soil fertilization, particularly with nitrogen (N), does mitigate the *Striga* parasitism ill effects in cereals by reducing *Striga* infestation, as result of reduced production of stimulants by host, delayed emergence and stunted growth, and increased host tolerance (Agbawi & Younis 1965; Parker 1984b). Parker (1984b) also suggested that N application may have an indirect effect via the encouragement of rhizosphere microflora pathogenic to *Striga* which, thus, reduce its virulence. These unfavourable effects of soil fertility improvement on *Striga* parasitism apparently justify -- as noted earlier -- the stocking of fields, by farmers in West and Central Africa, with livestock to mitigate *Striga* damages in crop production without the fear of reinfestating soils with new *Striga* seeds (Lagoke *et al.* 1991).

In cowpea production, P is the most growth and development limiting nutrient (Muleba & Coulibaly 1997). It is required for *Rhizobium* nodulation (Ofori 1973) and uptake of other essential nutrients which accumulate in the leaves as well as in the seeds (Omueti & Oyenuga 1970; Kang & Nangju 1983). Its soil fertilization could, thus, favourably influence the physiology of cowpea as does N fertilization in cereals (Agbawi & Younis 1965; Parker 1984b). Cowpea crop also enrich soils with biologically fixed N (Nnadi 1978; Kang 1983), which is unfavourable to *Striga* infestation (Parker 1984b). The overall effect of P application appears, therefore, conducive, over the years, to mitigating *Striga* parasitism and the severity of cowpea yield losses in infested soils as observed at Kamboinse, Burkina Faso, by Muleba *et al.* (1996).

Conclusions

A comprehensive strategy for controlling *S. gesnerioides* in cowpea production is now available. It provides policy frameworks for decision makers to act upon and alternative technologies readily available, accessible and affordable for use by both resource poor as well as rich farmers. The technologies include resistant as well as tolerant cowpea cultivars and agronomic practices such as prevention of *Striga* seed dispersal, crop rotations including the combination of cereal-cowpea intercropping or cereal-cowpea relay-cropping systems with *Striga* destruction before reproductive maturity through either weeding out or herbicide applications, and the use of optimum sowing dates and appropriate soil fertilization programmes. The proper implementation of this strategy is highly conducive to the control of *Striga* damages and the optimization of cowpea productivity in *Striga* infested regions.

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Table 1. Days to *Striga* emergence and *Striga* density as affected by cowpea cultivars and sowing dates in *Striga* infested soils at Kamboinse, Burkina Faso, in 1983. (from Muleba & Mosarwe 1994)

Cultivars	Days to *Striga* emergence*			*Striga* density
	21 June	18 July	12 August	
	--------(days after sowing)---------			---(shoot/m^2)---
Ouahigouya	37	32	37	17
Kaya	38	32	37	24
Kamboinse N.	37	32	38	20
Kamboinse R.	38	34	34	22
KN-1	39	33	33	24
Suvita-2†	193	166	144	0
S.E. (45 D.F.)	--------------1.64---------			3.68
	Mean *Striga* density (shoot/m^2)			
	24	20	10	
S.E. (6 D.F.)	--------------1.36---------			

* Only the crop sown on 18 July did not experience a moisture stress within the first three weeks after sowing.

† A resistant cultivar, *Striga* did not emerge from its plots: it, thus, delayed indefinitely *Striga* emergence.

Table 2. *Striga* density of cultivars at 13 locations infested with *Striga* in West and Central Africa in 1992 (adapted from Muleba *et al.* 1996)

Location	Cowpea Cultivar													
	IT82E-32*		KVx164-65-5		KVx291-47-222		KVx397-6-6		KVx402-5-2		KVx402-19-2		KVx402-19-5	
	(shoot/m²)	Transf.	(shoot/m²)	Transf	(shoot/m²)	Transf	(shoot/m²)	Transf	(shoot/m²)	Transf	(shoot/m²)	Transf	(shoot/m²)	Transf
Benin														
Tindji	4.19	2.4	0.0	1.0	0.22	1.1	0.05	1.0	0.0	1.0	0.0	1.0	0.0	1.0
Zakpota	3.32	2.1	0.0	1.0	0.22	1.1	0.05	1.0	0.05	1.0	0.05	1.0	0.0	1.0
Burkina Faso														
Kamboinse	24.62	5.0	0.0	1.0	0.77	1.3	0.17	1.1	2.76	1.9	0.36	1.1	0.29	1.1
Kouare	6.10	2.5	0.1	1.0	0.28	1.1	0.11	1.1	0.28	1.1	0.29	1.1	0.0	1.0
Cameroon														
Dourom	2.02	1.6	0.0	1.0	3.93	2.1	0.0	1.0	0.39	1.2	2.24	1.7	3.66	1.9
Maroua	5.36	2.5	0.36	1.1	0.55	1.2	1.58	1.6	5.25	2.5	1.74	1.6	1.38	1.5
Ghana														
Manga	3.29	2.0	1.07	1.4	0.05	1.0	0.17	1.1	0.0	1.0	0.56	1.2	0.0	1.0
Mali														
Koporo	17.73	4.3	1.63	1.6	6.73	2.7	4.11	2.2	14.78	3.9	2.94	1.9	0.90	1.3
Niger														
Konni	7.36	2.9	2.58	1.8	4.96	2.3	1.47	1.5	3.21	2.0	0.40	1.2	0.17	1.1
Tarna	13.36	3.8	7.68	2.9	9.71	3.2	2.37	1.8	9.94	3.3	1.19	1.5	0.55	1.2
Nigeria														
Bakura	0.81	1.3	0.22	1.1	0.22	1.1	0.05	1.0	1.11	1.4	0.28	1.1	0.05	1.0
Minjibir	2.56	1.8	1.41	1.5	0.86	1.3	1.02	1.4	3.16	2.0	0.71	1.3	0.05	1.0
Togo														
Pissare	12.73	3.4	0.57	1.2	4.61	2.2	1.01	1.4	17.84	3.7	3.09	1.8	0.44	1.2
Mean	8.01	2.7	1.20	1.4	2.55	1.7	0.94	1.3	4.52	2.0	1.07	1.3	0.58	1.2
S.E. (12 D.F.)	-	0.23	-	0.10	-	0.09	-	0.05	-	0.11	-	0.06	-	0.07
β	-	1.72	-	0.91	-	1.56	-	0.79	-	2.25	-	0.50	-	0.16
r^2	-	0.46	-	0.55	-	0.83	-	0.79	-	0.86	-	0.50	-	0.07

* Susceptible control.

Transf., is the square root transformation of striga density.

β, regression slope; it measures the stability of *Striga* infestation across locations; β = 1, stable; β > 1, least stable; β < 1, highly stable.

r^2, coefficient of determination.

Table 2. *Striga* density (Cont'd)

Location	KVx305-118-31 (shoot/m²)	Transf.	IT81D-994 (shoot/m²)	Transf	TN5-78 (shoot/m²)	Transf	IT82D-849 (shoot/m²)	Transf	B301 (shoot/m²)	Transf	Mean Transf	S.E. (33 D.F.)
Benin												
Tindji	0.05	1.0	0.0	1.0	0.05	1.0	0.0	1.0	0.05	1.0	1.1	0.07
Zakpota	0.0	1.0	0.10	1.1	0.05	1.0	1.21	1.4	0.85	1.3	1.2	0.09
Burkina Faso												
Kamboinse	0.33	1.1	0.0	1.0	0.16	1.1	0.0	1.0	0.10	1.1	1.5	0.17
Kouare	0.82	1.3	0.05	1.0	0.10	1.1	0.0	1.0	0.61	1.2	1.2	0.17
Cameroon												
Dourom	0.63	1.3	0.31	1.1	1.07	1.3	0.0	1.0	0.11	1.1	1.3	0.30
Maroua	2.73	1.9	0.05	1.0	1.67	1.6	0.0	1.0	0.0	1.0	1.5	0.18
Ghana												
Manga	0.39	1.1	0.05	1.0	0.17	1.1	0.86	1.3	0.0	1.0	1.2	0.15
Mali												
Koporo	9.09	3.1	0.24	1.1	11.72	2.8	0.0	1.0	2.01	1.5	2.3	0.44
Niger												
Konni	6.07	2.5	0.70	1.3	1.43	1.5	0.0	1.0	0.10	1.1	1.7	0.24
Tarna	10.08	3.3	4.18	2.0	13.36	3.7	0.0	1.0	0.05	1.0	2.4	0.29
Nigeria												
Bakura	0.62	1.2	0.11	1.1	0.05	1.0	0.0	1.0	0.05	1.0	1.1	0.07
Minjibir	2.83	1.9	0.60	1.2	2.09	1.7	0.0	1.0	0.0	1.0	1.4	0.14
Togo												
Pissare	5.05	2.4	0.27	1.1	9.38	2.8	0.0	1.0	0.47	1.2	1.9	0.54
Mean	2.98	1.8	0.51	1.2	3.18	1.7	0.16	1.1	0.34	1.1	1.53	
S.E. (12 D.F.)	-	0.07	-	0.06	-	0.08	-	0.04	-	0.04		
β	-	1.76	-	0.42	-	1.90	-	-0.12	-	0.14		
r^2	-	0.90	-	0.44	-	0.90	-	0.13	-	0.13		

Transf., is the square root transformation of striga density.

β, regression slope; it measures the stability of *Striga* infestation across locations; $\beta = 1$, stable; $\beta > 1$, least stable; $\beta < 1$, highly stable.

r^2, coefficient of determination.

Table 3. *Striga* density and grain yield of cowpea cultivars at two locations infested with *Striga*, Gabougoura, Niger, and Koporo, Mali, in 1991 (adapted from Muleba *et al.* 1996)

	Gabougoura			Koporo		
Cultivar	Striga density (shoot/m²)	Trans.	Grain yield (kg/ha)	Striga density (shoot/m²)	Trans.	Grain yield (kg/ha)
IT82E-32*	3.3	2.0	993	4.3	2.2	1043
KVx164-65-5	17.4	3.8	1174	0.2	1.1	1670
KVx291-47-222	4.0	2.0	352	0.2	1.1	1419
KVx397-6-6	17.0	3.6	747	0.1	1.0	1690
KVx402-5-2	23.0	4.4	800	0.5	1.2	1712
KVx402-19-2	10.7	3.2	651	2.4	1.6	1586
KVx402-19-5	33.2	5.2	758	0.0	1.0	1545
KVx305-118-31	19.3	3.2	480	0.3	1.1	2108
IT81D-994	6.9	2.3	598	0.2	1.1	1377
TN5-78	15.8	3.7	566	0.0	1.0	1670
IT82D-849	24.7	5.0	790	0.0	1.0	1169
B301	14.9	3.6	982	0.0	1.0	1190
Mean	15.8	3.5	741	0.7	1.2	1515
S.E. (33 D.F.)		1.11	220.7		0.22	214.5

Transf., is the square root transformation of *Striga* density.
* Susceptible control.

Table 4. *Striga* density and grain yield of susceptible, tolerant and resistant cowpea cultivars in *Striga* free (SFP) and infested (SIP) plots at Kamboinse, Burkina Faso, in 1989 (adapted from Muleba *et al.* 1997).

Cultivar	*Striga* density		Grain yield (kg/ha)	
	Shoot/m²	Trans.	SFP	SIP
1. Susceptible cultivars				
KN-1	9.75	3.02	1396	916
TN88-63	5.50	2.32	1349	715
KVx396-18-10	7.25	2.63	1374	950
Mean	**7.50**	**2.66**	**1373**	**860**
2. Tolerant cultivars				
KVx396-4-2	8.50	2.79	1622	1144
KVx396-4-4/2	8.75	2.92	1352	1233
KVx396-4-4/4	11.50	3.35	1656	1064
Mean	**9.58**	**3.02**	**1543**	**1147**
S.E. (15 D.F.)	-	0.330		
3. Resistant cultivars				
B301	0.0	-	899	953
KVx61.1	0.0	-	991	1215
KVx65-114	0.0	-	1094	1226
Mean	**0.0**	-	**995**	**1131**
S.E. (33 D.F.)	-	-	153.6	110.0

Transf., is the square root transformation of *Striga* density.

Table 5. Grain yield of cultivars at 12 locations infested with *Striga* in West and Central Africa in 1992 (adapted from Muleba *et al.* 1996)

Location	Cowpea Cultivar													
	IT82E-32*	KVx164-65-5	KVx291-47-222	KVx397-6-6	KVx402-5-2	KVx402-19-2	KVx402-19-5	KVx305-118-31	IT81D 994	TN5-78	IT82D-849	B301	Mean	S.E. (33D.F.)
	(kg/ha)													
Benin														
Zakpota	321	367	484	576	714	618	618	593	626	827	509	576	569	92.9
Burkina Faso														
Kamboinse	768	807	978	628	1265	1025	943	926	746	565	710	784	845	116.4
Kouare	996	580	533	507	932	507	449	775	170	544	313	673	582	104.8
Cameroon														
Dourom	1187	896	583	304	1125	687	417	608	320	367	913	838	687	216.5
Maroua	1096	987	471	362	1012	629	516	612	328	259	1188	683	679	147.2
Ghana														
Manga	500	541	500	708	458	542	667	583	417	625	416	709	556	97.4
Mali														
Koporo	42	1023	918	1294	636	1711	1983	981	897	2171	876	1273	1151	267.8
Niger														
Konni	918	918	835	1545	1336	1482	2087	1148	21	1691	939	1482	1200	169.6
Tarna	38	66	30	181	53	189	151	94	4	212	133	366	127	35.2
Nigeria														
Bakura	1032	459	314	366	737	876	432	348	54	484	424	1879	616	173.5
Minjibir	578	311	246	286	100	403	336	269	229	77	440	501	315	81.3
Togo														
Pissare	495	1110	872	783	879	762	829	1043	185	822	622	1115	793	134.3
Mean	664	672	564	628	771	786	786	665	333	720	624	907	677	
S.E. (11 D.F.)	118.5	57.3	41.5	62.2	85.8	45.1	80.8	43.0	81.3	103.2	66.4	104.2		
β	0.22	0.89	0.85	1.19	0.99	1.36	1.85	0.96	0.36	1.70	0.71	0.93		
r^2	0.03	0.67	0.78	0.75	0.53	0.88	0.81	0.81	0.14	0.69	0.49	0.40		

* Susceptible control.

β, regression slope; it measures the stability of *Striga* infestation across locations; $\beta = 1$, stable; $\beta > 1$, least stable; $\beta < 1$, highly stable.
r^2, coefficient of determination.

Table 6. Days to flowering and seed yield as affected by cowpea cultivars and sowing dates under *Striga* infestations at Kamboinse, Burkina Faso, in 1983 (from Muleba & Mosarwe 1994)

Cultivar	Days to 50% flowering			Seed yield		
	21 June	18 July	12 August	21 June	18 July	12 August
	(days after sowing)			(kg/ha)		
Ouahigouya*	168	58	45	12	468	338
Kaya*	193	166	73	8	0	18
Kamboinse N.*	163	166	51	0	0	50
Kamboinse R.*	168	57	46	0	382	178
KN-1†	49	46	45	697	171	116
Suvita-2†	51	47	47	1571	1034	261
S.E. (45 D.F.)	15.2			82.8		

* Daylength sensitive cultivars; half of them failed to flower when sown before mid-July.
† Daylength insensitive cultivars; Suvita-2 is a *Striga* resistant control.

Table 7. *Striga* density and seed yield of cowpeas as affected by continuous cultivation of susceptible cultivars in *Striga* infested field plots at Kamboinse and Gampela, Burkina Faso, in 1984-87 (from Muleba *et al.*, 1996)

Location/ Year	*Striga* density (shoot/m^2)	Seed yield (Kg/ha)
Kamboinse*		
1984	1.34	242
1985	2.14	871
1986	0.16	669
Gampela†		
1987	20.73	425
S.E. (24 D.F.)	1.060	45.7

* in 1984, this field plot was already in its third year of continuous cultivation with *Striga* susceptible cultivars.
† first year of cultivation of susceptible cultivars.

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