GENETIC STUDY OF COWPEA (*VIGNA UNGUICULATA* (L.) WALP.) RESISTANCE TO *STRIGA GESNERIOIDES* (WILLD.) VATKE IN BURKINA FASO

by

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GENERAL ABSTRACT

In Burkina Faso, the existence of different races of *Striga gesnerioides* (Willd.) Vatke, with apparent variable aggressiveness on cowpea (*Vigna unguiculata* (L.) Walp) renders the breeding task very complex. Therefore, a number of studies was carried out from 2006 to 2009 in field, pot and ‘*’in-vitro’’* to identify new sources of resistance to three prevailing *Striga* races, SR 1, SR 5 and a newly occurring *Striga* race named SR Kp and to understand the genetic pattern of the underlying resistance of cowpea germplasm to *Striga* races found in Burkina Faso.

To achieve these objectives, the following investigations were initiated: (i) a participatory rural appraisal (PRA), a participatory variety selection (PVS) and grain quality survey were implemented to identify cowpea breeding priorities for Burkina Faso *Striga* hot-spots; (ii) the identification of sources of resistance in Burkina Faso germplasm, using three prevailing *Striga* races of *S. gesnerioides* as sources of inoculum; (iii) the identification of the mechanisms of resistance underlying the resistance to *Striga* in such genotypes; (iv) a study of combining abilities of selected parents through a diallel cross; (v) a study of the segregation patterns in crosses involving resistant and susceptible sources and a study of the allelic relationships between different resistance sources.

The participatory studies conducted in 2007 and 2008 over three districts in *Striga* hot-spots; there was no effective control method against *Striga* at farmers’ level. These investigations highlighted the importance of cowpea across all sites. Rain decline over time, low input use coupled with a poor extension system were the major constraints mentioned by farmers. Differential reactions of genotype KVx61-1 for *Striga* resistance suggested that different *Striga* races were prevailing in different areas. Farmers’ preferred traits in cowpea genotypes were oriented towards grain quality such as big sized grain, white seed colour and rough texture of cowpea grain, except in Northern-Burkina Faso, where farmers preferred brown-coloured grain for food. Cowpea was also seen as an income generating crop.

An evaluation of 108 genotypes was done in 2007 in the field (rainy season) and in pots (off-season) for *Striga* resistance assessments. The screening trials enabled the identification of sources of resistance to *S. gesnerioides*. Genotypes KVx771-10, IT93K-693-2, KVx775-33-2, Melakh and IT81D-994 are potential sources of resistance to all three *Striga* races with acceptable yield. Landraces were susceptible and late-maturing whilst most wild species were resistant but with unwanted shattering traits.

A combining ability study for *Striga* resistance parameters conducted in pots and a resistance mechanism study conducted ‘’*in-vitro’’* were performed using F_1 populations from a 10 x 10 diallel cross. The general combining ability (GCA) effects were significant for the resistance parameters *Striga* emergence date (DSE), *Striga* height above soil (SH), cowpea grain weight (CGW), hundred grain weight (HGW) for all *Striga* races involved and *Striga* vigour (SVIG) for SR 5 and SR Kp. The pot-screening showed that, regardless of the SR used as inoculum, the additive genes were important in conferring *Striga* resistance for parameters DSE, SH, CGW and HGW. The selection of parents could therefore result in breeding advance. Complete dominance, partial, over-dominance and non-allelic interactions (epistasis or failure of some assumptions) were present for some parameters.

The ‘’*in-vitro’’* screening showed that additive genes were important, with high narrow sense heritability values for the resistance mechanisms *Striga* seed germination frequency (GR) for SR 1 and SR Kp, the frequency of *Striga* radicle necrosis before the penetration in cowpea rootlet (NBP) for SR 5, the frequency of *Striga* radicle necrosis after the penetration in cowpea rootlet (NAP) for SR 1 and SR Kp and the susceptibility *‘’in*-vitro’’ (SIV) for SR 5 and SR Kp. The selection of parents can be useful in accumulating the genes for *Striga* resistance mechanisms in progenies.

The F2 populations derived from crosses between *Striga*-resistant x susceptible genotypes were evaluated in *Striga* infested benches in 2008 and 2009. The segregation patterns suggest that single dominant genes govern *Striga* resistance. The test for allelism showed that two non-allelic genes were responsible for the resistance to *S. gesnerioides* in cowpea. A new *Striga* resistance gene seems to be involved in genotype KVx771-10 resistance to *S. gesnerioides*, which confers resistance to all studied *Striga* races. Gene *994-Rsg* in

genotype IT81D-994 which confers *Striga* resistance to SR 1 and gene *Rsg 3* also conferring *Striga* resistance to SR 1 segregated differently for the resistance to SR 5 suggesting that they were different but both confer resistance to SR 5.

Declaration

I **Jean Baptiste De La Salle Tignegre** declare that:

(i) The research reported in this thesis, except where otherwise indicated, is my original work.

(ii) This thesis has not been submitted for any degree or examination at any other university.

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…… Date…….

Jean Baptiste De La Salle Tignegre (Candidate)

As the candidate's supervisors, I agree to the submission of this thesis

Signed

…… Date…….

Professor Rob Melis (Supervisor)

Signed

…… Date…….

Professor Pangirayi Tongoona (Co-supervisor)

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Dedication

I dedicate this thesis to:

Ariste Angelina, my wife; I am grateful for all the cares, you have been providing to Jonathan, Myriam and Juvens,

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GENERAL INTRODUCTION

Cowpea (*Vigna unguiculata* (L.) Walp.) is a grain legume grown on over 12.5 million hectares, with a production of three million tons worldwide (Singh, 1997). Cowpea is mostly grown in West and Central Africa, where it shows adaptation to semi-arid conditions (Ehlers and Hall, 1997). In West Africa, cowpea is grown on over 9.5 million ha with a production of 2.9 million tons (Omo-Ikerodah *et al.*, 2005). Two-third of the production and more than three-fourth of the areas covered by cowpea in Africa occur in Sudan Savanna and Sahelian areas of Sub-Saharan Africa. A yield of 7000 kg ha^{-1} was achieved in the USA under optimum conditions (Ehlers and Hall, 1997). However, at the level of the resource poor farmer, the average cowpea yield in Africa is less than 300 kg ha^{-1} (Ehlers and Hall, 1997). The low yields could be attributed to low input applications and the wide practice of cowpea/cereal intercrops (Pasquet, 1999).

In 2007, Burkina Faso was ranked amongst the top three cowpea producers in West Africa (455,000 tons), behind Nigeria (3.15 million tons) and Niger (1.001 million tons) (FAOSTAT, 2008). In Burkina Faso, cowpea production has increased from 338,100 tons in 1998 to 455,000 tons in 2007, with fluctuations due to climatic variations (Figure 1). The same trend is observed for the areas planted with cowpea during the same period which grew from 650,196 ha (1998) to 728,000 ha (2008) (Figure 2).

Cowpea is important due to several attributes. This crop is high in nutritional value, and plays an important role as a cash-crop in semi-arid areas (Ehlers and Hall, 1997). It has high tolerance to drought (Singh, 1997), exhibits tolerance to shade, fixes atmospheric nitrogen (Singh, 1997), the grain has high protein content (25%) (Marconi *et al.*, 1992), and fits well in several low input farming systems (D.S.A.P., 2002; PRONAF, 2003). In addition, cowpea fodder is fed to livestock. In 2002, in Burkina Faso, 57% and 61% of cowpea production and planted areas respectively were achieved under intercrop conditions (Palenfo, 2007). In terms of utilization, the diversity of diets based on cowpea, and the short cooking time renders cowpea popular for rural people and low income workers in towns. Leaves, fresh peas and fresh pods are also consumed (Ehlers and Hall, 1997). However, cowpea

production is affected by several biotic and abiotic constraints that lead to severe yield reduction at the smallholder farmer level (Ehlers and Hall, 1997).

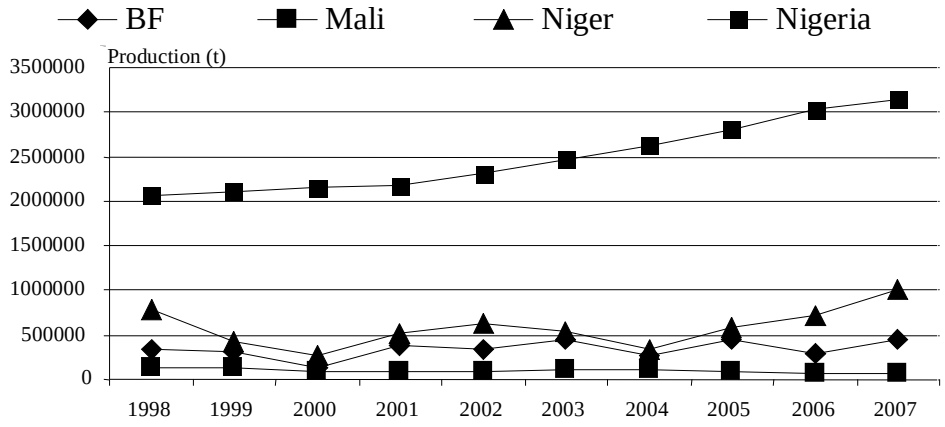

Figure 1 Yearly cowpea production (tons) in Burkina Faso, Mali, Niger and Nigeria from 1998-2007 (FAOSTAT, 2008).

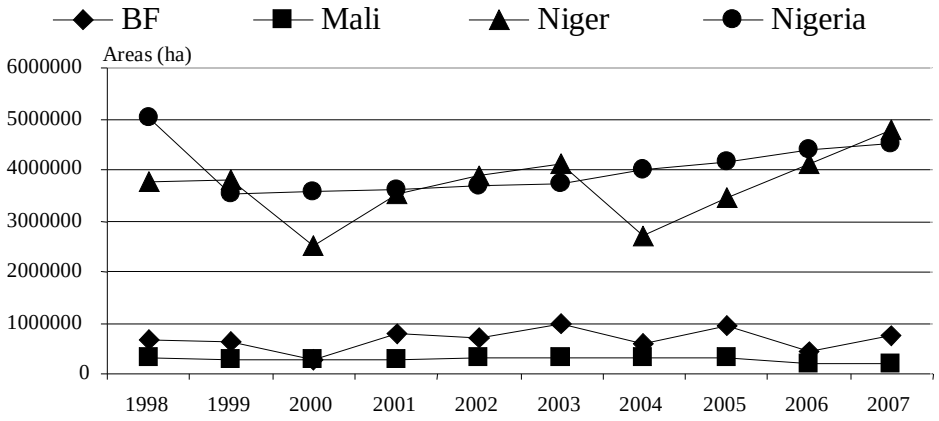

Figure 2 Yearly areas (ha) covered by cowpea in Burkina Faso, Mali, Niger and Nigeria from 1998-2007 (FAOSTAT, 2008).

The most significant causes of yield loss are (i) insect pests; (ii) foliar, stem, pod and seedling diseases; (iii) drought and high temperatures in dry areas (Sahelian zones); (iv) weeds such as *Striga gesnerioides* (Willd.) Vatke*;* (v) the low yield potential of landraces; (vi) the unavailability of improved varieties, and (vii) the lack of accessibility to inputs such as pesticides. Yield losses due to *S. gesnerioides* vary between 30% and 50% in Burkina Faso (Aggarwal and Ouédraogo, 1989; Muleba *et al.*, 1997; Tignegre, 1988), and can be as high

as 100% under farmers' field conditions (Alonge *et al.*, 2001). Up to now, there is no effective and affordable control method against *Striga*.

Cowpea is one of the most important staple crops grown in the three ecological zones of Burkina Faso, which comprises the Sahel, the North Sudan Savanna and the South Sudan Savanna. Recently, Burkina Faso has targeted cowpea as a strategic crop that could contribute to achieving food security and alleviating poverty, due to its market potential. However, its production is hampered by *S. gesnerioides*; a cowpea root parasite whose effect coupled with drought, always causes severe yield loss in the crop.

On average, 40% of loss occurring in crop production in Africa is caused by *Striga* species, which represents an annual value loss of agricultural revenues estimated to be seven billion dollars (Robson and Broad, 1989). *Striga* is one of the major causes of food insecurity in the world as it affects the production of maize (*Zea maize*), sorghum (*Sorghum bicolor*), millets (*Pennisetum typhoides* and *Euleusine species*) and cowpea (*V. unguiculata*) (Lane and Bailey, 1992). These crops provide more than 70% of the diets in semi-arid Sub-Saharan Africa, with the cowpea providing 50% of proteins in the same diets (Lane and Bailey, 1992). On cowpea, *S. gesnerioides* causes the pods to be empty (Hibberd *et al.*, 1996), hence reducing yield. Complete yield losses of 100% due to *Striga* species can be obtained (Berner and Williams, 1998).

Five virulent races of *S. gesnerioides* have been reported in different countries of Africa (Table 1). In Burkina Faso, a selected cowpea landrace, Gorom local, confers resistance to race 1 prevalent in Burkina Faso (Aggarwal and Ouédraogo, 1989) and race 5, but has shown susceptibility to an unknown isolate or race confined to the eastern part of Burkina Faso (Koupela). This race looks more aggressive than race 1 and race 5 reported in the centre and south of Burkina Faso respectively (Cardwell and Lane, 1995). It could be a new or simply a different race recorded elsewhere. A landrace of cowpea from Botswana (B301) confers resistance to four (1, 2, 3 and 5) of the five *Striga* races reported in Africa (Atokple *et al.*, 1995). However, B301 and other improved resistant varieties are either not locally adapted, or lack desirable agronomic characteristics and/or grain and leaf qualities accepted in Burkina Faso. Recently, Li and Timko (2009) reported the existence of seven races in

Sub-Saharan Africa based on molecular characterization of *Striga* races. However, the geographic distribution of the new *Striga* races (6 and 7) was not defined.

Table 1 Distribution of *Striga gesnerioides* races in Africa (Singh, 1997).

	Different races of *Striga gesnerioides*				
	1	2	3	4	5
Area of distribution	Burkina Faso	Mali	Niger, Nigeria	Bénin	Cameroon Burkina Faso

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Assessing *Striga* resistance in the field is difficult, expensive and sometimes unreliable (Haussmann *et al.*, 2000). *Striga* seeds also have long viability in the soil and are difficult to control (Lane and Bailey, 1992). Artificial field-screening increases the risks of disseminating *Striga* to new geographical areas. As a result, field infestations with *Striga* seeds are often prohibited. This necessitates the development and use of new and effective screening methods such as "*in-vitro*" and molecular techniques. Successful identification of locally adapted and *Striga*-resistant cultivars, coupled with knowledge of the genetic inheritance of resistance genes involved in new and adapted sources and efficient screening methods, could provide effective *Striga*-resistant cultivars.

Burkina Faso is geographically located in West Africa, the centre of domestication of cowpea, which could be exploited in selecting locally adapted genotypes for further improvement. *V. unguiculata* var. *spontanea* is a close relative of cultivated cowpea. The domesticated (*V. unguiculata* var. *unguiculata*) and the wild forms (*V. unguiculata* var. *spontanea*) are cross-compatible (Pasquet, 1999). High levels of resistance to pests have been detected in some wild *Vigna* species such as *V. vexillata* (Fatokun, 2002). *Vigna* species are genetically highly variable and comprise wild perennial, wild annual and cultivated species used for consumption (Pasquet, 1999). Gorom local, a landrace in the Sahel area of Burkina Faso, was identified as the first source of resistance to *S. gesnerioides* (Aggarwal and Ouédraogo, 1989). The resistance gene was named Rsg_3 (Atokple *et al.*, 1995). Wild relatives and landraces of cowpea are abundant in Burkina Faso and are sources of wide environmental adaptation and resistance to parasites.

Despite the genetic variability existing within wild *Vigna* species and landraces in Burkina Faso (Tignegre, unpublished data), no in-depth investigation has been done to determine their resistance to *S. gesnerioides* with regard to the prevailing *Striga* races. Likewise, their role as sources of resistance is unknown.

The overall research goal of this study was to identify new sources of resistance to the occurring *Striga* races and to understand the genetic pattern of the underlying resistance mechanisms in order to improve food security by developing new, high yielding, and *Striga*-resistant cowpea cultivars for semi-arid areas of Burkina Faso. The specific objectives were to:

(i) determine the production system, farmers' awareness of *S. gesnerioides* and their preference for cowpea cultivars through a participatory rural appraisal (PRA), and a participatory variety selection (PVS),

(ii) screen Burkina Faso cowpea landraces, wild species and new improved genotypes for *S. gesnerioides* resistance and for good grain characteristics,

(iii) establish whether SR Kp is a new *Striga* race,

(iv) determine the combining ability for *Striga* resistance parameters and *Striga* resistance mechanisms, and

(v) determine the segregation patterns of resistant x susceptible crosses, and the allelic relationships between existing and new *Striga*-resistant genes, with regard to the *Striga* race prevailing in each zone.

These specific objectives aim at providing responses to the following hypothesis:

- Farmers are aware of *S. gesnerioides* damage and they have specific preference for cowpea genotypes,
- Sources of resistance to *S. gesnerioides* exist among cowpea wild relatives and landraces,
- Genes with additive effects are mostly involved in the resistance to *S. gesnerioides*,
- *Striga* resistance in cowpea wild species and landraces is qualitatively inherited, and

- The new identified *Striga* resistance genes are allelic to genes Rsg_1, Rsg_2, and Rsg_3, and confer *Striga* resistance to all three *Striga* races prevailing in Burkina Faso.

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CHAPTER ONE

Literature review

1.1 Introduction

This review focuses on the resistance of cowpea (*Vigna unguiculata* (L.) Walp.) to *Striga gesnerioides* (Willd.) Vatke, a parasitic root plant, damaging cowpea in semi-arid areas of Africa. The importance of cowpea, the production constraints with a focus on *S. gesnerioides* will be discussed. This review also covers screening and breeding approaches that could be exploited for developing adapted and *Striga* resistant varieties of cowpea.

1.2 Cowpea

1.2.1 Origin and taxonomy

It is believed that cowpea originated from Africa because of the high diversity in *Vigna* genera on the continent (Raynal-Roques, 1993). Southern Africa and the region of Africa around the Equator have been reported to be centers of origin of cowpea (Rawal, 1975; Vaillancourt *et al.*, 1993). Cowpea was domesticated in West Africa (Padulosi and Ng, 1997). Cowpea belongs to *Papillionaceae* (or *Fabaceae*) sub-family, and to *Leguminoseae* family. Domesticated cowpea belongs to genera *Vigna* and to the species *unguiculata*. Cowpea is a diploid species with a chromosome number of 2x=2n=22 (Fery, 1985). There are five sub-species, which are *Vigna unguiculata*, V. *cylindrica*, *V. sesquipedalis, V. dekindtiana,* and *V. mensensis* (Ng and Maréchal, 1985). Cowpea species are morphologically and genetically variable, and comprise wild perennial, wild annual and cultivated species used as staples (Pasquet, 1999). Wild species are named *V. unguiculata ssp dekintiana* also called *V. unguiculata ssp spontanea* (Pasquet, 1999). Cultivated cowpeas are grouped as *V. unguiculata ssp unguiculata. Vigna unguiculata ssp dekindtiana* refers to wild crossable cowpeas or *V. unguiculata ssp pubescens*. Burkina Faso is geographically located in the centre of diversity of cowpea, and wild relatives of cowpea could be exploited for breeding more locally adapted varieties.

1.2.2 Floral biology and breeding system

The breeding procedure for a crop can be influenced by its floral biology. The floral structure in cowpea is characterized by a symmetric flower with a style with a short beak (stigma) (Marechal *et al.*, 1978). It contains ten stamens (Figure 1.1), each carrying an anther sac providing pollen. The structure of the flower of cultivated cowpea favours self-pollination in that both sexes are in the same flower. Flowering occurs after pollination and fertilization, which reduces chances for out-crossings due to foreign pollen (Marechal *et al.,* 1978).

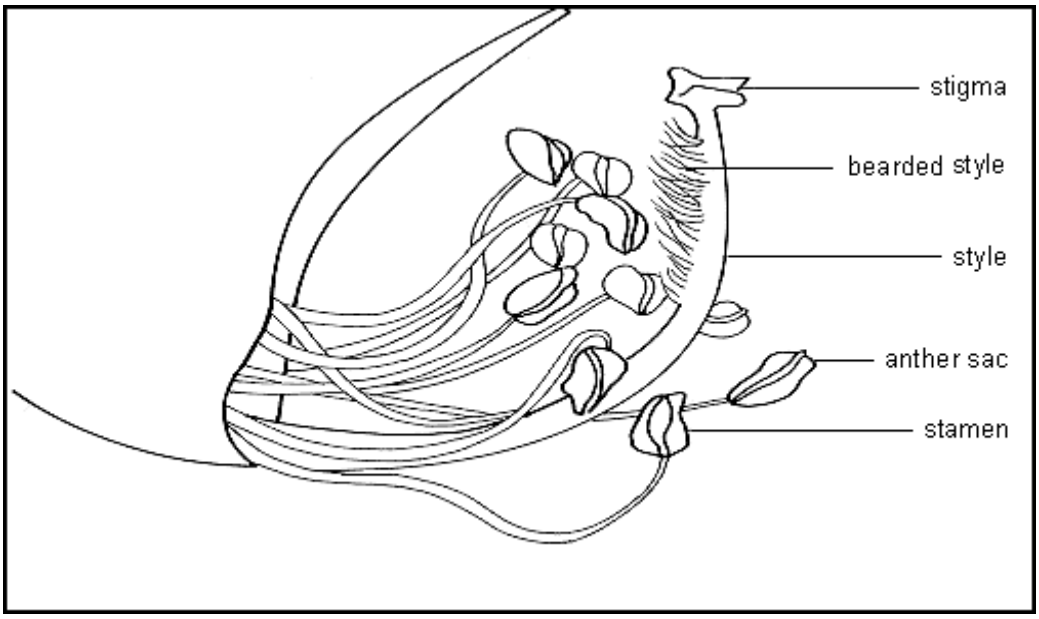

Figure 1.1 A cowpea flower showing female (stigma) and male (anthers) sexes (IITA, 2005).

In Burkina Faso in winter (November to January), the pollination in cowpea occurs during cool nights (personal data), and the exact time differs slightly from one genotype to another. However, the flowers open hours later than fecundation, early in the morning. In some wild species, the stigma position is much higher than the stamens, which favors cross-pollination.

Self-pollination is the natural way of reproduction in cowpea. Hybridization can be done artificially to enable the recombination of desirable characters. Segregating populations produce a high genetic variation, partly due to recombination events and to occasional gene flow via pollen from neighbouring populations (Hamrick, 1989). Other genetic differentiation

occurring could be due to mutation. In other words, self-pollinated species have limited gene movement which tends to favour a genetic differentiation into pure lines (Loveless and Hamrick, 1984).

1.2.3. Crossing or hybridization techniques

Achieving successful crosses is a prerequisite to any genetic study. Crossing cowpea is relatively easy compared to other grain legumes, but the rate of success is 10-20% under natural conditions (Myers, 1996). Usually, a successful cross produces a pod with 8-12 seeds. Myers (1996) also reported that synchronizing flowering under cool temperatures (early in the morning), and a high humidity may increase the success of hand crossing to 50%. In cowpea flowers, anthesis takes place just before the opening of the corolla. Hence, flower buds destined to open the following morning are ready for emasculation (Myers, 1996). These buds have now reached their maximum unopened size, and have started to pale slightly from the deep rich green colour of earlier development. Cool nights provide better conditions for fertilization than the hotter daytimes. The emasculated flower should be crossed immediately after emasculation, or pollinated the following morning (Myers, 1996).

1.3 *Striga gesnerioides*

1.3.1 Economic importance and damage to crops

Botanga and Timko (2005) consider the genera *S. hermonthica,* S. *aspera* and *S. gesnerioides* as the most agronomically important parasitic weeds. *S. asiatica* is another species that can cause complete yield loss in cereals (Hood *et al.* 1998). Lane and Bailey (1992) indicated that these parasites are the species of major economic importance in the world. *Striga* genera are spread across the semi-arid tropics (Hibberd *et al.*, 1996). *Striga gesnerioides* (Willd) Vatke is particularly damaging on cowpea in Sudan-Sahelian areas on sandy and water-stressed soils (Singh, 2002). Seventy five per cent of *Striga* damage occurs during the pre-emergence stage (Singh, 2002). Yield loss due to *S. gesnerioides* is estimated to be 30% in Burkina Faso (Aggarwal and Ouédraogo, 1989) and is more severe with susceptible cowpea cultivars under farmers' field conditions (Alonge *et al.*, 2004; Muleba *et al.*, 1996; Tignegre, 1988). In some cases with severe attacks, 100% yield loss is recorded (Singh, 2002). Five virulent races of *S. gesnerioides* have been reported in different countries of Africa (Table 1) and their rapid spread requires an urgent need for

multiple resistance genes (Boukar *et al.*, 2004). In addition, the longevity of *Striga* seeds is estimated to be about 20 years in the soil (Lane *et al.*, 1997); this renders all other control methods inefficient. *Striga* damage can be reduced by growing high yielding *Striga*-resistant cultivars and using agronomic practices to increase soil fertility (Muleba *et al.*, 1997).

Damages due to *S. gesnerioides* can be assessed by the symptoms induced by *S. gesnerioides* on cowpea. *Striga* damage occurs at various parts of cowpea plants (Alonge *et al.*, 2004). Furthermore, the physiological functions of cowpea plants can be affected by *S. gesnerioides*. Reduced leaf area, leaf photosynthesis reduction and limited flowering, podding and seed development have been reported (Alonge *et al.*, 2004). Such damage is often aggravated by transpiration by the parasite when drought prevails (Alonge *et al.*, 2004). Increases in nitrogen content in cowpea plants, and protein content in cowpea grain may be observed with *Striga* infestation due to a concentration of inhibitors reducing the canopy and the plant growth (Alonge *et al.*, 2004). Once a field is infested with *Striga* seeds, the underground *Striga* seed stock will increase, which sets up a situation of potential yield loss in the future (Cardwell and Lane, 1995).

The incidence and the severity of *S. gesnerioides* damage depend on soil type, the cropping system and the genotype involved (Cardwell and Lane, 1995). Edaphic factors affect severity of *S. gesnerioides* in that its severity is higher on sandy soils than clay soils (Cardwell and Lane, 1995). The confinement of *Striga* to Sahelian and North Guinea zones and sandy soils seems to confirm that *Striga* is a parasite of low-fertile areas. Consequently, appropriate technologies should be developed for an efficient control of *S. gesnerioides*. However, the incidence of *S. gesnerioides* is determined by the interaction between the host and the parasite (Cardwell and Lane, 1995).

1.3.2 Geographical distribution

According to Lane and Bailey (1992), *S. asiatica* is distributed in West, East and Southern Africa, India, Near East, East, Far East and USA. It parasitizes maize, finger and pearl millets, sorghum and sugar cane. The same authors mentioned that *S. hermonthica* is confined to East and West Africa and attacks the same crops as *S. asiatica*. The geographic areas of *S. gesnerioides* comprise West and Southern Africa, India, Near East and USA. In

West Africa, *S. gesnerioides* was reported to occur in Benin, Burkina Faso, Mali, Niger and Nigeria (Cardwell and Lane, 1995) with one race at least prevailing in each country. The races 1 and 5 of *S. gesnerioides* were reported to prevail in Burkina Faso (Cardwell and Lane, 1995).

1.3.3 Taxonomy

The genus *Striga* belongs to the family of *Scrophulariaceae*, which comprises about 50 species (Botanga and Timko, 2005). *Alectra vogelii* (Benth.) is a hemiparasite of the same family, which causes moderate damage to cowpea by reducing yield and protein content (Alonge *et al.*, 2001a; 2001b). *Striga spp*. belongs to *Orobanchaceae* and are hemiparasites because of the aerial photosynthetic activity occurring after *Striga* emergence from soil (Matusova *et al.*, 2005). However, some authors considered *Striga* species as holoparasites, since the photosynthesis is nil or low after they have emerged from soil (Wolfe and DePamphilis, 1998). *Striga* species are considered as witch weeds in that, their entire development before emerging above soil, depends on the uptake of water and nutrients from the host and even growth hormones, especially with *S. gesnerioides*. *Striga gesnerioides* is more dependent on its host than *S. hermonthica* and *S. asiatica* due to its higher transpiration requirement (Thalouarn *et al.*, 1991).

1.3.4 *Striga* species and hosts

There are roughly 3,000 plant species of parasitic weeds grouped in 17 families (Kuiper *et al.*, 1998). Several genera in this group, amongst which *Striga* genera, damage crops (Kuiper *et al.*, 1998). They can be parasites of cereals and legumes (Botanga and Timko, 2005). There are different species of *Striga* amongst which, *S. hermonthica* and *S. aspera* are parasitic on cereals and *S. gesnerioides* which causes threats to dicotyledonous in particular to cowpea (Berner and Williams, 1998). Other hosts for *S. gesnerioides* include tobacco (*Nicotiana tabacum* L.), sweet potato (*Ipomea batatas* (L.) Lam.), *Tephrosia sp., Indigofera tinctoria* L. and *Indigofera spicata* Forsk (Musselman and Ayensu, 1984). The race attacking *Indigofera* does not attack cowpea (Botanga and Timko, 2005).

1.3.5 *Striga gesnerioides* life cycle

The life cycle of *Striga* comprises a series of growth phases that are linked to the developmental stages of the host's plant growth (Lane and Bailey, 1992; Matusova *et al.*, 2005). There are biochemical signals that coordinate *Striga* life cycle to the host's (Matusova *et al.*, 2005). After *Striga* seeds are formed, they need a post-harvest maturation period of six to seven months upon which *Striga* completes the physiological maturing process (Thalouarn and Fer, 1993). The *Striga* seeds will remain dormant if the temperature is below 25^{O}C or above 35^{O}C (Kuiper *et al.,* 1996). Seeds require an imbibition period or a seed conditioning phase of 10-21 days before they can germinate (Okonkwo, 1991; Lane and Bailey, 1992). Such conditions are normally fulfilled at the beginning of the rainy season in the semi-arid areas. Within a period of two to five days, *Striga* seeds germinate if a stimulus from exudates is produced by cowpea roots within a distance of 2 mm (Dube and Olivier, 2001; Lane *et al.*, 1991). The radicle of *Striga* grows and penetrates the host root, whereby it forms a tubercle called *haustorium,* which is visible on the host root surface (Lane *et al.*, 1991). The *Striga* radicle cannot survive more than seven days if the connection to the host is not achieved, because nutrients in seed albumen are very limited due to its small size (Berner and Williams, 1998). The *haustorium* is an organ designed to drain nutrients, and water from the host to feed the *Striga* plant during its early and underground development stage (Lane and Bailey, 1992). At this stage the damage as a result of *Striga* attack is high in that *Striga* is a full parasite (Lane and Bailey, 1992) and depends entirely on the host for its survival. The emergence above the soil happens between four to six weeks on susceptible cowpea genotypes (Tignegre, 1988). Thereafter, *Striga* develops stems and leaves and synthesizes chlorophyll (Hibberd *et al.*, 1996). *Striga gesnerioides*, unlike *S. hermonthica* is autogamous and this reduces the eventual risk of pollen flow which consequently causes the population of *S. gesnerioides* to be uniform (Botanga and Timko, 2005). Botanga and Timko (2005) have shown that the existence of races in *S. gesnerioides* is associated with a host-driven selection. The cycle from flowering to seed maturing is achieved in five to seven weeks after cowpea planting, upon which, 50,000 to 500,000 seeds per plant will be released (Lane and Bailey, 1992). Seeds are microscopic in size (0.20 mm to 0.35 mm long), each weighing 4 to 7 µg (Dubé and Olivier, 2001). This renders *Striga* seed dissemination easy in nature, through water, wind, animals and farming tools. *Striga gesnerioides* plants flower within four to seven days after *Striga* emergence (Dube and Olivier, 2001). Eighty percent of *S. gesnerioides* seeds are distributed in the first 15 to 30 cm layer of the soil (Touré *et al.*, 1997). The huge amount of seeds produced, coupled

with the highly degraded soils in semi-arid zones and the poor access of smallholder farmers to herbicides and germination stimulants, make it difficult to eradicate *S. gesnerioides*.

1.3.6 Available control measures

Germination stimulants of *Striga* seeds can be effective in controlling *Striga* by inducing suicidal germination (Berner and Williams, 1998; Berner *et al.,* 1997). However, such methods are expensive to smallholder farmers of Sub-Saharan Africa. The bacterium *Pseudomonas seringae*, when incorporated in the soil, stimulates more abortions of *S. gesnerioides* seeds than the *Striga*-seed germination stimulants, such as strigol analogues (Berner *et al.*, 1997). Alternatively, trap-crops can be used to reduce *Striga* seed stock in the soil. Amongst the effective trap crops, a variety of *Sorghum bicolor* named Bagauda farafara was found to be the highest germination stimulant of *S. gesnerioides* (Berner and Williams, 1998), while to a lesser extent, pigeon pea, *Cajanus cajan,* can also stimulate *S. gesnerioides* germination. Such crops could therefore be integrated in a farming system management scheme (rotations, mixed crops) for an effective control of *S. gesnerioides*. Legumes (cowpea, groundnut, bambara groundnut and soybean) cultivations are alternatives to bush fallows, a current farmer practice to control *Striga* affecting cereals. These practices proved effective in reducing by three times *S. hermonthica* seed stock in the soil (Abunyewa and Padi, 2003; Cardwell and Lane, 1995).

Cowpea intercrops, and rotations with cotton, rice, cereals or vegetables can reduce *Striga* impact on the cereals (Cardwell and Lane, 1995). However, such cowpea intercrops would be effective if *Striga*-resistant cowpea was involved in the system. Fertilization with high rates of nitrogen, appropriate sowing dates and adequate irrigation of cowpea are other options for controlling *S. gesnerioides* (Dembélé*,* 1988). However, farmers often cannot afford these measures. Field solarization, exploiting plastic films to heat the soil, were shown to be effective only for destroying *Striga* seeds in the first 2 cm of the soil layer (Parker, 1991). Therefore, they are not effective in reducing the *Striga* seed stock for the entire volume of soil explored by cowpea roots. Durable and cheap technologies are being investigated in view of the unsuitability of the current control methods for smallholder farmers of Sub-Saharan Africa.

The control of *Striga* is difficult to achieve due to the close association with its host (Lane *et al.,* 1997). However, Cardwell and Lane (1995) have reported the effectiveness of farming systems such as rotation involving cotton or vegetable, cowpea and millet or sorghum intercrops to control *S. gesnerioides.* However, cotton cannot be grown in stress prone areas such as the Sahelian zones, in which the annual average rainfall is only 300 mm. In moderately stressed environments, *Striga* seed conditioning takes place with rains by imbibition at the beginning of the rainy season. Therefore, early planting is used as a *Striga* control method, since the earliest development stages of cowpea escape to *Striga* damage (Muleba *et al.*, 1996; Alonge *et al.*, 2004). Nevertheless, this may not be entirely applicable, since early planting could expose early maturing cultivars to pod damage due to season-end rains. However, with high income-generating crops, herbicides applied at pre-emergence stage, combined with soil fumigants, were effective in controlling *Striga* (Jacobsohn, 1994). However, this approach is beyond the smallholder farmers' means. Consequently, the use of resistant genotypes remains the most appropriate way to control *S. gesnerioides* on cowpea (Alonge *et al.,* 2004).

1.4 Mechanisms involved in the resistance to *Striga gesnerioides*

The life cycle of *Striga* before it emerges above the soil comprises germination, haustorial induction, attachments to the host root and the penetration of the host vascular cells. All these stages are critical for the successful development of *Striga* (Botanga and Timko, 2005). The study of *Striga* growth ‘*'in-vitro''* using parasitized hosts could shed more light on the underlying mechanisms of resistance to *S. gesnerioides* at different development stages. The mechanisms are as follows:

1.4.1 Resistance at germination

In sorghum, the variety N13 induces very low number of *Striga* shoots (Ramaiah, 1987; Lane and Bailey, 1992), which is a form of resistance. A single recessive gene governs the low-stimulant ability (Ejeta *et al.*, 1991; Ramaiah *et al.*, 1990). In cowpea, no genotypes have been found that do not induce the germination of seeds of *S. gesnerioides* (Lane *et al.*, 1991). The chemical signals inducing *Striga* seed germination in maize, sorghum and

cowpea are the strigolactones, namely strigol, sorgholactone and alectrol respectively (Ejeta *et al.,* 1991; Matusova *et al.,* 2005; Ramaiah *et al.*, 1990).

1.4.2 Resistance at fixation level

Fixation starts with the tubercle formation and the growth of the tubercle tip. This stage is not specific to cowpea-*S. gesnerioides* interactions. Dubé and Olivier (2001) assume that the phenylpropanoids of the host are degraded into quinones, which induce formation of ramifications and their subsequent fixation onto the host. Botanga and Timko (2005) mentioned that the *S. gesnerioides* tubercle growth can be stopped for weeks with no connection to the host vascular system. Research with cowpea genotype 58-57 showed that there was a first level of resistance, resulting in an incompatibility, as a result of necrosis before the fixation of the root cortex by the parasite (Lane *et al.*, 1991). Hood *et al.* (1998) considered such a resistance mechanism as being supported host reaction which was generally expressed at the root cortex level. Such effects were termed as hypersensitive reactions, which show that vertical resistance and therefore, single genes might be involved.

1.4.3 Resistance at and after the penetration of the host vascular cells

Anatomical factors prevent or delay the penetration of *Striga* in cells of sorghum variety N13 (Maiti *et al.*, 1984). However, some genotypes, such as sorghum variety IS-7777, though resistant, exhibit anatomical structures similar to susceptible genotypes, but show resistance to *S. asiatica*. It has been shown that a cellulose rich wall layer accumulation in the host roots following the contact with the invading parasite cells can be a form of resistance to *Striga* (Maiti *et al.*, 1984). In cowpea, a similar resistance mechanism is observed with resistant cowpea genotype B301; the *Striga* seed germinated, formed tubercles, but developed no *Striga* stems (Lane *et al.*, 1991). The SR 4 of Benin developed tubercles/*haustoria* and stems, but these did not develop further (Lane *et al.*, 1994). This type of mechanisms is similar to antibiosis which results in an incompatibility between cowpea and *Striga* (Hood *et al.*, 1998). Hood *et al.* (1998) suggested that such a mechanism of resistance is durable in that the resistance involved is due to the lack of chemical signals or nutrients produced by the host, as prerequisite to further development of *Striga*. In another form of resistance, host tissues alter their own structure as a response to the infection (Olivier *et al.,* 1991). However in susceptible genotypes, such a response is very slow to be effective in stopping the penetration (Olivier *et al.*, 1991). Lane and Bailey (1992)

concluded that the resistance to *S. gesnerioides* in cowpea is likely to remain stable in that (i) mechanisms in most cases involve post-infection resistance; (ii) *S. gesnerioides* is a monocyclic parasite, and (iii) a soil parasite.

1.5 Available sources of resistance to *Striga gesnerioides*

Two to five recessive genes appear to be involved in the resistance to *S. hermonthica* in sorghum (Obilana, 1984). In cowpea, different sources of resistance, each combining the resistance to at least two races of *S. gesnerioides* of West and Central Africa, are available. Up to now, there is no resistance based on low stimulation ability of *Striga* seed germination in cowpea (Lane and Bailey, 1992). However, two genotypes were discovered to have mechanisms of resistance starting at the infection phase. In cowpea genotype 58-57, the penetration of cowpea roots by *Striga* radicles of SR 1 of Burkina Faso, resulted in cell necrosis around the parasite radicles. This implies that hypersensitive reactions may occur in response to the infection (Lane and Bailey, 1992). In cowpea genotype B301, low numbers of *Striga* radicles succeeded to penetrate the host tissues, but they died from necrosis (Lane and Bailey, 1992). Hypersensitive resistance and non-viable *Striga* tubercles occur on cowpea genotype IT81D-994 when screened using SR 4 from Zakpota in Benin (Lane *et al.*, 1994). Cowpea genotype IT93K-693-2 confers the resistance to all five *S. gesnerioides* races occurring in West Africa (Boukar *et al.* 2004). Genetic resistance to *Striga* is the most appropriate control method for poor resource farmers in Burkina Faso and some coastal countries of West Africa (Carsky *et al.*, 2003; Kuiper *et al.*, 1998; Lane and Bailey, 1992). However, varieties B301 as well as IT93K-693-2, though *Striga*-resistant, lack good grain characteristics (white seed type) and were not accepted by farmers in Burkina Faso (Lane and Bailey, 1992). The likelihood that farmers accept *Striga*-resistant lines would be higher if selection for organoleptic qualities is included in the breeding programme (Dubé and Olivier, 2001).

Sources of resistance with different mechanisms were identified ‘’*in-vitro”*. A first level of resistance concerns the ability of cowpea genotypes to stimulate *Striga* seed germination, and the penetration of the cowpea roots by *Striga* tubercles. In genotypes 58-57 and 872, *Striga* seedlings die within three to four days of penetration, accompanied by a necrosis of host tissues around the penetration site. A second level of resistance involves a reduced

development of *Striga* on its host, with much reduced *haustoria* size (less than 1 mm and limited stem development). This was observed with genotype B301.

The combination of resistance genes in locally adapted genotypes such as landraces, and well performing improved varieties, wild cowpeas and *Striga* resistant sources should render the breeding efficient. In Burkina Faso, studies of wild cowpea collections have confirmed the existence of a high variability in these cowpea populations (unpublished data). The country is located in West Africa, which is the centre of domestication of cowpea (Padulosi and Ng, 1997). Thus, wild relatives and landraces can provide a valuable source in breeding cowpea for *Striga* resistance.

1.6 Techniques in screening for *Striga* resistance in cowpea

Different screening techniques have been applied in order to identify sources of resistance to *S. gesnerioides* in cowpea (Muleba *et al.*, 1997; Lane and Bailey, 1992; Ouedraogo *et al.*, 2002a; Ouedraogo *et al.*, 2002b; Boukar *et al.*, 2004). These techniques comprised (i) field and pot screenings where field were generally less reliable than pot screenings due to uneven distribution of *Striga* races (seed), (ii) "*in-vitro*" screening techniques, which enabled the study of *Striga* resistance mechanisms (Lane *et al.*, 1991), and (iii) the molecular screening technique, using DNA markers associated with the resistance to *S. gesnerioides* in cowpea.

1.6.1 Field and pot-screening techniques for resistance to Striga gesnerioides

Field experiments are still required for evaluating yield. Pot and field screenings are useful in studying post-emergence *Striga* development such as *Striga* emergence date, numbers of *Striga* shoots per host and vigour of *Striga.* A successful field screening requires improved field-testing methodologies (Haussmann *et al.*, 2000), consisting of combining suitable field layouts, with appropriate inoculation techniques (Haussmann *et al.*, 2000). More importantly, susceptible and resistant checks should be planted at regular intervals, including adjacent *Striga*-free and *Striga* sick-plots (Haussmann *et al.,* 2000). For instance, including TVx3236, a universal susceptible cowpea genotype would increase the accuracy of a *Striga*-infested field experiment (Botanga and Timko*,* 2005). The use of pot screening techniques is an attempt to reproduce *Striga*-infested field conditions. Pot screening is designed to ensure

even infestation with *Striga* seeds, which is rarely obtained under field conditions. An effective pot-screening method for *Striga* resistance is available. Musselman and Ayensu (1984) recommended 1000 *Striga* seeds per pot (8 to 10 litre-content) to achieve an effective screening for *S. gesnerioides*. However, prior to implementing an artificial screening, pots and their sandy-content are sterilized at 150^{o}C using an autoclave.

In sorghum, a *Striga* vigour score with a scale from 1 to 9 was developed by Haussmann *et al.* (2000) which could be adjusted for studying *S. gesnerioides* infesting cowpea. In cowpea Atokple *et al.* (1995) proposed a scale with two classes (resistant or susceptible) but they considered individuals or genotypes with intermediate resistance as susceptible individuals. The vigour score is measured from *Striga* height and branching (Rubiales *et al.*, 2006). *Striga* severity is obtained by multiplying *Striga* vigour by the total number of emerged *Striga* plants (Haussmann *et al.,* 2000). Shaner and Finney (1977) and Haussmann *et al.* (2000) suggested that the number of *Striga* plants emerged over time could be used to estimate the area under *Striga* number progress curve.

1.6.2 "in-vitro" screening and data collection methods

Different mechanisms of resistance can be evaluated by using an "*in-vitro*" screening technique using petri dishes. An ''*in-vitro*'' growth media is made of a combination of macro and minor nutrients, providing optimum growing conditions for both cowpea and *S. gesnerioides,* using petri dishes. The laboratory screening techniques can be used to observe the underground *Striga* development stages that are not visible under field conditions. Lane *et al.* (1991), proposed a liquid nutrient media. The nutrient media proposed by Berner *et al.* (1997) is agar-based. A methodology developed by (Berner *et al.*, 1997) also enables measurements of these mechanisms. Lane *et al.* (1997) have focussed the record taking at the critical levels of the process as follows:

- the ability of cowpea genotypes to stimulate *Striga* seed germination, and
- the penetration of the cowpea roots by *Striga* tubercles.
- Post penetration development of *Striga*.

1.6.3 DNA screening techniques: use of marker assisted selection in breeding cowpea for Striga resistance

Marker-assisted selection techniques are promising because the assessment for *Striga* resistance in the field is difficult, expensive and sometimes unreliable (Haussmann *et al.,* 2000). In cowpea, DNA markers can be used to improve the effectiveness of conventional breeding. Races 1 and 5 of *S. gesnerioides* are present in Burkina Faso (Lane *et al.,* 1997). In cowpea, seven markers linked to two cowpea genes of resistance Rsg_1 and Rsg_3 have been identified, by combining bulk segregant analysis (BSA) and amplified fragment length polymorphism (AFLP) (Ouedraogo *et al.,* 2001, 2002a, 2002b). Table 1.1 shows the different genes and lists the derived markers that have been developed.

Ouedraogo *et al.* (2002a) also mapped markers for resistance to *S. gesnerioides*, c*owpea mottle virus* (CPMV), c*owpea severe mosaic virus* (CPSMV) and Fusarium wilt (*Fusarium oxysporum*). The DNA techniques are promising approaches in cowpea breeding as segregating cowpea populations can be screened for the presence of resistance genes. This would be time-saving and less labour demanding. Though crosses and classical selection procedures remain indispensable steps in studies involving markers, AFLP markers and other types of molecular markers, such as randomly amplified polymorphic DNA (RAPD) could be efficient techniques in identifying genes of resistance to *Striga*. This can be achieved by converting these markers into sequence characterized amplified regions (SCAR) (Boukar *et al.,* 2004). AFLP-SCAR markers are cheap, specific for a given gene, co-dominant and generate a single polymorphism (Boukar *et al.* 2004). They generate quick results and are alternatives to dissemination of new *Striga* races associated with pot and field screenings (Dita *et al.*, 2006). This will also enable more reduced population size and number of generations of selection required in conventional breeding (Ouedraogo *et al.*, 2008).

Table 1.1 DNA markers associated with *Striga gesnerioides* in cowpea.

Resistant cowpea lines	Susceptible cowpea line	Crosses	Genes of resistance involved	Markers identified	Genetic distance (cM)	Nature of markers	Method used	Authors, years
Gorom	TVx3236	Gorom x TVx3236	Rsg_3	E-AGA/M-CTA_{460} E-AGA/M-CAG_{300} E-AGA/M-$CAG_{300,}$ E-AGA/M-CAG_{450}	2.5 to 9.9 - - -	dominant	AFLP-BSA	(Ouedraogo *et al.,* 2002a)
IT81D-994	TVx3236	IT81D-994 X TVx3236	994-Rsg	E-AAG/M-AAC_{450} E-AAG/M-$AAC_{150,}$ E-AGA/M-$CAG_{300,}$ E-AGA/M-CAG_{450}	2.1 2.0 - -	dominant	AFLP-BSA	(Ouedraogo *et al.,* 2002a)
IT82D-849	TVx3236	IT82D-849 X TVx3236	$Rsg_{2\text{-}1}$	E-AAC/M-CAA_{300} E-ACT/M-CAA_{524} E-ACA/M-$CAT140/_{150}$	2.6 0.9 0.9	dominant	AFLP-BSA	(Ouedraogo *et al.,* 2001)
TVU 14676	IT84S-2246-4	TVU 14676 X IT84S-2246-4	$Rsg_{4\text{-}3}$	E-ACA/M-CAG_{120} E-AGC/M-CAT_{80} E-ACA/M-CAT_{150} E-AGC/MCAT_{150} E-AAC/M-CAA_{300} EAGC/M-CAT_{70}	10.1 4.1 2.7 3.6 3.6 5.1	dominant	AFLP-BSA	(Ouedraogo *et al.,* 2001)
IT84S-2049	524B	IT84S-2049 x 524B	-	E-AAC/M-CAA_{300} E-ACA/M-CAG_{120}	- -	-	AFLP RAPD RFLP	(Menéndez *et al.*, 1997)
IT93K-293-2		IT93K-293-2 x IAR 1696	Rsg_1	SEACTM-$CAC_{83/85}$	-	Codominant	AFLP/SCARS	Boukar *et al.* (2004)
IT82D-849	TVx3236	IT82D-849 X TVx3236	Rsg_3, Rsg_1	E-ACT/M-CAA_{524}	0.9	Codominant	AFLP/SCARS Mahse-1 (61R) and Mahse-2	(Ouedraogo unpublished)

1.7 Gene action and allelic relationships

1.7.1 Gene action

Several mating designs are available, which could provide information about the type of gene action in *Striga* resistance. Among the mating designs, the diallel cross analysis is an accurate tool providing the most complete genetic information and is used to exploit hybrid vigour or to determine the performance of parental lines in combinations (Hill *et al.,* 1998). It is a method that gives more precise information about the general and specific combining abilities (GCA and SCA) than any other mating design (Hill *et al.,* 1998). The nature of the genetic information obtained from the diallel analysis depends on (i) the statistical model, which is based on a random genotype effect, or a fixed genotype effect, (ii) the level at which the diallel analysis is conducted.

In cowpea, sources of resistance to *S. gesnerioides* were found with genotypes B301, IT82D-849 and SUVITA2 (Gorrom local) (Aggarwal *et al.* 1984; Emechebe *et al.* 1991; Aggarwal, 1991). For these authors, the resistance to *S. gesnerioides* in cowpea is governed by a single dominant gene. Muleba *et al.* (1996) reported that quantitative gene effects may be involved in the resistance to *S.* gesnerioides due to the varying level of resistance of B301, IT82D-849 according to the area.

1.7.2 Allelic relationships between sources of resistance

Different non-allelic genes can confer resistance behaving as isoepistatic. Fasoula and Fasoula (1997) defined the isoepistatic genes as two or more non-allelic genes that are functionally equivalent in the control of a particular trait. Isoepistatic genes compensate for each other completely so that phenotypic expressions remain the same with varying numbers of genes. If two isoepistatic genes are involved in a cross between a parent of known single resistance gene (example of *Rsg1* in B301), and a tested parent (with unknown resistance gene), hence the two genes are isoepistatic if the F_2s give a ratio of 15 resistant: 1 susceptible (Fasoula and Fasoula, 1997). If three or four isoepistatic genes are involved, these ratios will be 63: 1 and 255: 1 respectively (Fasoula and Fasoula, 1997). Different dominant genes are involved in the resistance to *S. gesnerioides* of the resistant genotypes B301, IT82D-849, and Gorom local (or SuVita2). These genes were named

Rsg1, Rsg2, and Rsg3 respectively (Atokple *et al.*, 1995). The same authors reported that the genes governing the resistance in these cowpea genotypes are either very closely linked or two alleles of the same gene at the same loci. The resistance to SR 1 of cowpea genotype Gorom (SuVita2) was reported to be conferred by a unique and dominant gene (Atokple *et al.*, 1995). Dubé and Olivier (2001) suggested that the genetic inheritance and allelic relationship between the available genes conferring the resistance to *S. gesnerioides* be taken into account to achieve effective breeding of *Striga*-resistant cowpea varieties.

1.8 Correlation studies

Berner *et al.* (1998) found the ‘’*in-vitro”* selection of sorghum varieties for resistance to *Striga* to be highly correlated with field selection of sorghum genotypes. Correlation is measured by the correlation coefficient, which is useful in establishing the degree of association between one or more characters (Hallauer and Miranda Fo, 1981). The causes of correlations may be genetic (Hallauer and Miranda Fo, 1981). The genetic correlations are due to genetic factors such as pleitropy and/or genetic linkage. In pleitropy, one gene influences several physiological traits (Hallauer and Miranda Fo, 1981). Traits with a high recombination rate are highly linked, and therefore exhibit a high correlation degree. If the correlation is significant among two traits, this implies that a selection of one trait will affect the other (Hallauer and Miranda Fo, 1981).

1.9 Breeding procedures in cowpea

The following strategies were proposed for developing *Striga*-resistant cultivars in sorghum (Haussmann *et al.*, 2000), which could be applied to cowpea: (i) the characterization of germplasm for *Striga* resistance, (ii) the improvement of available sources of resistance for better agronomic characteristics, (iii) the transfer of resistance genes into adapted, farmer selected cultivars, and (iv) the pyramiding of resistance genes into these adapted cultivars. The development of molecular markers could also ease marker-assisted selection (Boukar *et al.*, 2004; Haussmann *et al.*, 2000; Ouédraogo *et al.*, 2002b; Ouédraogo *et al.*, 2001; Ouédraogo *et al.*, 2002a). In addition, multilocation experiments could test the identification of stable resistance across different environments (Muleba *et al.,* 1996; Haussmann *et al.,* 2000).

The breeding procedure in cowpea involves conventional and innovative breeding techniques. Intervarietal breeding involved diverse methods: pedigree, bulk, single seed descent, and double haploid method. Backcross and pedigree methods apply to genetically segregating generations, with the aim to develop pure lines (Singh, 1993). The pedigree method emphasizes on the record keeping. Whatever the generation of concern, each offspring can be traced back to the F_2 generation from which it originates (Singh, 1993).

The classical pedigree breeding method has been effective in breeding for characteristics that are governed by a single or a few genes, such as *Striga* specific resistance genes in cowpea (Aggarwal and Ouédraogo, 1989; Muleba *et al.*, 1997). In the bulk selection method, population improvement methods can be exploited by using recurrent selection to incorporate multiple traits, resistance to insects and resistance to diseases, if only low to moderate levels of resistance are available (Ehlers and Hall, 1997). This method is appropriate for achieving long-term objectives (Ehlers and Hall, 1997). Ehlers and Hall (1997) proposed an efficient recurrent selection for combining multiple desirable traits in cowpea consisting of:

- developing sets of early F_3 or F_4 generations inbred lines from different biparental crosses,
- screening them to identify individuals or lines with desirable new combinations of traits, crossing selected individuals from different biparental crosses, and
- selecting progeny individuals with desirable traits common to all four parents.

The characteristics of grain types that suit local preferences have different genetic background. In cowpea, at least six genes control the inheritance of seed size and complementary genes (incomplete dominance) govern the seed coat traits (Drabo, 1981). Additive gene effects are involved in grain and fodder yield characters, though non-additive effects are more important for fodder character (Jatasra, 1979; 1980). Therefore, a recurrent selection scheme can accommodate population breeding methods.

In interspecific hybridizations, backcross methods are currently used for transferring simply inherited characters in cowpea. For instance, cultivated cowpea is very susceptible to pod sucking bugs (*Clavigralla tomentosicolis*) and borers (*Maruca vitrata*). Some wild species possess the pubescence which is a physical pod barrier to those pests and the Backcross technique was applied to incorporate this trait into cultivated cowpea (Fatokun, 2002).

At another level, attempts made to obtain interspecific hybrids between cowpea and *V. vexillata* have often been unsuccessful because of incompatibility. Fatokun (2002) used several techniques to overcome interspecific incompatibility by adopting embryo rescue techniques, reciprocal crosses among different genotypes of both species, and by treating pistils with hormones prior to pollination and polyploidizing of parental lines. These efforts did not produce any interspecific hybrid between cowpea (*V. unguiculata*) and *V. vexillata*.

In conclusion, cowpea is one of the most important pulses in semi-arid areas, which contributes both as food and fodder. This review shows that:

- two among five *Striga* races reported by Singh (2002) to occur in West and Central Africa are present in Burkina Faso in different areas;
- *Striga gesnerioides* is a soil parasite which feeds on cowpea, by developing a connection through which it sucks nutrients and water. *Striga* can cause complete yield loss if susceptible cowpea genotypes are involved;
- *Striga*-resistant cultivars are available, but they do not have good agronomic characteristics and are therefore rejected by farmers. Though more recent works have supported the single gene inheritance pattern of *Striga* resistance in cowpea, some authors such as Muleba *et al.* (1994) supported the views that quantitative genes were also involved;
- different *Striga* resistance mechanisms were found in cowpea genotype 58-57 and B301. However, the genetic inheritance of such mechanisms has not yet been investigated;
- cowpea is a self-pollinating crop. The floral structure of cowpea favours self-pollination and pure line production. Consequently, the breeding procedures are those of self-pollinating crops consisting mainly of pure line breeding, pedigree breeding, bulk population breeding and backcross breeding.

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CHAPTER TWO

Study of *Striga* and farmer preferred cowpea traits, using participatory research methods in *Striga*-stress-prone areas of Burkina Faso

Abstract

Cowpea is well adapted to semi-arid areas and is an affordable source of protein. It is also source of income for resource poor people of the Sahelian zones. However, in *Striga* hot-spots, this parasitic weed can cause complete yield loss of cowpea. The objective of this research was to identify breeding priorities using a participatory approach, and to determine the farmers' preferred traits for cowpea genotypes. The participatory rural appraisal (PRA) team comprised of farmers, traders, food processors, extension agents and a multidisciplinary team of researchers. A stratified sampling of individuals was used in selecting the PRA farmers. Farmers ranked *Striga* damage on cowpea among the major constraints. There was no effective control method against *Striga* at farmers' level. Trained farmers were aware that the *Striga* problem arose from combined effects of both soil degradation and reduced rain over time. In areas covered by improved and released cowpea genotypes such as Donsin and Bik Baskoure (provinces of Oubritenga and Kouritenga), cowpea was ranked as the most important legume staple crop. Farmers' desirable traits for cowpea genotypes were oriented towards grain quality, such as large-sized and white-coloured grain except in Northern Burkina Faso, where brown-coloured grain was preferred. None of the available cowpea genotypes combined farmer and other users' preferred traits with *Striga* resistance.

2.1 Introduction

The current extension system in Burkina Faso is based on the classical training and visit approach. The extension agents are the link between farmers and researchers for releasing improved crop varieties. The interactions between farmers and researchers are facilitated by the “on-farm tests of new technologies” in which researchers obtain feed-back on their technologies from farmers. In this system, the research results have proved ineffective in addressing farmers’ needs in terms of appropriate varieties. This coupled with the practice of traditional production systems might be one of the reasons why, with 80 to 90% of the population involved in agriculture, Burkina Faso is still not achieving food security. It is wasteful in time and efforts when farmers reject a variety at the end of the selection process, because their own criteria have not been taken into account. Participatory approaches have proved more economic and time saving (Christinck *et al.*, 2005).

In 1996, the breeding team of cowpea (*Vigna unguiculata* (L.) Walp.) sponsored by the Africa Cowpea Project of the International Institute for Tropical Agriculture (PRONAF/IITA) implemented a participatory rural appraisal (PRA) study to identify cowpea production constraints, with a focus on the village of Thiougou, Donsin and Bik-Baskoure respectively in Southern, Central and Eastern Burkina Faso (PRONAF, 2003). The study, whose objectives were to evaluate the social and economic impacts of cowpea technologies, showed that the income generated by cowpea at Donsin had increased from 0.0% (1990) to 14.1% (2001). At Bik Baskoure, it had increased from 15.7% to 49.9% in the same period.

Burkina Faso is a net exporter of cowpea (Langyintuo *et al.*, 2003), which generates incomes to cowpea producers. Where such export opportunities are not available, farmers reduce their production since the extra production cannot be sold with an added value solely based on the local demand. Langyintuo *et al.* (2003) showed that the preference of farmers for grain type was site-specific. However, in West and Central Africa, the common choice of consumers is always for the white color of the testa (Langyintuo *et al.*, 2003). The same authors pointed out that in most cases, price fluctuations are a function of cowpea grain quality and the seasonal supply and demand levels. In Ghana and Cameroon for instance, consumers “pay a premium” if their preferences are met, regardless of their economic status (Langyintuo *et al.*, 2004). Consequently, Langyintuo *et al.* (2003) advised

that cowpea breeders develop varieties taking into account the regional differences in terms of farmers' preferences.

In terms of *Striga* management, different approaches are being tested in Burkina Faso. Recently, a participatory method has been implemented with success through farmer field fora (FFF) as an alternative to the weaknesses of the training and visit approaches (Labrada, 2008). In Mali, where climatic conditions are similar to those of Burkina Faso, a participatory breeding research was successfully used for developing adapted sorghum varieties (Christinck *et al.,* 2005). This highlights the usefulness of conducting a PRA, before implementing any breeding programme.

The objective of this research was to study the cowpea production system, the importance of cowpea and its production constraints, farmers' perception of *Striga gesnerioides* (Willd) Vatke and farmers' preferred traits.

2.2 Materials and methods

2.2.1 Study sites

General information on the PRA research sites are presented in Table 1. The PRAs were conducted in the villages of Donsin, Bik Baskoure and Songo 2 in December 2007, May 2008 and June 2008 respectively. Farmers came from different villages around the PRA site. Figure 2.1 shows the PRA sites within the different agricultural regions (Bacye *et al.*, 2000).

Table 2.1 General information on the research sites.

	Villages		
	Donsin	Bik-Baskoure	Songo 2
Farmer organization name	Song-Koadba	Nabonswende	-
Region	Central	Eastern centre	Southern centre
Province	Oubritenga	Kouritenga	Nahouri
District	Ziniare	Koupela	Po
Ecological zone	North Sudan	North Sudan	South Sudan
Longitude	001°25.007' W	000° 19.156' W	001°03.351' W
Annual average rainfalls (mm)	500-700	600-800	700-1000
Latitude	12°35.443' N	12°13.219 N	11°06.742' N
Altitude above sea level (m)	395	309	303

2.2.2 Participatory rural appraisal

The basic unit for analyzing diversity was the focus groups. Preliminary data collection was initiated based on the current PRA sub-tools such as direct observations, semi-structured interviews, individual discussions and triangulations. Semi-structured interviews were informal in that only the topic was known. The questions were built according to the answers from previous questions.

The methodology used for collecting the data was a stratified sampling method, in which two regions in the cowpea adaptation zones were targeted (Central, Eastern). Two districts, Ziniare and Po were chosen in the central region due to the occurrence of two different *Striga* races in these districts (*Striga* races 1 and 5). The third district (Koupela) was selected in the Eastern region because of the presence of a newly occurring SR called ‘’SR Kp’’. The PRA sites, Donsin, Songo 2 and Bik-Baskoure were identified respectively in the districts of Ziniare, Po and Koupela (Figure 2.1).

A random sample of at most ten villages per district was used. In each village, a number varying between two to four individuals (depending on the availability) was chosen in a random way from the list of cowpea growers. Thirty five to forty farmers were sampled with equity for gender whenever possible; some cowpea food processors and cowpea traders were included for their views on cowpea processing and market requirements. Two

extension specialists from the targeted zones were included to make use of their local knowledge. The team of facilitators comprised one or two cowpea breeders, a pathologist, an entomologist and a social scientist. In each of the three regions, the team worked at the PRA sites for three days. Figure 2.2 shows the PRA team at Donsin (2007) at the end of the PRA.

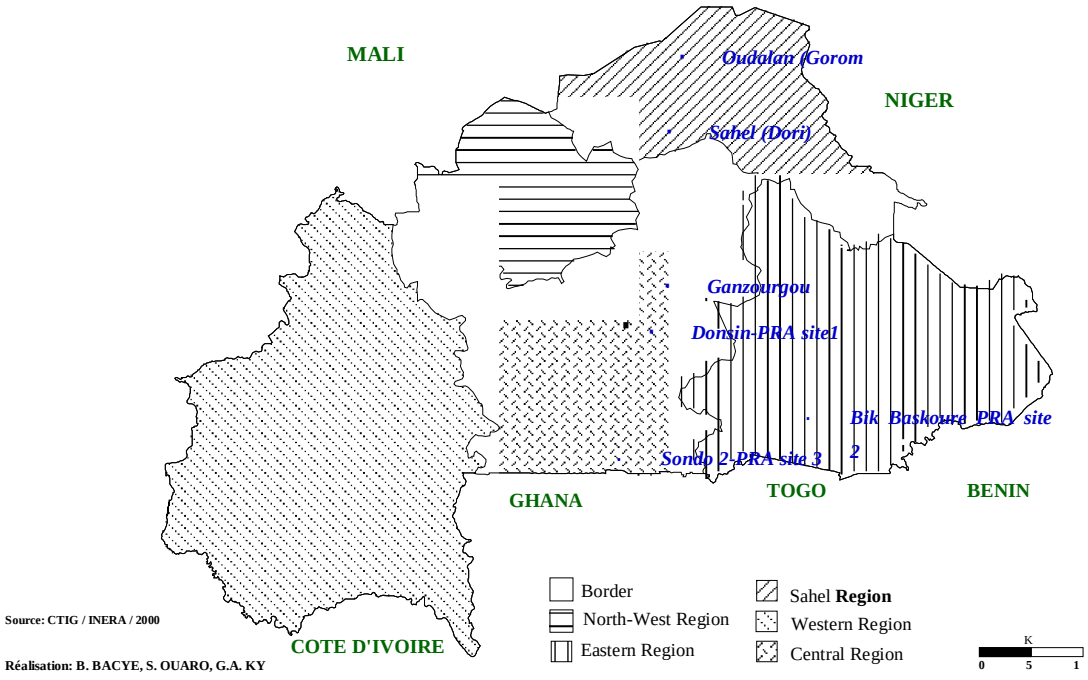

Figure 2.1 Burkina Faso agricultural regions, showing the study sites (Bacye *et al.*, 2000).

Figure 2.2 The participatory rural appraisal team at the closing session, at Donsin 2007.

2.2.3 Participatory variety selection

The participatory variety selection (PVS) sessions were held with 41, 44 and 56 farmers respectively in the village of Donsin, Bik Baskoure and Songo 2. Samples of varieties at maturing stage in pots and 5 kg of grains per variety were presented to farmers for the pupose of selection. Matured fruits of *Diospyros mespiliformis* or stones were used to help farmers with quantifying varieties and traits they preferred. The ranking of cowpea genotypes for desirable selection criteria were done by giving hundred fruit of *Diospiros mespiliformis* or stones to one farmer. The preferred variety or trait was given the highest number of fruit, while the rejected variety or trait was given zero or few number of fruit. The rank (percentage) was obtained by counting the number of fruit with regard to the variety or trait. High number of allocated fruit meant that farmers approved the option. Data were recorded individually for the preference for different traits (size, colour and the texture of cowpea grain) and the reasons they were preferred. Percentages of favorable cases for all traits were calculated for each site.

2.2.4 Survey of grain traits

In addition to the PRA sessions, a survey was organized with cowpea farmers in Oudalan (extreme North Burkina Faso), Sahel (North Burkina Faso) and Ganzourgou (East Burkina Faso) provinces. The number of farmers that attended these sessions was 30, 28 and 62 respectively for Oudalan, Sahel and Ganzourgou provinces. Farmers were asked to select the varieties and grain characteristics they preferred and give reasons for those preferences.

2.3 Results

2.3.1 The participatory rural appraisal

2.3.1.1 Importance of cowpea in the cropping system

The results of the PRA showed that cowpea, groundnut and soyabean (Bik Baskoure and Songo 2) and Bambara groundnut (Donsin and Songo 2) were grown as food-legumes. At all three sites, farmers grew sorghum and millet. Maize was grown at Bik Baskoure and Songo 2 and rice was grown at the low lands of Donsin and Songo 2. All these crops covered areas of 63.422 ha, 71.820 ha and 17.293 ha in the districts hosting Donsin, Bik Baskoure and Songo 2 respectively (Agristat Burkina Faso, 2009). The crops were mostly grown during the uni-modal rainy season (June to October), while most vegetables were grown in the off-season (October to May) under irrigation.

Cowpea-cereals intercrops were common practices and involved inclusion of photoperiod sensitive landraces which provided farmers with leaves for sauces during season-end subsistence periods. Farmers agreed that, they grew cowpea either as single crop or mixed with cereals. Areas allocated for cowpea grown in pure stand were higher than those assigned to mixed cowpea crops. Farmers considered that cowpea-cereal intercrops were less subjected to cowpea pest damage than cowpea grown in pure stand. There was a specific geographical distribution of fields. Most cowpeas were grown in family fields, which were usually bigger and distant from the village. Rotations between cereals (sorghum and millet) and legumes (cowpea and groundnut) were frequently practiced with varying sequences.

At all sites, there were few or no inputs applied in cowpea production which farmers attributed either to non-availability of inputs or high costs. Agro-chemicals such as insecticides were provided by agro-dealers at all sites. However, the quality of chemicals, the storage conditions, the accessories for use were generally not appropriate resulting in hazards. At Songo 2, pesticides with high toxicity and used for cotton, were applied on cowpea resulting in hazards on humans. Farmers of Donsin and Bik Baskoure grew certified cowpea seeds to meet the increasing local demand. They had been trained by the National Agricultural and Environmental Research Institute in cowpea production and storage techniques. However, farmers of Songo 2 had no access to training and improved cowpea seeds.

Figures 2.3 and 2.4 show Donsin farmers ranking their products. At Donsin, during the humid season (June to October), brown and white-seeded sorghum were the most important crops (30.5%), followed by cowpea (16%), bambara groundnut (14%), sesame (12%), maize (5.5%) and cowpea (14%), livestock (5%) and Okra (3%) (Figure 2.5). At Bik Baskoure, cowpea was ranked the second most important crop (10%) with maize, after sorghum (figure 2.6). At Songo 2, cowpea was ranked fifth after rice, groundnut, soyabean and *Hibiscus sabdarifa* (Figure 2.7). Other products included vegetables (tomato, cabbage, red pepper). Cowpea appeared to be an important staple in the three investigated zones. The priority ranking of products by farmers showed that cowpea was the most important staple legume crop except at Songo 2.

Figure 2.3 Samples of crops grown at Donsin before priority ranking by farmers, 2007.

Figure 2.4 Product priority ranking by farmers at Donsin, 2007 (left to right: cowpea, red pepper and cabbage).

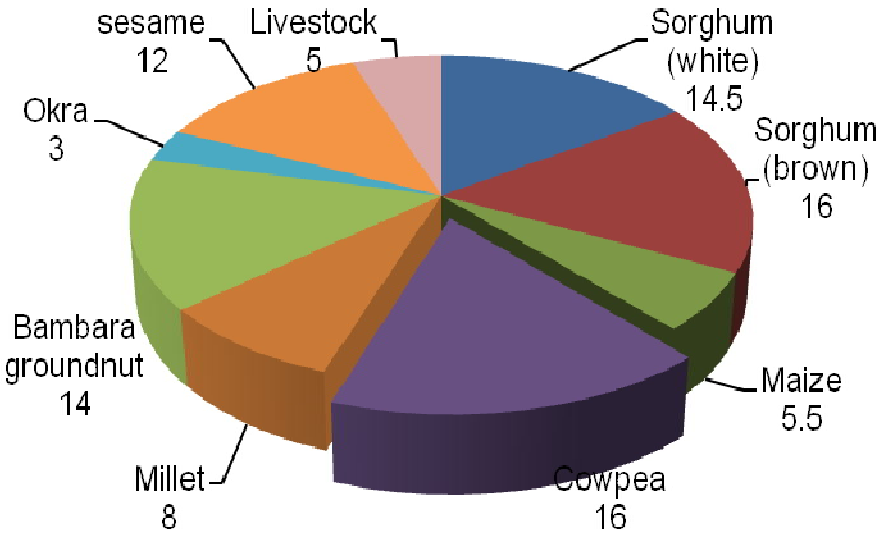

Figure 2.5 Pie graph of different enterprises ranked by farmers (% agreement) at Donsin (Ziniare), 2007.

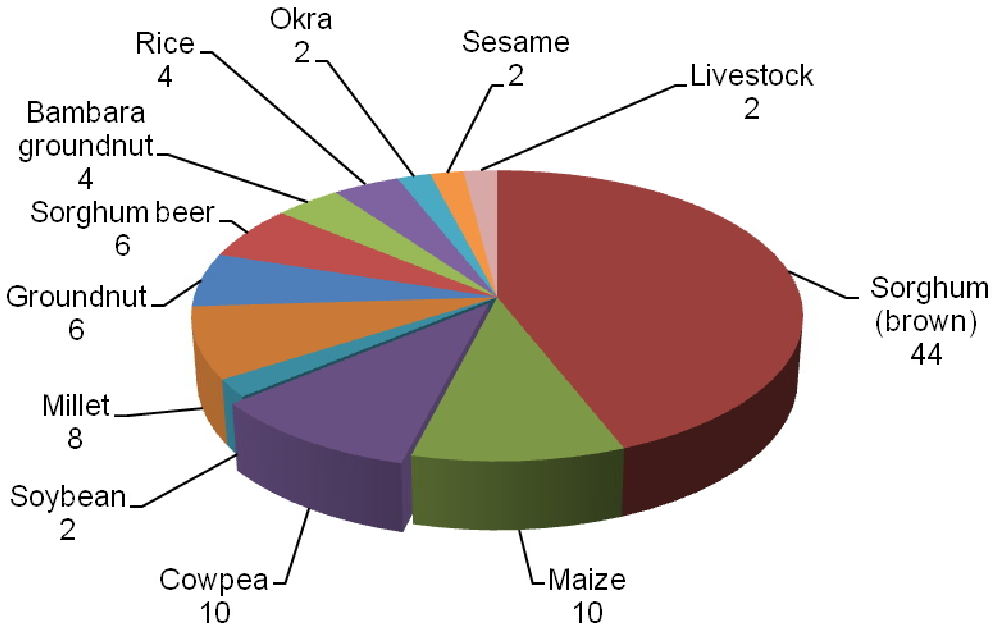

Figure 2.6 Pie graph of different enterprises ranked by farmers (% agreement) at Bik Baskoure (Koupela), 2008.

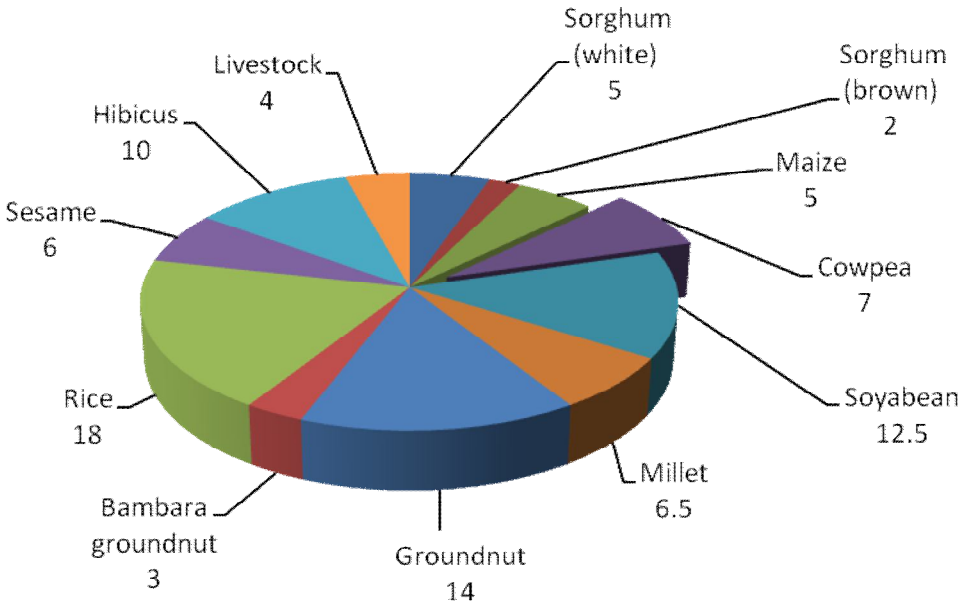

Figure 2.7 Pie graph of different enterprises ranked by farmers (% agreement) at Songo 2 (Po), 2008.

2.3.1.2 Constraints to cowpea production

Farmers identified general and specific cowpea constraints to cowpea production at the three different sites and ranked them as shown in Table 2. At Donsin, soil degradation, and reduced rainfall over time were regarded as the most limiting factors and ranked before the *Striga* problem. At Bik Baskoure, soil degradation due to humans and animals, weather patterns and cowpea flower abortions caused by insects (thrips) were serious constraints ranked before *Striga* damage. Female farmers were the main cowpea producers, but they had poor access to land. Figure 2.8 shows female farmers of Songo 2 discussing the land issue. At Songo 2, the lack of cowpea market opportunities and the limited access to inputs and equipment were ranked before the damage caused by *Striga*. Farmers reported that landraces were less adapted in terms of resistance to drought stress and matured too late. Farmers did not mention diseases as a serious constraint.

Table 2.2 Cowpea production constraints ranked by farmers at Donsin (2007), Songo 2 (2008), and Bik Baskoure (2008).

Constraint rank order	Donsin	Bik Baskoure	Songo 2
1	Soil degradation	Soil degradation	No market for extra production
2	Climate change and shortening rainy seasons	Cowpea flower abortions	No access to inputs (pesticides, fertilizers, sprayers and chemicals)
3	*Striga* damage	*Striga* damage	No access to equipment
4	Insect damage on cowpea in field and during storage	Pod sucking bug attacks	*Striga* damage
5	Poor access to land	Poor access to land	Poor access to good land
6	Unadapted landraces	Unadapted landraces	Insect damage
7	Infrequent rains	Infrequent rains	Failure in storing cowpea
8	-	-	Most soils are gravel-like “Zeguedeghin” and not suitable for cowpea cultivation

Figure 2.8 Female farmers discussing the issue of access to land for their specific crops (cowpea and other legumes) at Songo 2, 2008.

2.3.1.3 Importance of *Striga gesnerioides* in the cropping system and control methods

Farmers rated *Striga* in cowpea amongst the top three constraints in cowpea production at all three sites. The various agronomic practices and the traditional control methods proposed by farmers were not effective to control *Striga* in cowpea. As a result, farmers who had already been exposed to the improved and resistant variety KVx61-1, proposed this variety as an alternative control measures to *Striga*. In contrast, farmers of Lesogtenga, a village located at about 50 km further from Bik Baskoure indicated that the same variety could not control *Striga* in their fields. From the discussion, it was evident that two different *Striga* races cohabit the same district (Koupela).

Striga damage on cowpea was higher in family fields distant from the village due to the lack of fertilizer applications. Farmers involved in farmer field fora were conscious that *Striga* in cowpea was as noxious as *S. hermonthica* of millet; nonetheless, most untrained farmers considered *Striga* as part of cowpea rooting system. Therefore, for them agronomic practices to control *Striga* such as pulling out *Striga* shoots would destroy cowpea or cause damage to cowpea roots.

For farmers, at all three PRA sites, stony soils locally called “Zeguedeguin” were associated with high infestation by *S. gesnerioides* (PNGTII, 2002). These soils were dominant at Donsin. The lack of *Striga*-resistant landraces coupled with degraded soils and low use of inputs by farmers provided conditions for the development of *S. gesnerioides.*

2.3.2 Farmer participatory variety selection

Farmer participatory variety selection is an approach designed to ensure that farmer preferences are included from the early stages of a breeding programme. Varieties planted in pots and their grains were presented to farmers for the purpose of selection.

At Donsin, farmers listed cowpea varieties they had been growing and the major criteria for adopting the cowpea varieties (Figure 2.9). The released variety KVx61-1 was rated the

best in terms of productivity (35.5%), resistance to *S. gesnerioides* (48%) and processing qualities (36.5%). Varieties KVx414-22-2 and the landrace Moussa had the highest scores (29% and 27.5% respectively) as income generating varieties. Genotype Moussa was well ranked for the long term storage ability (31%). Variety KVx396-4-5-2D was ranked high (> 25%) for the productivity only. Varieties KVx61-1 and Moussa had high ranks (>20%) across all characteristics. Figure 2.10 shows ranking for farmers' preferred traits for cowpea varieties at Donsin in 2007.

At Bik Baskoure, variety KVx61-1 was highly ranked for resistance to *Striga* (60%), diseases (26%), drought resistance (32%), short cooking time (40%) and long term storage ability (40%) (Figure 2.11). Variety KVx396-4-5-2D had the highest scores for productivity (28%) and disease resistance (26%). Variety KVx745-11P had the highest score for fodder production (50%). Landraces Moussa, and two other landraces, (early and late maturing) had the highest scores for generating income (30%), for the resistance to insects (30%) and the utilization of leaves as food (26%).

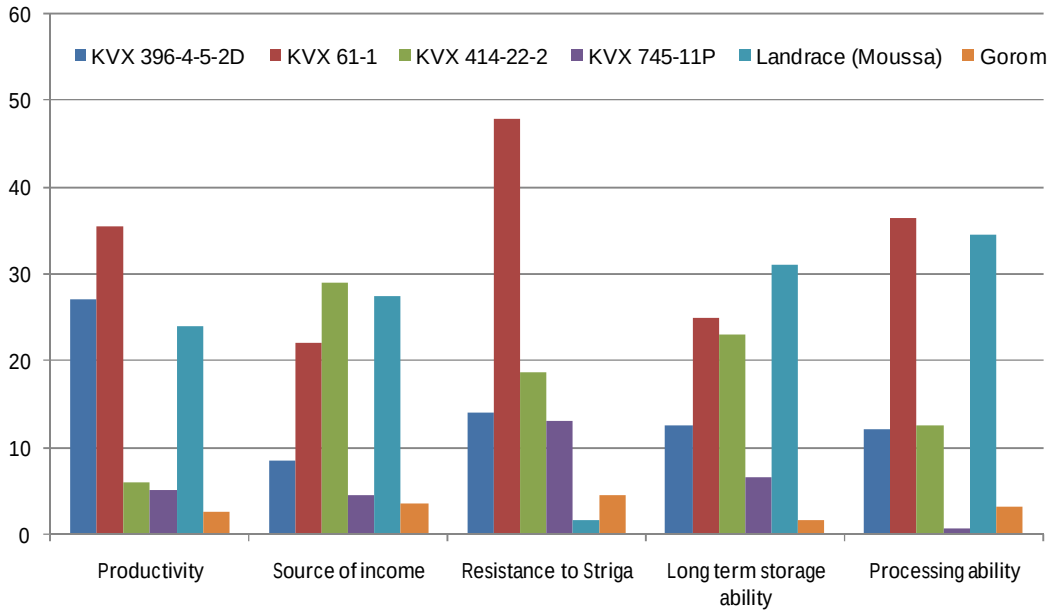

Figure 2.9 Cowpea variety acceptability (%) based on farmers' preferred characteristics for genotypes at Donsin (Ziniare), 2007.

Figure 2.10 Variety evaluations by farmers at Donsin, 2007.

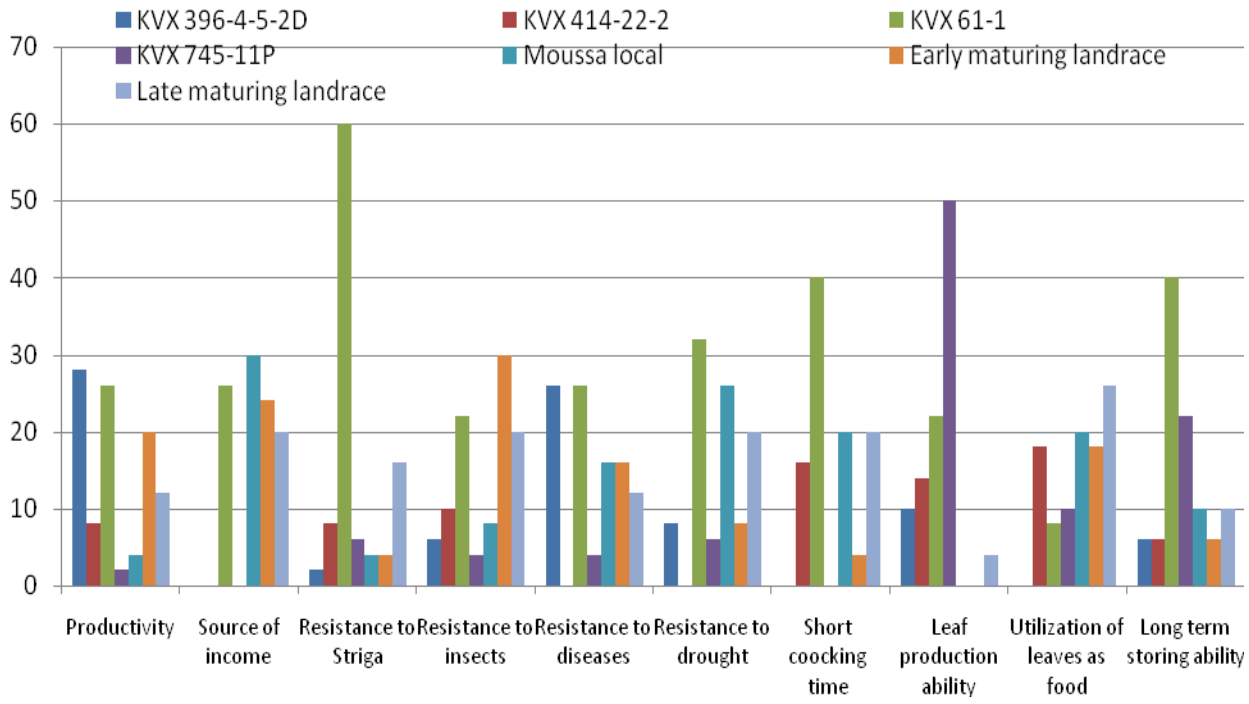

Figure 2.11 Cowpea variety acceptability (%) based on farmers' preferred characteristics for genotypes at Bik Baskoure (Koupela), 2008.

Figure 2.12 Farmer ranking cowpea genotypes for different characteristics at Songo 2, 2008.

Figure 2.13 shows farmers at Songo 2, ranking cowpea genotypes for different characteristics. At this site, farmers ranked variety KVx414-22-2 as a top performer for the characteristics of productivity (47%), resistance to *Striga* (68%) and fodder production (71.5%) (Figure 2.13). Variety KVx396-4-5-2D was highly ranked for the income generating (60.5%).

At Donsin and Bik Baskoure, the PVS showed that KVx61-1 was a variety with high productivity, resistance to *S. gesnerioides* and good processing characteristics, which confirms that farmers make choices for varieties based on multiple characteristics. When compared to landraces, variety KVx61-1 was attractive to farmers for the resistance to *Striga*, resistance to diseases and drought, short cooking time and long term storage ability. Variety KVx396-4-5-2D performed well for productivity and disease resistance. Variety KVx745-11P was the best as a dual purpose variety (fodder and grain) and useful for livestock.

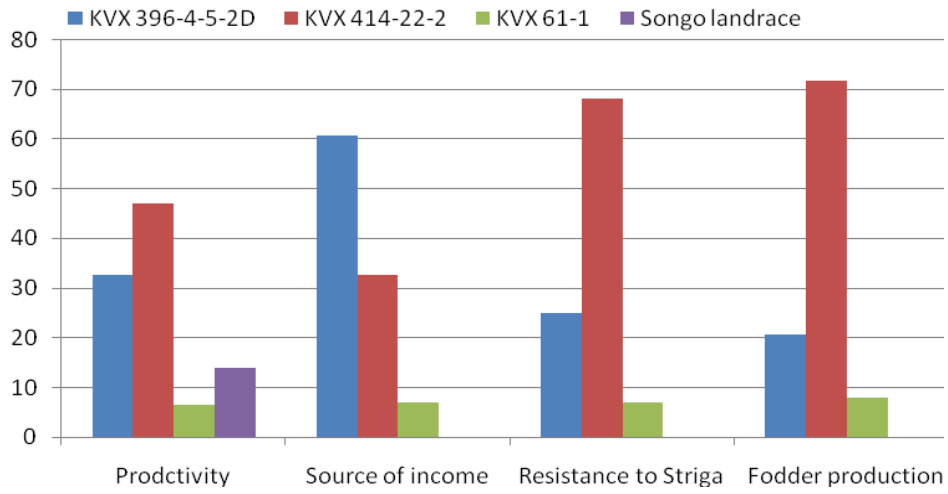

Figure 2.13 Cowpea variety acceptability (%) based on farmers' preferred characteristics for varieties at Songo 2 (Po), 2008.

2.3.3 Study of preferred grain quality traits

Farmers' preferences for grain characteristics were tested in a separate study. In this research, farmers listed grain size and grain color as the traits that they looked for in terms of quality. Table 2.3 shows farmers' choices for grain size in three provinces (Ganzourgou, Sahel and Oudalan) within cowpea production areas of Burkina Faso. In all three areas, farmers preferred large grain-sized for their own consumption as well as for the market. Farmers also agreed that big sized-grain had good market value.

Table 2.3 Grain size preferences (%) of farmers in Ganzourgou, Sahel and Oudalan provinces, 2008.

	Provinces				
	Ganzourgou	Sahel		Oudalan	
	Consumption	Consumption	Market	Consumption	Market
Big size[1]	70	100	100	100	100
Medium size[2]	30	0.0	0.0	0.0	0.0
Small size[3]	0.0	-	-	-	-

([1]): hundred grain weight less than 11 g; ([2]): hundred grain weight between 11 to 17 g; ([3]): hundred grain weight higher than 17 g.

In the province of Ganzourgou, white grain was preferred (87%) to brown (3%) and other grain color (10%) (Table 2.4). In the provinces of Sahel and Oudalan, brown grain-type of cowpea grain was preferred by consumers (100%), whilst white grain-type was preferred for the market (85.7 to 100%). In Ganzourgou province, the preference of farmers for cowpea grain colors varied depending on the location, the end-users, the consumption and the market.

Figure 2.14 shows cowpea genotypes, with different seed colours grown by farmers in different areas of Burkina Faso. In term of seed coat texture, farmers preferred rough grain texture (67%) to smooth texture (33%).

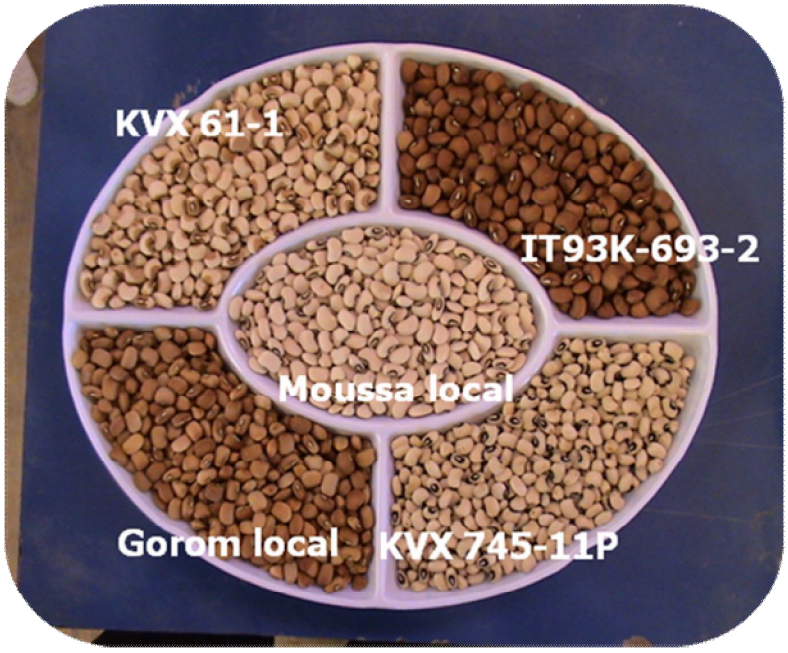

Figure 2.14 Seed characteristics of farmer preferred varieties, Kamboinse 2008.

In the provinces of Ganzourgou, Sahel and Oudalan, farmers preferred large grain size characteristics rather than intermediate to small grain sizes, because they were attractive for the market. In the province of Sahel, Oudalan (desert area) in North Sudan savanna zone, all cowpea lines and landraces had a rough texture of grain.

Table 2.4 Farmers' preference (%) for seed color of 30, 28 and 62 individuals, respectively in Ganzourgou, Sahel and Oudalan provinces.

Seed colour	Provinces				
	Ganzourgou	Sahel		Oudalan	
	Own consumption and market	Own consumption	Market	Own consumption	Market
White	87	0	100	0	86
Brown	3	100	0	100	14
Brown and white	10	-	-	-	-

2.4 Discussion and conclusion

In this study, PRA and PVS methods, as well as standard surveys were used to engage farmers regarding their opinion on their farming systems, cowpea constraints, cowpea variety and cowpea grain preferences.

Cowpea was a key component of the cropping system in the study sites. The farming system in the areas was characterized by low use of inputs. Fertilizers, agro-chemicals and irrigation were seldom used, especially for cowpeas. Though some farmers had access to improved varieties, they were still growing late-maturing and photosensitive landraces under mixed-cropping. Farmers were still practicing mixed-cropping because they perceived that it reduced high insect pressure on cowpea than when cowpea was grown in pure stands. None of the farmer-proposed control methods was effective in controlling *Striga*. These observations, therefore, point to the need to improve the farming systems which would include trap cropping, rotation and intercropping.

Several cowpea production constraints were highlighted by the farmers. There was poor access to inputs (fertilizers, pesticides) which was not favorable for improved varieties. There was a general perception that rainfall had been declining over time and soils had been degraded over the past few years. Some of the constraints were linked to the poor extension system (no access to training), the lack of infrastructure (equipment, access to a range of improved seed varieties) and other constraints were biotic, such as insects, diseases and *Striga*. Abiotic constraints, such as drought were also mentioned. Diseases were not cited by the farmers as a constraint, though they were observed in the study sites.

This was mainly due to the fact that the farmers did not see or know their causes. Most farmers' perceptions were that *Striga* was one of the most serious constraints in cowpea production constraints in all three regions. The development of *Striga*-resistant varieties should, therefore, be part of the integrated control programme to develop varieties adapted to low input conditions.

According to the farmers, *Striga gesnerioides* had no or minor uses, suggesting that, developing *Striga*-resistant lines that reduced or eradicated *S. gesnerioides,* would not have any negative impact on farmer community (for example, need of plant bio-diversity as traditional medicines). Farmers also associated sandy to loam soils with severe *Striga* damage on cowpea. This observation agreed with those of Cardwell and Lane (1995). Such a problem could be resolved if fertilizers and resistant varieties were involved in the system to compensate the mineral uptakes by crops. Farmers from two PRA sites (Bik Baskoure and Songo 2) reported that *S. gesnerioides* was observed on variety KVx61-1 in farmers' fields or seed production fields. This statement was confirmed later by the results of preliminary on-farm tests in same sites (unpublished data). Variety KVx61-1 reacted differently to *Striga* in the three areas, which could indicate the presence of several races of the parasitic weed.

Productivity is a weighting factor for farmers, though yield is not the sole criterion upon which farmers always choose a variety (Madamba *et al.*, 2003). For instance, the choice of KVx61-1 by farmers at Donsin and Bik Baskoure showed their preference for more than one characteristic in the same variety (source of income, drought and *Striga* resistance). The choice of varieties KVx414-22-2 and the landrace Moussa local as income generating varieties was due to the quality of their grain: large-sized grain or extreme whiteness of the testa colour. This variation in the variety choices by farmers appeared to be influenced by the market demand. This observation was in accordance with the conclusion made by Zannou *et al. (*2004) on the management of cowpea diversity by farmers in the Guinea-Sudan transition zone of Benin. In general, landraces were the most income-generating genotypes because of their good agronomic and culinary characteristics (grain quality and taste). Most landraces had farmers' preferred traits but lacked the genes for resistance to *Striga*, diseases and productivity. There was a need to identify cultivars including farmers' preferences in order to meet the demand (Yadaw *et al.*, 2006).

Recent surveys (PRONAF, 2003) have shown that cowpea has increasingly become a source of income for farmers in Burkina Faso. For example, the income generated by cowpea at Bik Baskoure had increased from 15.66% (1990) to 49.88% (2001). In addition to providing food, Ouedraogo *et al.* (1996) reported that cowpea generated as much income (for people of Sahel and North Savanna zones) as cotton for people in more humid areas. Farmers considered that the importance of cowpea was due to its roles as staple, its adaptations (climate and local utilizations) and role as a source of income. According to Zannou *et al.* (2004), the market demand can control farmers' preferences for grain characteristics. For example, in Sahel and Oudalan provinces, though farmers preferred the brown-colored cowpea grain from their grown landraces, they also grew white-coloured grain of cowpea mostly for the market. These grain characteristics were considered by Kitch *et al.* (1998) as farmer acceptability criteria in breeding cowpea varieties. Consequently, the breeding objectives in Burkina Faso could consist of selecting varieties with (i) large-sized and white-coloured grain with local adaptation for both the local food consumption and market demand for all sites and, (ii) brown coloured grain for consumption purpose in the Sahel and Oudalan provinces. There is a potential to increase cowpea production if farmers have access to more agricultural inputs, including improved, *Striga*-resistant varieties, with the preferred grain characteristics. The achievement of such potential would also require that the abiotic constraints (soil degradation, rain decline over time), the production systems (rotations, cowpea intercrops) and market network be addressed.

At the PRA closing, farmers had the feeling that they had been involved and were content when selecting varieties by themselves. They were hopeful that some urgent queries would be considered for the sake of their welfare: training, access to inputs (seeds, fertilizers, pesticides) and a better organized cowpea market network. They made a request to be involved in future research actions that would enable them to have access to the improved variety seeds and a need to be trained as cowpea producers.

In conclusion:

- the development of *Striga*-resistant cultivars for Burkina Faso will need a simultaneous selection for genotypes with resistance to the major abiotic and biotic constraints as well for farmers and market preferred grain traits;
- the preferred grain traits for all regions were white, large seeded, with a rough texture for food and market purposes, except for the northern region where brown grain was preferred for food;
- these grain characteristics should therefore be included in cowpea breeding programmes to ease the adoption of improved varieties by Burkina Faso farmers.

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CHAPTER THREE

Identification of sources of resistance to *Striga gesnerioides* in cowpea germplasm from Burkina Faso

Abstract

Cowpea landraces, improved varieties and wild relatives were evaluated for *Striga gesnerioides* resistance to identify new adapted and *Striga*-resistant sources. To identify such sources, cowpea genotypes were screened in fields infested with *S. gesnerioides* in three *Striga* hot-spots at Kamboinse, Koupela and Po in Burkina Faso under rainfed conditions. The 108 genotypes were also screened in pots under artificial infestation with each of the *Striga* races SR 1, SR 5 and SR Kp, separately, at Kamboinse Research Station. The experiments, both field and pots, were conducted as α-lattice design replicated three times during 2007. *Striga* density (DS) and yield were recorded in the field, whilst *Striga* vigour (SVIG), *Striga* dry biomass (SDB) and number of *Striga* shoots per cowpea plant (NSSP) were recorded in pots. The results of these investigations showed that the three *Striga* races involved were different since cowpea genotypes had differential reactions for *Striga* resistance over sites for field experiments or *Striga* races for pot experiments. Sources of resistance were found that confer site-specific or multiple *Striga*-race resistance. The field results were consistent with the pot experiments. Genotypes KVx771-10 and IT93K-693-2 conferred resistance to all three *Striga* races and had yields of at least 434 kg ha^{-1} in the highly infested site of Koupela. Genotype KVx396-4-5-2D was *Striga*-tolerant and resulted in high grain yield of at least 624 kg ha^{-1} despite the high *Striga* densities of 1.35 *Striga* shoots per plant. Some wild relatives of cowpea, such as No 91 P4, SP118-P24, No 2300 P, NS 1, NS 3 were *Striga*-resistant, suggesting that they could be used as donor-parents of resistance genes in breeding resistant cultivars. Most cowpea landraces, which included Moussa local, Niaogo local with farmers' preferred traits, need to be improved for *Striga* resistance, since they ranked amongst the worst performers for *Striga* resistance.

3.1 Introduction

Cowpea (*Vigna unguiculata* (L.) Walp.) is an important source of protein and income among the resource-poor farming communities of the semi-arid areas of Africa (Lane and Bailey, 1992). However, production of the crop is faced by a lot of challenges, which include land degradation, reduced rainfall over time, insect pests, diseases and weeds. *Striga gesnerioides* (Willd.) Vatke is one of the most important parasitic weeds that affect cowpea and contributes to low crop yields in West Africa (Muleba *et al.*, 1997). As a result of its importance, breeding programmes to channel *Striga* resistant sources to the farmers have been initiated. Therefore, the identification of sources of *Striga* resistance for use in the breeding programmes is an important activity.

In previous studies, genotypes 58-57, B301, IT82D-849 were identified as sources of resistance with single dominant genes conferring the resistance to one or two reported *Striga* races (races 1 and 5) prevailing in Burkina Faso (Atokple *et al.*, 1995). However, these sources have not been ideal as they lack the traits preferred by the farmers. Furthermore, in some *Striga* hot-spots of the country, farmers have reported *Striga* infestations on cultivars previously reported as resistant. This suggests the breakdown of *Striga* resistance, an increase in aggressiveness of the current *Striga* races or the presence of new *Striga* races. This therefore necessitates the search for new sources of resistance through germplasm screening.

Field screenings with *Striga* inoculum have been effective in selecting cowpea genotypes with resistance to *S. gesnerioides* and to assess yield loss due to *Striga* (Muleba *et al.*, 1997). However, field screening using artificial inoculation is not always feasible because of its potential to cause *Striga* dissemination to new areas and may not always be reliable because the researcher has no control over the weed pressure and distribution (Haussmann *et al.*, 2000). On the other hand, pot screening has been effective as an alternative method to ensure even infestation of *Striga* inoculum. Atokple *et al.* (1995) have successfully used *Striga* infested pots to study the inheritance of the resistance of cowpea to *S. gesnerioides*. The pot-screening technique is an attempt to simulate *Striga* infested field conditions. Pot-screening was designed to ensure even infestation with *Striga* seeds, which is rarely obtained under field conditions. It can, therefore, be argued that the use of both hot-spots and pot screening might increase the chances of correctly identifying *Striga*-

resistant cultivars. Therefore this study was aimed at screening cowpea germplasm for resistance to *Striga* using three *Striga* hot-spots and pot-screening under artificial *Striga* inoculation in Burkina Faso. The specific objectives were to: i) identify high yielding and *Striga*-resistant genotypes in highly infested *Striga* hot-spots where the most prevalent *Striga* races occur in Burkina Faso, ii) identify high yielding and *Striga*-resistant genotypes under artificial *Striga* infestation in pot experiments using the three most prevalent *Striga* races in Burkina Faso namely SR 1, SR 5 and SR Kp, and iii) determine whether SR Kp is a new race.

3.2 Materials and methods

3.2.1 Cowpea germplasm and *Striga* inoculum

The cowpea germplasm comprised of 108 entries, which included 45 wild cowpea relatives, landraces, improved and introduced genotypes. Cultivar B301, resistant to four cowpea *Striga* races, and TVx3236, which is susceptible to all races of *Striga*, were included as controls (Table 3.1). The wild germplasm were collected during 2003 while landraces have been collected throughout the country over a long period of time. The genotypes were planted in 2006 rainy season for homogeneity verification and seed multiplication purposes in preparation for the large-scale screening and hybridisation purposes.

Three races of *S. gesnerioides*, races 1, 5 and Kp, were used as inoculum for pot screening. Race 1, 5 and Kp were designated SR 1, SR 5 (Cardwell and Lane, 1995) and SR Kp, respectively. The races were collected from Kamboinse (SR 1), Po (SR 5) and Koupela (SR Kp) in the 2006 rainy season and stored in the weed germplasm collection at Kamboinse Research Station.

3.2.2 Experimental sites

Field trials were conducted at three sites, namely Kamboinse, Koupela and Po in Burkina Faso. Kamboinse is 15 km North of Ouagadougou, and received 669 mm of rainfall in 2007. Koupela is about 140 km east of Ouagadougou in the Sudan-savanna zone and received 1131 mm rainfall in 2007. Po is 160 km South of Ouagadougou in the Sudan-savanna zone and received 1105 mm of rainfall in 2007. The three sites represented the *Striga* hot-spots

in the country. The pot-screening experiments were conducted at INERA at Kamboinse Research Station in Burkina Faso during 2007 off-season (March 2007 to June 2007).

Table 3.1 Cowpea germplasm tested in field and pot experiments

Variety	Origin	Type	GH	Gr. colour	Gr. Texture	Gr. Size
58-57	Senegal	I	E	Wh	R	M
NS 4	BF	W	E	Br	Smth	Sml
524B	UC Riverside	I	E	Wh	R	M
Apagbaala	Ghana	L	SE	Wh	R	M
B02 03a	BF	W	S	Br	Smth	Sml
B05 5a	BF	W	S	Br	Smth	Sml
B06 06	BF	W	S	Br	Smth	Sml
B07 13	BF	W	S	Bl	Smth	Sml
B09 46	BF	W	S	Br	Smth	Sml
B12 07a	BF	W	S	Bl	Smth	Sml
B16 1a	BF	W	S	Bl	Smth	Sml
B26 01a	BF	W	S	Br	Smth	Sml
B27 07a	BF	W	S	Br	Smth	Sml
B28 02b	BF	W	S	Br	Smth	Sml
B30 01	BF	W	S	Br	Smth	Sml
B31 1b	BF	W	S	Br	Smth	Sml
B32 03a	BF	W	S	Br	Smth	Sml
B22 Vallenga	Ghana	L	S	Wh	Smth	M
B301	Botswana	L	SE	Br	Smth	M
Bagre-1	BF	L	S	Wh	R	M
Bousse local	BF	L	S	Wh	R	B
Cameroon 24-130	Cameroon	L	SE	Wh	R	B
Dassanga-1	BF	L	S	Wh	R	M
Diabiga	BF	L	S	Wh	R	M
Dimbo local	BF	L	S	Br	Smth	M
Djouroum local	BF	L	S	Wh	R	B
Donsin local	BF	L	S	Wh	R	M
Gaoua local-2	BF	L	S	Br	Smth	M
Goinkoro-2	BF	L	S	Wh	R	M
Gorom local	BF	L	SE	Br	R	M
Ife Brown	Nigeria	L	SE	Br	R	M
IT81D-994	IITA	I	E	Wh	R	B
IT82 D-849	IITA	I	E	Br	Smth	M
IT84D-449	IITA	I	E	Wh	Smth	M
IT84S-2049	IITA	I	SE	Wh	R	M
IT86D-716	IITA	I	E	Wh	R	M
IT93K-687-1	IITA	I	E	Wh	R	M
IT95K-1072-57	IITA	I	E	Wh	R	B

Table 3.1 Continued.

Variety	Origin	Type	GH	Gr. colour	Gr. Texture	Gr. Size
IT95K-1381	IITA	I	E	Wh	R	M
IT95K-627-34	IITA	I	E	Wh	Smth	M
IT93K-693-2	IITA	I	E	Br	R	M
IT98K-205-8	IITA	I	E	Wh	R	M
ITN87-71-21-P2	IITA	I	SE	Wh	R	M
Kano local	Nigeria	L	S	Wh	R	M
Koakin	BF	L	S	Wh	R	M
Kolondura local	BF	L	S	Br	Smth	M
Komsare	BF	L	SE	Cr	Smth	M
KVx771-10	BF	I	E	Wh	R	M
KVu150	BF	L	S	Wh	R	M
KVx396-4-5-2D	BF	I	SE	Wh	R	M
KVx402-5-2	BF	I	SE	Br	R	M
KVx404-8-1	BF	I	SE	Wh	R	M
KVx414-22-2	BF	I	SE	Wh	R	B
KVx61-1	BF	I	E	Br	R	M
KVx65-114	BF	I	E	Br	R	M
KVx745-11P	BF	I	E	Wh	R	M
KVx775-33-2	BF	I	E	Wh	R	B
KVx421-2J	BF	I	SE	Br	R	B
LARS -1	United Kingdom	I	E	Wh	R	M
Logofrousso	BF	L	S	Wh	R	M
Melakh	Senegal	I	SE	Wh	R	M
Mouride	Senegal	I	SE	Wh	R	M
Moussa local	BF	L	S	Wh	R	B
MT621	Botswana	W	S	Br	Smth	Sml
N'Diambour	Senegal	I	SE	Wh	R	M
SP81C	Madagascar	W	S	Br	Smth	Sml
Niaogo	BF	L	S	Br	Smth	Sml
NS -1	BF	W	S	Bl	Smth	Sml
NS -1-P29-14B	BF	W	S	Br	Smth	Sml
NS-3	BF	W	S	Br	Smth	Sml
No 2300-P45	Cameroon	W	S	Br	Smth	Sml
No 3076-P22	Cameroon	W	S	Bl	Smth	Sml
No 91 P4	Cameroon	W	S	Br	Smth	M
Pa local-GJ	BF	L	S	Wh	R	B
Pouytenga-3	BF	L	S	Wh	R	M
Sadore	Nigeria	L	SE	Wh	R	M
Sakoula	BF	L	S	Wh	R	M
Sanematenga local	BF	L	S	Wh	R	B

Table 3.1 Continued.

Variety	Origin	Type	GH	Gr. colour	Gr. Texture	Gr. Size
Sanga-2	BF	L	S	Br	Smth	M
Sewe GN	Ghana	L	SE	Br	Smth	Sml
SP111-P25a	Cameroon	W	S	Br	Smth	Sml
SP114-P20	Cameroon	W	S	Br	Smth	Sml
SP115-P14	Cameroon	W	S	Br	Smth	Sml
SP118-P24	Cameroon	W	S	Br	Smth	Sml
SP130-P19b	Cameroon	W	S	Br	Smth	Sml
SP131-P21	Cameroon	W	S	Wh	R	M
SP155	Botswana	W	S	Br	Smth	Sml
SP17-P30b	Cameroon	W	S	Br	Smth	Sml
SP180	Congo Brazzaville	W	S	Br	Smth	Sml
SP19 A-P31	Cameroon	W	S	Br	Smth	Sml
SP26-P29	Cameroon	W	S	Br	Smth	Sml
SP369 A-P39b	Sudan	W	S	Br	Smth	Sml
SP38-P52b	Cameroon	W	S	Br	Smth	Sml
SP5-P51b	Cameroon	W	S	Wh	R	M
SP88-P13a	Malawi	W	S	Br	Smth	Sml
SP9-P49a	Cameroon	W	S	Bl	Smth	Sml
Sul 518	Ghana	I	S	Wh	Smth	M
Tampouy local	BF	L	S	Wh	R	M
TV1089-P43A	Zambia	W	S	Wh	Smth	Sml
TV286b-P12	Botswana	W	S	Br	Smth	Sml
TV359-P34	Zambia	W	S	Bl	Smth	Sml
TV365-P41a	Malawi	W	S	Br	Smth	Sml
TV365-P41b	Malawi	W	S	Br	Smth	Sml
TV554-P44A	Zambia	W	S	Br	Smth	Sml
TV709-P7	Zambia	W	S	Br	Smth	Sml
TVx3236	IITA	I	E	Br	Smth	M
TVx3236 b	IITA	I	E	Br	R	M
UCR779	Botswana	I	SE	Br	Smth	M

Gr.: Grain; W: Wild species are from sub-species *unguiculata var*. *spontanea;* L: landrace; I: Improved variety; GH: Growth habit; E: Erect growth habit; SE: Semi-erect growth habit; S: Spreading growth habit; BF: Burkina Faso; ICIPE: International Centre for Insect Physiology and Ecology; IITA: International Institute for Tropical Agriculture;
Genotype : I: Improved; L: Landrace; W: Cowpea wild relative;
Growth habit : E: Erect; SE: Semi-erect; S: Spreading;
Grain colour: Bl: Black; Br: Brown; Smth: Smouth; Wh: White;
Grain size: Sml: Small sized-grain (< 11 g/100 seeds) ; M: Medium sized-grain (11-17 g/100 seeds); B: Big sized-grain (>17 g/100 seeds).

3.2.3 Experimental designs and management

3.2.3.1 Pot experiments

The experiment was laid out at Kamboinse Research Station as a 12 x 9 row-column α-lattice design replicated three times. The pots were the experimental units consisting of a single cowpea genotype. Each pot had a volume of eight litres and the approximate dry soil weight per pot was 10.5 kg. The pot screening for *Striga* resistance was conducted according to the method by Musselman and Ayensu (1983). About one thousand *Striga* seeds (7.5 mg) per pot were used according to the recommendations by Musselman and Ayensu (1983). Pots and potting mix (2 sand: 1 clay by volume) were first sterilized at 100^{o}C for 24 h using humid heating, prior to the infestation with *Striga*. After soil infestation with the one year-old *Striga* seeds, the pots were watered for three weeks to precondition *Striga* seeds in order to break their dormancy and ensure optimum germination. The 108 cowpea genotypes were then planted three weeks after pot inoculation with *Striga* seeds. Three sets of the trial were carried out, each infested with one of the three *Striga* races. The pots were supplied with adequate moisture (300 ml daily) and kept weed-free through hand-weeding. Half a gram fertilizer comprising 45% P_2O_5 units were applied per pot before *Striga* inoculation.

3.2.3.2 Field experiments

The field experiments were also laid out as 12 × 9 row-column α-lattice design replicated three times at all the three sites. One trial was at Kamboinse Research Station, where SR 1 naturally occurs. Two other trials were conducted on farmer-fields where each of the other races SR 5 and SR Kp occur. SR 1, SR 5 and SR Kp occur at Kamboinse (Centre), Po (South) and Koupela (East), respectively. The fields were selected on the basis of the occurrence of uniform, high *Striga* populations from observations made on farmers' plantings of a *Striga* susceptible cowpea variety KVx404-8-1 from 2005 to 2006. The plots were composed of two rows of 4.00 m long each with a spacing of 0.80 m between rows, and 0.25 m within the rows. Seeds were planted on hills and were thinned to one per hill, resulting in a total of 40 plants per plot. The trials were hand-weeded twice at three weeks and five weeks to avoid disturbing *Striga* emergence which normally starts around 40 days after planting on susceptible genotypes. Forty five kg ha^{-1} of P_20_5 fertilizer was applied before planting cowpea.

3.2.4 Data collection

Data collected from the pot trials included, number of days from planting to 50% cowpea flowering (FL) and maturity (MAT) dates, *Striga* vigour score (SVIG) using a 1-9 scale (Figure 3.1). The SVIG classes were 1: immune or presence of *Striga* shoots with height less than 0.5 cm; 2: highly resistant (*Striga* shoots emerged above soil level and with *Striga* shoot height less than 3 cm); 3: resistant (shoots height between 3- 5 cm); 4: moderately resistant (*Striga* height between 5-10 cm); 5: moderately susceptible (flowering *Striga sho*ots with height between 10-15 cm); 6: susceptible (*Striga* heigh*t* between 15-20 cm); 7: very susceptible (*Striga* height 20-25 cm); 8: highly susceptible (flowering *Striga* shoots with heights higher than 25 cm with no dead cowpea); and 9: highly susceptible (presence of dead cowpea plants with heights equal or higher than 25 cm), *Striga d*ry biomass (SDB) and number of *Striga* shoots per cowpea plant (NSSP),

For the field trials, the following data were collected; *Striga* density (DS) expre*ssed a*s the number of *Striga* shoots m^{-2} and yield (kg ha^{-1})

Figure 3.1 *Striga gesnerioides* vigour score scale with nine class*es in pot*-screening.

3.2.5 Data analysis

Data from field and pot experiments were analysed using the residual maximum likelihood (REML) procedure in GENSTAT 12th edition (Payne *et al.,* 2007) following the model*:*

$$Y = \mu + G_i + B_k + B_kR_jG_i + \varepsilon_{ijk}$$

Where, Y: the observed effect comprising; μ: overall mean; G_i: genotypic main effects; B_k: block or replication effects; R_j: row effects; ε_{ijk}: experimental error (environmental effects).

For pot experiments, the variance components were estimated using a randomized complete block design (in the general linear procedure) in GENSTAT 12th edition (Payne *et al.* 2009) using the model:

$$Y = \mu + G_i + B_k + G_i R_j + \varepsilon_{ijk}$$

Where, Y is the observed effects, with μ: overall mean; G_i : genotypic main effect; B_k: block (replication) effects and R_j: Row effects; ε_{ijk}: experimental error (environmental effects).

The genotype x environment (G x E) model was as follows;

$$Y_{ij} = \mu + G_i + B_j + (GE) + \varepsilon_{ij,}$$

where, Y: genotype mean; μ: overall mean; G_i: genotypic main effects, and B_j: block effects; ε_{ij}: experimental error; G x E: genotype x environment interactions.

3.3 Results

3.3.1 Field screening

Striga races SR 1, SR 5 and SR Kp occurred in Kamboinse, Po and Koupela areas, respectively. Results of all the 108 cowpea genotypes for DS and grain yield are provided in Table 3.2 (summary) and appendices 3.6.1 and 3.6.2 (exhaustive lists).

3.3.1.1 Kamboinse site

Table 3.2 shows the top 15 most resistant, the 10 most susceptible genotypes, the resistant and susceptible controls for DS (shoots m^{-2}). The genotypes were also ranked according to cowpea yield (kg ha^{-1}).

Striga density varied from 0.00 to 0.89 *Striga* shoots m^{-2} with an overall mean of 0.12 shoots m^{-2}. The susceptible check, TVx3236 had the highest DS of 0.89 shoots m^{-2}. Fifty one genotypes including wild relatives of cowpea such as NS 4, TV365 P41a, B12 07 a, B32 03a, SP369A P39b, No 2300 and the best resistant check, IT82D-849 did not produce *Striga* shoots (Figure 3.2).

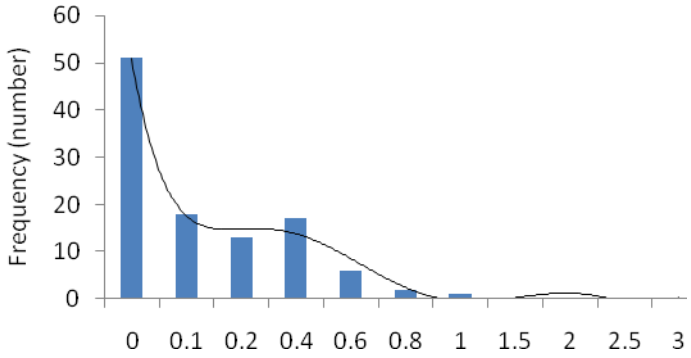

Figure 3.2 Cowpea genotype frequencies for *Striga* density (number m^{-2}) in field at Kamboinse, 2007.

Cowpea yield varied from 0 kg ha^{-1} for the wild cowpea relative SP9P 49a to 1,052 kg ha^{-1} for the improved genotype KVx396-4-5-2D and the overall mean of the trial was 390.7 kg ha^{-1}. Twenty one genotypes including IT93K-693-2, KVx61-1, KVx775-33-2 and KVx771-10, wild relatives SP155 and NS 4 had grain yield exceeding 500 kg ha^{-1}.

3.3.1.2 Po site

Po is the site where SR 5 is naturally present. *Striga* density varied from 0 to 2.5 *Striga* shoots m^{-2}, with an overall mean of 0.30 *Striga* shoots m^{-2}. Thirty eight genotypes, including the best resistant check IT82D-849 had no *Striga* shoots (Figure 3.3), while the susceptible check Moussa local had the highest DS. *Striga* density of most genotypes was significantly different from DS of the most susceptible genotype Moussa local. Genotypes IT81D-994,

KVx771-10 and KVx775-33-2 were among the genotypes with no *Striga* shoots. IT93K-693-2 and the farmer preferred genotype KVx61-1 had 0.1 and 0.30 *Striga* shoots m^{-2}, respectively.

Cowpea yield varied from 0 kg ha^{-1} for wild cowpea relatives SP111-Profil-25a to 1.208 kg ha^{-1} for genotype KVx421-2J, with an overall mean of 360 kg ha^{-1}. Forty one genotypes including Apagbaala, KVx775-33-2, KVx771-10, Melakh, IT82D-849 had grain yield exceeding 500 kg ha^{-1}. The susceptible genotype, TVx3236 had grain yield of 390 kg ha^{-1}. Genotypes KVx396-4-5-2D and Moussa local, included as susceptible checks had high yield (> 736 kg ha^{-1}) despite the high DS.

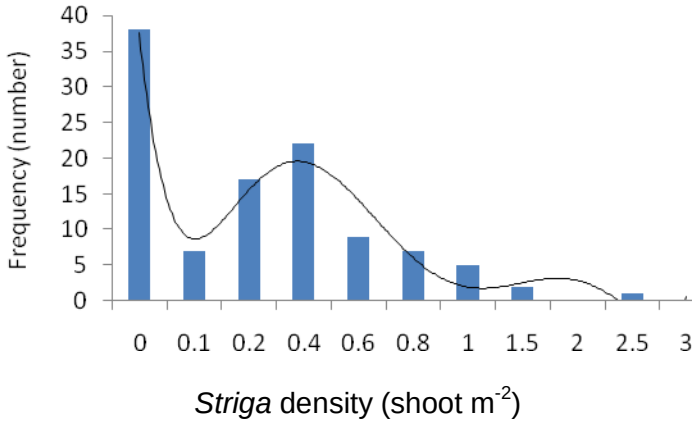

Figure 3.3 Cowpea genotype frequencies for *Striga* density (number m^{-2}) in field at Po; 2007

Table 3.2 *Striga* density (DS) and yield of the most resistant and susceptible cowpea genotypes based on *Striga* density at three study sites including controls (Kamboinse, Po and Koupela) 2007.

	Kamboinse		Po			Koupela	
Genotype	DS	Yield	Genotype	DS	Yield	Genotype	DS	Yield
15 most resistant								
IT93K-693-2	0.00	911.60	Apagbaala	0.00	833.30	KVx421-2J	0.00	667.00
IT95K-627-34	0.00	893.20	IT95K-627-34	0.00	752.10	KVx65-114	0.00	601.30
KVx65-114	0.00	850.80	Kano local	0.00	692.30	KVx402-5-2	0.00	518.00
Kano local	0.00	833.10	IT95K-1072-57	0.00	679.40	KVx775-33-2	0.00	440.00
UCR779	0.00	772.60	IT81D-994	0.00	665.40	KVx771-10	0.00	434.00
LARS -1	0.00	763.60	KV 771-10	0.00	658.20	Melakh	0.00	374.80
IT95K-1381	0.00	737.80	Sul 518	0.00	602.50	IT84S-2049	0.00	365.60
KVx61-1	0.00	735.00	KVx775-33-2	0.00	572.90	SP38-P52b	0.00	368.00
Cameroon 24-130	0.00	734.40	Gorom local	0.00	534.10	58-57	0.00	346.60
SP38-P52b	0.00	731.40	SP155	0.00	454.70	Gorom local	0.00	251.00
KVx775-33-2	0.00	725.50	IT98K-205-8	0.00	449.30	SP118-P24	0.00	7.10
IT95K-1072-57	0.00	724.50	Melakh	0.00	434.80	No 91 P4	0.00	1.20
KVx421-2J	0.00	720.70	Goinkoro 2	0.00	434.20	NS 1	0.00	0.90
Mouride	0.00	720.60	IT84S-2049	0.00	383.90	B27 05a	0.05	10.30
KVx771-10	0.00	677.30	Sadore	0.00	383.90	IT81D-994	0.05	455.50
Resistant ckecks								
B301	0.05	468.40	B301	0.26	550.50	B301	0.00	385.50
IT82 D-849	0.00	770.20	IT82 D-849	0.00	655.80	IT82D-849	0.00	493.20
Susceptible checks								
KVx396-4-5-2D	0.31	1052.50	KVx396-4-5-2D	0.21	782.20	KVx396-4-5-2D	1.35	624.20
TVx3236	0.89	540.70	TVx3236	0.78	390.30	TVx3236	0.83	495.00
Moussa local	0.52	749.50	Moussa local	2.45	736.80	Moussa local	0.99	377.30
10 most susceptible								
Sanematenga local	0.36	754.70	B05 5a	0.68	13.50	58-53	1.15	491.20
KVx404-8-1	0.36	663.10	Donsin local	0.78	903.10	IT84D-449	1.15	430.60
KVu150	0.36	662.10	B07 13	0.78	15.50	UCR779	1.20	461.10
Bagre 1	0.42	812.30	Sewe local (GN)	0.83	411.70	KVu150	1.25	446.80
Goinkoro 2	0.42	630.70	IT86D-716	0.89	779.20	Ife Brown	1.35	393.50
Sul 518	0.47	777.20	Ife Brown	0.94	517.50	Donsin local	1.46	434.20
Donsin local	0.52	608.30	IT84D-449	0.99	487.80	Apagbaala	1.51	349.80
B07 13	0.57	2.90	B28 02b	0.99	145.70	Bousse local	1.61	789.90
Djourom local	0.63	437.50	Bousse local	1.15	1001.10	Pa local (GJ)	1.93	296.60
IT86D-716	0.73	837.40	Bagre 1	1.30	824.30	IT86D-716	2.14	417.70
Mean	0.12	390.70	Mean	0.26	360.00	Mean	0.46	257.00
SED	0.21	127.20	SED	0.53	141.60	SED	0.49	212.10
LSD (5%)	0.41	249.30	LSD (5%)	1.04	277.53	LSD (5%)	0.97	415.71

DS: *Striga* Density (shoot m^{-2}); Yield (kg ha^{-2}); SED: Standard error of difference; LSD: Least significant difference;

3.3.1.3 Koupela

Striga race SR Kp is the isolate of *Striga* prevailing on cowpea at Koupela. *Striga* density varied from 0.00 to 2.10 *Striga* shoots m^{-2}, with an overall mean of 0.50 shoots m^{-2}. Fifteen genotypes which included the best two *Striga*-resistant controls, B301 and IT82D-849 had no shoots m^{-2}. Genotypes IT93K-693-2, KVx61-1, KVx775-33-2, KVx771-10, No 2300, and IT81D-994 had DS that were not significantly different from the resistant checks. The farmers' preferred varieties KVx61-1 and IT93K-693-2 had 0.10 and 0.20 *Striga* shoots m^{-2} respectively, and this was significantly different from DS for susceptible genotype KVx396-4-5-2D (1.40 *Striga* shoots m^{-2}). Figure 3.4 shows cowpea genotype frequency for different classes of *Striga* densities. The majority of the genotypes had no shoots to about 0.4 *Striga* shoots m^{-2}.

Yield varied from 0 kg ha^{-1} for the cowpea wild relatives SP111-Profil, SP88 SP9 and landrace Logofrousso to 922 kg ha^{-1} for genotype Waongo-1. The overall mean yield of the trial was 257 kg ha^{-1}. Twenty one genotypes including IT93K-693-2, KVx61-1, KVx775-33-2 and KVx771-10 and the cowpea wild relatives SP155 and NS 4 had grain yield exceeding 500 kg ha^{-1}.

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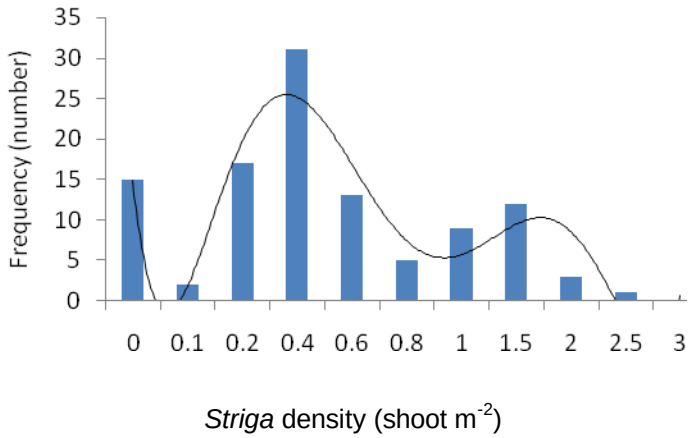

Figure 3.4 Cowpea genotype frequencies for *Striga* density (shoot m^{-2}) in field at Koupela, 2007.

3.3.2 Genotype by environment interactions

Table 3.3 shows the mean squares for the genotype x environment (G x E) analysis. The mean squares for the genotype and environment main effects were significant (P<0.01) for DS, while the mean squares for the G x E interaction were non-significant (P>0.05). The environment means were 0.12, 0.46 and 0.26 *Striga* shoots m^{-2} respectively for the locations of Kamboinse, Koupela and Po (Table 3.2).

For cowpea yield, the mean squares for genotype main effects were significant (P<0.01), while both the environment main effect and the G x E interaction mean squares were non-significant (P>0.05, Table 3.3). The environment means were 390.7, 256.7 and 360.1 kg ha^{-1} respectively for the sites of Kamboinse, Koupela and Po (Table 3.2).

Table 3.3 Mean squares of the genotype x environment interaction of *Striga* density and cowpea yield, 2008.

Source	DF	DS (nb. Shoot m^{-2})	Yield (kg ha^{-1})
Total	971	0.33	119817
Treatments	323	0.43 **	277660 88
Genotypes (G)	107	0.67 **	734259 **
Environments (E)	2	9.84 **	1598710 NS
Block	6	1.59	933969
Interactions (G x E)	214	0.23 NS	37014 NS
Error	641	0.27	32846

DF: Degrees of freedom; nb.: number; **: probability significant at 1%; NS: analysis of variance not significant. DS: *Striga* Density (shoots m^{-2}); Yield (kg ha^{-1})

3.3.3 Pot screening

3.3.3.1 Race SR 1

The 15 most resistant and 10 susceptible cowpea genotypes were obtained by ranking the genotype means from high to low performing (Table 3.4).

Flowering dates (FL) of the genotypes varied from 48 days (KVx775-33-2) to 90 days (SP111-P25 and Sanematenga local), with an overall mean of 66 days after planting. The mean maturity date (MAT) varied from 64 (KVx775-33-2) to 105 days (SP111-P25 and

Sanematenga local) with an average of 83 days after planting. Most landraces and wild species were late maturing.

Striga vigour varied from a score of 1.0 for the resistant checks (B301 and IT82D-849) to 8.0 for the susceptible check (TVx3236). Sixty seven genotypes had scores ranging from immune (score 1.0) to resistant (score 3.0). The differences in SVIG of cowpea genotypes were highly significant (P<0.001). Figure 3.5 shows the histogram of cowpea genotype frequencies for *Striga* vigour classes. More than 65 genotypes were immune (score 1.0) or highly resistant (scores 2.0 and 3.0).

The *Striga* dry biomass varied from 0.0 to 15.4 g per cowpea plant, with a mean across the genotypes of 4.7 g per cowpea plant. The differences in SDB for cowpea genotypes were highly significant (P<0.001).

The number of *Striga* shoots per cowpea plant varied from 0.0 to 12.3 with an average of 1.4 *Striga* shoots per cowpea plant. The differences in NSSP for the cowpea genotypes were highly significant (P=0.002). N'Diambour had the highest number of *Striga* shoots per cowpea plant.

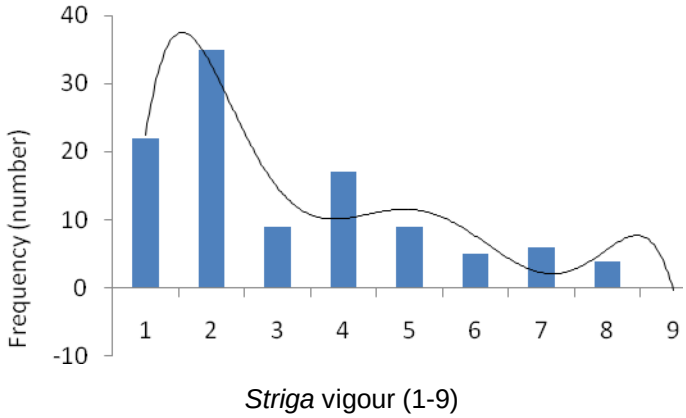

Figure 3.5 Cowpea genotype frequencies according to *Striga* vigour (SVIG) classes in pot trial infested with SR 1, Kamboinse 2007.

Table 3.4 Number of days to flowering (FL) and maturing (MAT) dates, *Striga* vigour (SVIG), *Striga* dry biomass (SDB) and Number of *Striga* shoots per cowpea plant (NSSP) of most resistant and susceptible cowpea genotypes infested with *Striga* race SR 1 at Kamboinse (2007).

Genotype	FL	MAT	SVIG	[b] SVIG	SDB	[b] SDB	NSSP
15 most resistant							
Melakh	53	78	1.00	2.45	0.00	0.70	0.00
Kano local	59	74	1.00	2.45	0.00	0.70	0.00
KV 771-10	60	77	1.00	2.45	0.00	0.70	0.00
IT81D-994	62	84	1.00	2.45	0.00	0.70	0.00
IT93K-693-2	63	78	1.00	2.45	0.00	0.70	0.00
Mouride	65	83	1.00	2.45	0.00	0.70	0.00
NS 1 P14B	66	85	1.00	2.45	0.00	0.70	0.00
SP131 P21	67	80	1.00	2.45	0.00	0.70	0.00
No 2300	69	91	1.00	2.45	0.00	0.70	0.00
SP369 A P39b	70	83	1.00	2.45	0.00	0.70	0.00
SP118-P24	72	94	1.00	2.45	0.00	0.70	0.00
LARS -1	72	100	1.00	2.45	0.00	0.70	0.00
219-01	73	89	1.00	2.45	0.00	0.70	0.00
NS 3	74	88	1.00	2.45	0.00	0.70	0.00
SP5-P51b	75	87	1.00	2.45	0.00	0.70	0.00
B30 01	75	86	1.00	2.45	0.00	0.70	0.00
Resistant checks							
B301	58	76	1.00	2.45	0.00	0.70	0.00
IT82 D-849	65	92	1.00	2.45	0.00	0.70	0.00
Susceptible checks							
KVx396-4-5-2D	54	74	4.00	2.95	6.49	1.01	4.67
Niaogo local	76	97	4.33	3.01	12.00	1.22	1.00
Moussa local	53	72	5.67	3.22	5.56	0.98	4.67
TVx3236	63	78	8.00	3.60	12.40	1.23	3.67
Ten most susceptible							
Djouroum local	67	80	6.00	3.30	13.32	1.24	8.00
IT95K-627-34	58	75	6.33	3.31	5.90	0.99	4.00
Koakin	66	83	6.33	3.33	8.33	1.10	3.33
TV365 Profil-41b	64	82	6.67	3.38	12.09	1.21	7.33
IT84D-449	51	79	6.67	3.38	5.03	0.98	4.00
B28 02b	61	83	6.67	3.38	10.20	1.17	2.00
Tampouy local	67	82	7.00	3.44	15.42	1.27	4.00
Pouytenga 3	67	88	7.67	3.56	8.33	1.05	3.33
B12 07a	63	77	8.00	3.60	14.72	1.29	4.33
TVx3236 b	63	78	8.00	3.60	12.40	1.23	3.67
Mean	65.65	83.25	2.84	2.76	4.66	0.91	1.35
P value	<0.001	<0.001		<0.001		<0.001	<0.002
CV (%)	10.90	9.00		13.90		21.50	19.34
LSD (5%)	11.52	12.07		0.62		0.31	4.22

CV: Coefficient of variation; LSD: Least significant difference; FL: Flowering date (days); MAT: Maturing date (days); SVIG: *Striga* vigour (1-9); SDB: *Striga* dry biomass (g); NSSP: Number of *Striga* shoots per cowpea plant; ([b]): data transformed using Log (x + 5).

3.3.3.2 Race SR 5

Table 3.5 shows the 15 most resistant and 10 susceptible cowpea genotypes, and the checks for different parameters studied.

The flowering date varied from 49 (for IT95K-1381) to 90 days (for the wild species SP111-P25a) with an overall mean of 66 days. The difference between genotypes was highly significant (P<0.01) for FL. The maturing date varied from 63 to 105 days after planting, for genotypes IT95K-1381 and cowpea wild relative SP111-P25a, respectively. The average maturity date was 84 days after planting. Most landraces and cowpea wild relatives matured between 85 and 105 days after planting.

Striga vigour of the tested cowpea genotypes varied from a score of 1.0 with resistant checks (B301 and IT82D-849) to score 9.0 for the highly susceptible check TVx3236. Forty five genotypes ranged from immune (score 1.0) to resistant (score 3.0) (Figure 3.6). The overall mean score was 4.3. The differences in cowpea genotype SVIG were highly significant (P<0.01).

The *Striga* dry biomass (g) varied from 0 to 27.5 g per pot. The overall mean of SDB was 7.6 g per cowpea plant. The differences in SDB were highly significant (P<0.01). The *Striga* dry mass of most genotypes was as high as that of the resistant checks.

The number of *Striga* shoots per cowpea plant varied from 0 to 22.0 with an average of 3.8 *Striga* shoots per cowpea plant. The differences in NSSP were highly significant (P<0.001).

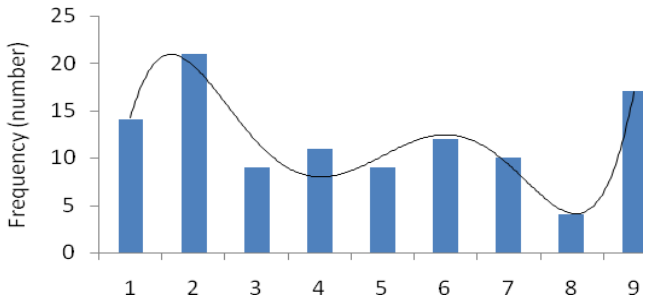

Figure 3.6 Cowpea genotype frequencies according to *Striga* vigour (SVIG) classes in pots infested with SR 5, Kamboinse 2007.

Table 3.5 Number of days to flowering (FL) and maturing (MAT) dates, *Striga* vigour (SVIG), *Striga* dry biomass (SDB) and Number of *Striga* shoots per cowpea plant (NSSP) of most resistant and susceptible cowpea genotypes infested with *Striga* race SR 5 at Po (2007).

Genotype	FL	MAT	SVIG	[b] SVIG	SDB	[b] SDB	NSSP	[a] NSSP
15 most resistant								
IT98K-205-8	50	77	1.00	2.45	0.00	0.70	0.00	2.24
KVx421-2J	52	69	1.00	2.45	0.00	0.70	0.00	2.24
Melakh	53	81	1.00	2.45	0.00	0.70	0.00	2.24
KV 771-10	55	72	1.00	2.45	0.00	0.70	0.00	2.24
IT93K-693-2	60	75	1.00	2.45	0.00	0.70	0.00	2.24
NS 1	61	79	1.00	2.45	0.00	0.70	0.00	2.24
Mouride	62	78	1.00	2.45	0.00	0.70	0.00	2.24
SP5-P51b	67	81	1.00	2.45	0.00	0.70	0.00	2.24
SP131-P21	70	82	1.00	2.45	0.00	0.70	0.00	2.24
SP180	75	91	1.00	2.45	0.00	0.70	0.00	2.24
SP9-P49a	79	105	1.00	2.45	0.00	0.70	0.00	2.24
SP130-P19	81	98	1.00	2.45	0.00	0.70	0.00	2.24
LARS -1	81	102	1.00	2.45	0.00	0.70	0.00	2.24
Gorom local	63	79	1.33	2.52	0.03	0.70	0.33	2.31
IT81D-994	61	77	1.33	2.52	0.33	0.73	0.33	2.31
KVx65-114	63	82	1.33	2.52	1.03	0.77	0.67	2.37
Resistant checks								
B301	62	76	1.00	2.45	0.00	0.70	0.00	2.24
IT82 D-849	64	78	1.00	2.45	0.00	0.70	0.00	2.24
Susceptible checks								
KVx396-4-5-2D	54	71	8.67	3.70	4.48	0.97	6.33	3.32
TVx3236	63	80	9.00	3.74	10.83	1.19	6.33	3.36
Niaogo local	78	99	9.00	3.74	20.78	1.37	11.67	4.07
Moussa local	58	77	4.00	2.95	4.13	0.91	1.67	2.56
Ten most susceptible								
B07 13	76	100	8.67	3.70	18.15	1.36	5.00	3.16
TV365 P41b	66	82	8.67	3.70	15.55	1.28	9.67	3.70
524B	49	73	8.67	3.70	10.33	1.17	8.33	3.62
Apagbaala	53	81	8.67	3.70	13.08	1.23	8.33	3.62
TVx3236 b	63	80	9.00	3.74	10.83	1.19	6.33	3.36
TV286b P12	57	73	9.00	3.74	19.52	1.36	12.00	4.05
Tampouy local	80	96	9.00	3.74	12.79	1.17	9.33	3.67
SP114 P20	64	79	9.00	3.74	10.85	1.20	10.00	3.86
B12 07a	62	76	9.00	3.74	20.22	1.38	17.67	4.71
KVx414-22-2	64	83	9.00	3.74	16.31	1.32	10.00	3.81
Mean	65.9	84.1	4.33	3.00	7.62	1.00	3.81	2.85
P value	<0.001	<0.001		<0.001		<0.001		<0.001
CV (%)	10.3	9.3		13.80		21.10		24.30
LSD (5%)	10.9	12.6		0.67		0.35		1.11

CV: Coefficient of variation; LSD: Least significant difference; FL: Flowering date (days); MAT: Maturing date (days); SVIG: *Striga* vigour (1-9); SDB: *Striga* dry biomass (g); NSSP: Number of *Striga* shoots per cowpea plant; ([a]): data transformed using square root (x + 5); ([b]): data transformed using Log (x + 5).

3.3.3.3 Race SR Kp

Table 3.6 shows the 15 most resistant and 10 susceptible genotypes.

The flowering date varied from 47 days (KVx775-33-2) to 90 days (Sanematenga local, Sanga 2, SP111-P25a and SP38-P52b), with an average across the genotypes of 68 days after planting. The maturing date varied from 62 to 105 days with an overall mean for maturing date of 85 days after planting. Genotype IT95K-1393 matured in 62 days. The differences in genotype FL and MAT were highly significant (P<0.01).

Striga vigour varied from a score of 1.0 for IT93K-693-2 and resistant check B301 to 9.0 for IT84D-449, B27 07a and Djouroum local, with an overall mean score of 3.9. Few genotypes were *Striga*-immune (score 1.0, Figure 3.7). Most genotypes ranked from 2.0 (resistant) to 4.0 (highly resistant to moderately resistant) as shown in Figure 3.7. The differences in SVIG for cowpea genotypes were highly significant (P<0.01).

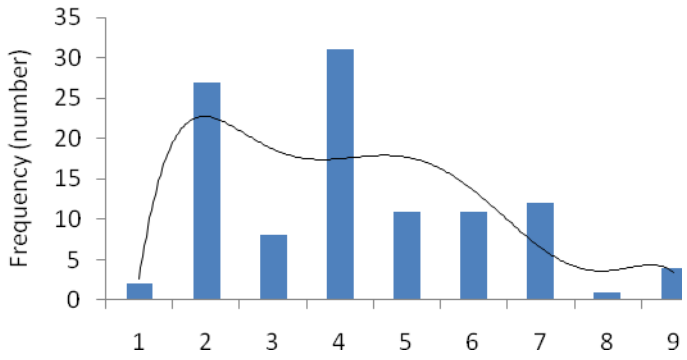

Figure 3.7 Cowpea genotype frequencies according to *Striga* vigour (SVIG) classes in pots infested with SR Kp, Kamboinse 2007.

Striga dry biomass varied from 0 (KVx771-10, IT93K-693-2 and the resistant check B301) to 42.00 g per cowpea plant for Djouroum local. The overall genotype mean for SDB was 12.19 g per cowpea plant. The differences in SDBfor cowpea genotypes were highly significant (P<0.01).

The number of *Striga* shoots per cowpea plant varied from 0.0 to 15.0 with an overall average of 3.3 *Striga* shoots per cowpea plant. The differences in NSSP for cowpea genotypes were highly significant ($P<0.01$).

Table 3.6 Number of days to flowering (FL) and maturing (MAT) dates, *Striga* vigour (SVIG), *Striga* dry biomass (SDB) and Number of *Striga* shoots per cowpea plant (NSSP) of most resistant and susceptible cowpea genotypes infested with *Striga* race SR Kp at Koupela (2007).

Genotype	FL	MAT	SVIG	[b] SVIG	SDB	[b] SDB	NSSP	[a] NSSP
15 most resistant								
KV 771-10	53	74	1.00	2.45	0.00	0.70	0.00	2.24
IT93K-693-2	66	81	1.00	2.45	0.00	0.70	0.00	2.24
IT98K-205-8	50	67	1.33	2.52	0.97	0.77	0.33	2.31
Kano local	54	70	1.33	2.52	1.66	0.80	0.67	2.37
UCR779	64	84	1.33	2.52	3.83	0.87	0.33	2.31
KVx775-33-2	47	68	1.33	2.52	1.08	0.77	0.33	2.31
SANGA-2	90	105	1.33	2.52	1.72	0.80	0.33	2.31
Mouride	57	77	1.33	2.52	0.33	0.73	0.33	2.31
TV365-P41b	75	91	1.33	2.52	1.37	0.79	0.33	2.31
KVx745-11P	65	93	1.33	2.52	0.33	0.73	0.33	2.31
IT95K-627-34	57	78	1.33	2.52	1.27	0.78	0.33	2.31
219-01	79	96	1.67	2.58	6.84	0.94	1.67	2.55
B07 13	78	96	1.67	2.58	3.12	0.87	0.67	2.38
TV359-P34	58	80	1.67	2.58	13.35	1.14	1.00	2.44
58-57	63	80	1.67	2.58	2.40	0.86	0.67	2.38
Resistant checks								
B301	57	76	1.00	2.45	0.00	0.70	0.00	2.24
IT82 D-849	63	85	1.33	2.52	0.33	0.73	0.33	2.31
Susceptible checks								
KVx396-4-5-2D	54	73	3.67	2.90	2.84	0.88	1.67	2.56
Moussa local	56	74	6.67	3.38	20.69	1.24	9.00	3.64
Niaogo local	72	88	4.67	3.07	31.28	1.55	7.67	3.53
TVx3236	58	75	6.67	3.38	15.43	1.31	12.00	4.08
10 most susceptible								
Bagre 1	69	91	6.33	3.35	17.66	1.25	3.67	2.93
Pouytenga 3	67	88	6.33	3.36	21.30	1.39	5.00	3.12
IT84S-2049	50	96	6.67	3.38	20.04	1.34	5.00	3.12
TVx3236 b	58	75	6.67	3.38	16.08	1.32	15.00	4.42
Bousse local	55	73	6.67	3.39	17.23	1.32	8.67	3.63
KVx414-22-2	65	86	8.00	3.60	15.40	1.26	7.00	3.41
SP19 A-P31	71	89	8.33	3.65	29.14	1.49	6.00	3.23
IT84D-449	49	77	9.00	3.74	28.33	1.52	11.67	4.07
B27 07a	66	83	9.00	3.74	26.55	1.44	8.33	3.64
Djouroum local	77	86	9.00	3.74	42.07	1.60	10.33	3.90
Mean	68.10	85.41	3.86	2.93	12.19	1.10	3.28	2.80
P value	<0.14	<0.00		<0.02		<0.00		<0.00
CV (%)	43.70	11.00		5.80		27.00		19.30
LSD (5%)	47.96	15.06		0.75		0.48		0.87

CV: Coefficient of variation; LSD: Least significant difference; FL: Flowering date (days); MAT: Maturing date (days); SVIG: *Striga* vigour (1-9); SDB: *Striga* dry biomass; (g); NSSP: Number of *Striga* shoots per cowpea plant; ([a]): data transformed using square root (x + 5); ([b]): data transformed using Log (x + 5); *: variance significant at p = 5%; **: analysis of variance significant at p = 1%.

3.3.4 Study of differential reaction to *Striga* races

Table 3.7 Comparison of cowpea genotypes for differential resistance to *Stiga gesnerioides* in pots.

Genotypes	[c]SR 1	[c]SR 5	[c]SR Kp
IT93K-693-2	R	R	R
B301	R	R	R
IT81D-994	R	S	S
Gorom local	R	S	S
58-57	R	R	R
IT98K-205-8	R	R	R
524B	S	S	R

([c]): The nine class *Striga* scoring scale was converted to a two class scale: absence (R) and presence (S) of *Striga,* to ease the comparison with known cowpea genotype resistance for *S. gesnerioides* according to Atokple *et al.* (1995).

Table 3.7 shows the differential reaction of cowpea genotypes to the *Striga* races. Races SR 5 and SR Kp infected IT81D-994 and Gorom local cowpea genotypes. However, SR 5 also infected 524B, which was resistant to SR Kp. All the genotypes, with the exception of 524B, were resistant to SR 1.

3.3.5 Phenotypic correlation studies

Tables 3.8, 3.9 and 3.10 show the phenotypic correlation coefficients between field yield, field DS, and pot resistance parameters (SVIG and SDB) for SR 1, SR 5 and SR Kp races, respectively. For SR 1, DS was significant ($P<0.01$) and positively correlated to SVIG ($r = 0.51$) and SDB ($r = 0.60$). SVIG was significant ($P<0.01$) and positively correlated with SDB for all the three races. On the other hand, yield for SR 5 was negatively correlated to DS ($r = -0.33$, $P<0.05$).

Table 3.8 Correlation between *Striga* resistance parameters in pots (SVIG, SDB) and field *Striga* resistance parameters (Yield, DS) with SR 1.

	Yield (kg ha^{-1})	DS	SVIG
DS (field)	0.20 NS		
SVIG (pot)	-0.14 NS	0.51**	
SDB (pot)	-0.09 NS	0.60**	0.83**

SVIG: Pot *Striga* vigour; SDB: Pot *Striga* dry biomass; DS: Field *Striga* density; (**): analysis of variance significant at P=0.01; NS: analysis of variance not significant.

Table 3.9 Correlation between *Striga* resistance parameters in pots (SVIG, SDB) and field *Striga* resistance parameters (Yield, *Striga* density (DS)) with SR 5.

	Yield kg ha^{-1}	DS	SVIG
DS (field)	-0.33*		
SVIG (pot)	0.02 NS	0.27 NS	
SDB (pot)	0.08 NS	0.24 NS	0.80**

SVIG: Pot *Striga* vigour; SDB: Pot *Striga* dry biomass; DS: Field *Striga* density; (*): analysis of variance significant at P=0.05; (**): analysis of variance significant at P=0.01; NS: analysis of variance not significant

Table 3.10 Correlation between *Striga* resistance parameters in pots (SVIG, SDB) and field *Striga* resistance parameters (Yield, *Striga* density (DS)) with SR Kp.

	Yield kg ha^{-1}	DS	SVIG
DS (field)	0.11 NS		
SVIG (pot)	0.23 NS	0.54**	
SDB (pot)	-0.08 NS	0.30 NS	0.63**

SVIG: Pot *Striga* vigour; SDB: Pot *Striga* dry biomass; DS: Field *Striga* density; (**): analysis of variance significant at P=0.01; NS: analysis of variance not significant.

3.4 Discussion and conclusion

The field study was aimed at the identification of new sources of *Striga* resistance, with farmers' preferred traits. Three *Striga* races SR 1, SR 5 and SR Kp were used as sources of inocula.

With SR 1, 47% of cowpea genotypes, including wild relatives of cowpea and the best resistant check, IT82D-849 did not induce *Striga* shoots. Nineteen percent of genotypes including IT93K-693-2, KVx61-1, KVx775-33-2 and KVx771-10, wild relatives SP155 and NS 4, had grain yield exceeding 500 kg ha^{-1}. Though most wild cowpea relatives had good resistance to *S. gesnerioides*, the grain yield was affected by pod shattering. Some genotypes such as KVx396-4-5-2D and IT86D-716, had high DS close to the susceptible check TVx3236, but performed well for yield, thus indicating they were tolerant to *Striga* infection.

With SR 5, 30% of genotypes, including the best resistant check IT82D-849, induced no *Striga* shoots, while the susceptible check Moussa local had the highest DS. *Striga* density of most genotypes was significantly different from the DS of the most susceptible genotype Moussa local. Genotypes IT81D-994, KVx771-10 and KVx775-33-2 were among the genotypes with no *Striga* shoots. IT93K-693-2 and the farmer preferred genotype KVx61-1 had low DS of 0.10 and 0.30 *Striga* shoots m^{-2}, respectively. This showed that, though they were not immune, they were good sources of resistance since the DS observed was lower than that of the susceptible controls TVx3236 (0.78 *Striga* shoots m^{-2}) and Moussa local (2.45 *Striga* shoots m^{-2}). Forty one genotypes including Apagbaala, 775-33-2, KVx771-10, Melakh, IT81D-849 had grain yield exceeding 500 kg ha^{-1}. The susceptible genotype, TVx3236 had grain yield of 390 kg ha^{-1}. Most of the high yielding genotypes had low infestations by *Striga*. As in the case with SR 1, the grain yield of most wild species that had good resistance to *S. gesnerioides* was affected by pod shattering. Genotypes KVx396-4-5-2D and Moussa local, included as susceptible checks performed well for yield (>736 kg ha^{-1}) despite the high DS.

With SR Kp, 14% of genotypes which, included the best two *Striga*-resistant controls, B301 and IT82D-849, had no shoots m^{-2}. Genotypes IT93K-693-2, KVx61-1, KVx775-33-2, KVx771-10, No 2300, and IT81D-994 were not significantly different from the resistant checks for DS. Among these genotypes are those preferred by the farmers, such as KVx61-1 and IT93K-693-2. Most cowpea wild relatives had good resistance to SR Kp despite grain yield being reduced by pod shattering. The yield of genotypes, which included KVx421-2J, KVx775-33-2, KVx771-10 and IT81D-994, were as high as that of the resistant checks, B301 and IT82D-849. These genotypes are potential sources of resistance and can therefore be used for breeding cowpea for resistance to the race SR Kp of *S. gesnerioides.*

Striga density was highest at Koupela, which could suggest that SR Kp was a more aggressive race than SR 1 and SR 5. The GxE interactions were not significant for DS and yield, which meant that the cowpea genotypes reaction were the same in all sites.

In pot screening, 50, 37 and 14 cowpea genotypes with resistance to SR 1, SR 5 and SR Kp respectively, were found to be as resistant as the best resistant control IT82D-849 with 0

Striga shoot m^{-2}. Several wild cowpea relatives, (29, 18 and 4 with SR 1, SR 5 and SR Kp respectively) performed as well as the resistant control (IT82D-849). However, few landraces were resistant to *Striga.* Most grown landraces and wild cowpea relatives were late-maturing. *Striga* dry biomass (SDB) was higher with SR Kp at Koupela. The resistant control, B301, though it was not *Striga*-free had very low DS with SR 1 (0.05) and SR Kp (0.26), implying that it was resistant.

Therefore the best sources of resistance identified from pot screening for the different races were as follows:

For SR 1, the resistant sources were: NS 4, LARS-1, IT93K-693-2, UCR779, TV365-P41a, B12 07 a, B32 03a, SP369A-P39b, No 2300-P45, IT95K-1381, B26 01a, B31 1b, SP180, Cameroon 24-130, KVx61-1, Mouride, B27 07a, B02 03a, SP19A-P51, SP88-P13A, B06 06, NS 3 and B28 02.

For SR 5, they were: TV1089-P44A, TV554-P44A, TV359-P34, Goinkoro 2, Diabiga, No 3076-P22, Sul 518, NS 1, B16 01a, Tampouy local, Kolondura local and Apagbala.

On the other hand, two resistant sources were identified for SR Kp only (not for SR 1 and SR 5), and these were KVx402-5-2 and B301.

Genotypes with high to moderately resistance to *Striga* were also identified to more than one race. For SR 1 and SR Kp, the sources included KVx421-2J, KVx65-114, SP38-P52b, NS 1, B29 14b and IT82D-849, whereas for SR 1 and SR 5 they were IT81D-994, Sanga 2, and IT98K-205-8. Genotypes with high to moderately resistance to all the three *Striga* races used in this study were 58-57, IT84S-2049, KVx771-10, KVx775-33-2, No 91-P4, SP118-P24, Gorom local and Melakh.

Results on differentiation of *Striga* races revealed that SR 1 and SR 5 were both different from SR Kp (Table 3.8). The reaction of SR 1 and SR 5 on the genotypes tested in this study was in agreement with the findings of other researchers (Lane *et al.,* 1991; Cardwell and Lane 1995; Ouedraogo *et al.,* 2001; Boukar *et al.,* 2004; Atokple *et al.*, 1995). Based on the observations made by the same authors for other races such as SR 2, SR 3 and SR 4, it was also clear that SR Kp was different from these three races. Lane and Bailey (1992)

reported that genotypes 58-57 was susceptible to SR 2 (Mali) and SR 3 (Niger and Nigeria) and resistant to SR 4 and SR 1 and SR 5. In this study genotype 58-57 was also resistant to SR Kp. According to Atokple *et al.* (2005), Boukar *et al.* (2004) and Timko *et al.* (2007), SR 4 infected B301, IT98K-205-8 and 524B, whereas in this study, all these genotype were resistant to SR Kp. Based on these findings it can be inferred that SR Kp was different from the reported *Striga* races, suggesting it could be a new race. It could be one of the two new *Striga* races reported in Sub-Saharan Africa by Li and Timko (2009).

Pot screening for *Striga* resistance appeared to be more accurate than field screening since the infestation was uniform and there was no interference with site effects. However, field screening was important for grain yield evaluation. With both pot and field evaluations for *Striga* resistance, when farmers preferred traits for cowpea were taken into account (that is, short maturity, grain size, colour and texture), varieties KVx771-10, IT93K-693-2 were the ideal sources of resistance to all the three *Striga* races, and had acceptable yields. The resistance of IT93K-693-2 confirmed the results of Boukar *et al.* (2004), whereas KVx771-10 was a new cowpea variety. These genotypes are potential parents for breeding new, adapted and *Striga* resistant genotypes with farmers' preferred traits and can therefore be used as donor parents. Genotypes B301 and IT82D-849, though, both were resistant to *S. generioides*, lacked the farmers' preferred grain traits. In addition, genotype IT81D-994 had a very long growing cycle. Genotype KVx61-1 was *Striga*-immune to SR 1 race. Genotype KVx396-4-5-2D was *Striga*-tolerant as it resulted in a high yield, despite the presence of high *Striga* density. This result confirmed the findings of Muleba *et al* (1997) for this genotype.

The results of the phenotypic correlation studies in pot screening showed that field yield tends to decrease when DS increases when *Striga* race SR 5 is involved. Field DS increased with SDBfor SR 1 race. Field DS was positively correlated with SVIG when SR 1 and SR Kp races were used. For all the three races, SVIG was positively correlated with SDB. Likewise, field DS was positively correlated with SDBfor SR 1.

In conclusion,

- genotypes such as KVx771-10 and KVx775-33-2 had a level of *Striga* resistance similar to that of the current sources of resistance to *S. gesnerioides* B301 and IT82D-849. They also have more farmers' preferred traits, which could ease their adoption by farmers;
- genotypes KVx771-10, and KVx775-33-2, No 2300, KVx745-11P, IT93K-693-2 were therefore proposed as potential parents for cowpea improvement for *Striga* resistance in cowpea. However, further investigations for taste and food processing abilities still need to be implemented at farmers' level;
- SR Kp were found to be a new *Striga* race;
- non-significant G x E interactions were involved for DS and yield.

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3.6 Appendices

Appendix 3.6.1 *Striga* density of 108 cowpea genotypes at three study sites (Kamboinse, Koupela and Po) 2007.

	Striga density (shoot m^{-2})		
Genotype	Kamboinse	Koupela	Po
58-57	0.00	0.00	0.00
219-01	0.00	0.16	0.05
B02 03a	0.00	0.21	0.52
B06 06	0.00	0.36	0.57
B12 07a	0.00	0.57	0.10
B26 01a	0.00	0.26	0.26
B27 07a	0.00	0.05	0.47
B28 02b	0.00	0.21	0.99
B31 1b	0.00	0.36	0.26
B32 03a	0.00	0.21	0.10
Cameroon 24-130	0.00	0.26	0.31
IT81D-994	0.00	0.05	0.00
IT82 D-849	0.00	0.00	0.00
IT84S-2049	0.00	0.00	0.00
IT95K-1072-57	0.00	0.26	0.00
IT95K-1381	0.00	0.57	0.21
IT95K-627-34	0.00	0.63	0.00
IT93K-693-2	0.00	0.21	0.05
IT98K-205-8	0.00	0.99	0.00
Kano local	0.00	0.10	0.00
KVx61-1	0.00	0.31	0.31
KVx65-114	0.00	0.00	0.21
KVx771-10	0.00	0.00	0.00
KVx775-33-2	0.00	0.00	0.00
KVx421-2J	0.00	0.00	0.16
LARS -1	0.00	0.16	0.05
Mouride	0.00	0.26	0.36
MT621	0.00	0.10	0.00
NS 1-P29-14B	0.00	0.00	0.42
NS 3	0.00	0.21	0.68
No 2300-P45	0.00	0.26	0.16
No 91-P4	0.00	0.00	0.00
Sadore	0.00	0.26	0.00
Sanga-2	0.00	0.31	0.00
SP111-P25a	0.00	0.10	0.00
SP115-P14	0.00	0.16	0.00

Appendix 3.6.1 continued.

	Striga density (shoot m^{-2})		
Genotype	Kamboinse	Koupela	Po
SP118-P24	0.00	0.00	0.00
SP131-P21	0.00	0.42	0.00
SP155	0.00	0.21	0.00
SP17-P30b	0.00	0.21	0.00
SP180	0.00	0.21	0.31
SP19 A-P31	0.00	0.26	0.52
SP369 A P39b	0.00	0.16	0.16
SP38-P52b	0.00	0.00	0.26
SP5-P51b	0.00	0.16	0.00
SP88-P13A	0.00	0.31	0.57
SP9-P49a	0.00	0.31	0.00
TV286b-P12	0.00	0.10	0.00
TV365-P41a	0.00	0.36	0.10
TV365-P41b	0.00	0.16	0.00
UCR779	0.00	1.20	0.05
B05 5a	0.05	0.42	0.68
B09 46	0.05	0.16	0.16
B30 01	0.05	0.42	0.16
B301	0.05	0.00	0.26
Diabiga	0.05	0.26	0.00
Gorom local	0.05	0.00	0.00
ITN87-71-21-P1-2	0.05	0.16	0.68
KVx402-5-2	0.05	0.00	0.10
KVx745-11P	0.05	0.10	0.26
Melakh	0.05	0.00	0.00
NS 1	0.05	0.42	0.00
No 3076 P22	0.05	0.31	0.00
Pouytenga-3	0.05	0.57	0.26
SP114 -P20	0.05	0.57	0.10
SP130-P19 b	0.05	0.16	0.10
SP26-P29	0.05	0.63	0.10
TV709-P7	0.05	0.21	0.05
TVx3236 b	0.05	1.15	0.47
524B	0.10	0.83	0.16
B16 1a	0.10	0.42	0.00
IT93K-687-1	0.10	0.36	0.16

SED: Standard error of difference; LSD: Less significant difference.

Appendix 3.6.1 continued.

	Striga density (shoot m^{-2})		
Genotype	Kamboinse	Koupela	Po
Tampouy local	0.10	0.42	0.00
TV1089 P43A	0.10	0.16	0.00
TV359 P34	0.10	0.21	0.00
Bousse local	0.16	1.61	1.15
Koakin	0.16	0.16	0.21
Komsare	0.16	0.73	0.26
KVx414-22-2	0.16	1.04	0.42
SP81C	0.16	0.73	0.16
TV554 P44A	0.16	0.16	0.00
Pa local-GJ	0.16	1.93	0.21
B22 Vallenga	0.21	1.04	0.16
Dassanga-1	0.21	0.47	0.16
Logofrousso	0.21	0.26	0.05
Gaoua local-2	0.26	0.31	0.78
IT84D-449	0.26	1.15	0.99
N'Diambour	0.26	1.04	0.31
Niaogo	0.26	0.47	0.31
Sewe GN	0.26	0.89	0.83
Apagbaala	0.31	1.51	0.00
Dimbo local	0.31	1.09	0.31
Ife Brown	0.31	1.35	0.94
Kolondura local	0.31	0.89	0.00
KVx396-4-5-2D	0.31	1.35	0.21
Sakoula	0.31	1.09	0.26
KVu150	0.36	1.25	0.21
KVx404-8-1	0.36	0.68	0.47
Sanematenga local	0.36	0.99	0.05
Bagre-1	0.42	0.83	1.30
Goinkoro-2	0.42	0.21	0.00
Sul 518	0.47	0.36	0.00
Donsin local	0.52	1.46	0.78
Moussa local	0.52	0.99	2.45
B07 13	0.57	0.57	0.78
Djouroum local	0.63	0.83	0.31
IT86D-716	0.73	2.14	0.89
TVx3236	0.89	0.83	0.78
Mean	0.12	0.46	0.26
SED	0.21	0.49	0.53
LSD (5%)	0.41	0.97	1.40

Appendix 3.6.2 *Y*ield of 108 cowpea genotypes at three study sites (Kamboinse, Koupela and Po), 2007.

	Yield (kg ha^{-1})		
Genotype	Kamboinse	Koupela	Po
58-57	310.00	346.60	231.20
219-01	524.50	546.80	452.30
524B	452.10	171.10	383.20
Apagbaala	795.10	349.80	833.30
B02 03a	10.30	16.70	73.00
B05 5a	14.20	13.20	13.50
B06 06	4.60	2.40	10.40
B07 13	2.90	1.00	15.50
B09 46	10.10	16.50	24.60
B12 07a	134.70	19.40	17.50
B16 1a	1.70	7.60	18.10
B26 01a	14.10	9.40	13.00
B27 07a	10.30	10.30	9.70
B28 02b	14.00	7.30	145.70
B30 01	8.00	8.20	28.30
B31 1b	20.20	11.80	8.70
B32 03a	5.50	1.90	52.60
B22 Vallenga	556.90	235.10	359.50
B301	468.40	385.50	550.50
Bagre-1	812.30	416.80	824.30
Bousse local	616.70	789.90	1001.10
Cameroon 24-130	734.40	553.70	649.60
Dassanga-1	407.90	225.10	431.60
Diabiga	24.50	41.60	364.30
Dimbo local	813.80	334.80	271.50
Djouroum local	437.50	497.00	924.90
Donsin local	608.30	434.20	903.10
Gaoua local-2	865.90	563.70	728.40
Goinkoro-2	630.70	353.60	434.20
Gorom local	440.60	251.00	534.10
Ife Brown	787.80	393.50	517.50
IT81D-994	559.60	455.50	665.40
IT82D-849	770.20	493.20	655.80
IT84D-449	541.90	430.60	487.80
IT84S-2049	507.10	365.60	383.90
IT86D-716	837.40	417.70	779.20
IT93K-687-1	977.10	519.80	720.50

Appendix 3.6.2 Continued.

	Yield (kg ha^{-1})		
Genotype	Kamboinse	Koupela	Po
IT95K-1072-57	724.50	738.00	679.40
IT95K-1381	737.80	421.40	741.70
IT95K-627-34	893.20	584.80	752.10
IT93K-693-2	911.60	631.60	406.40
IT98K-205-8	641.60	232.30	449.30
ITN87-71-21-P1-2	762.90	478.70	678.80
Kano local	833.10	631.70	692.30
Koakin	736.30	437.80	624.90
Kolondura local	417.20	287.70	376.90
Komsare	537.80	323.50	369.20
KVu150	662.10	446.80	719.80
KVx396-4-5-2D	1052.50	624.20	782.20
KVx402-5-2	769.60	518.00	605.90
KVx404-8-1	663.10	646.90	405.30
KVx414-22-2	890.40	485.70	715.80
KVx61-1	735.00	362.00	534.70
KVx65-114	850.80	601.30	453.20
KVx745-11P	478.70	230.70	434.40
KVx771-10	677.30	434.00	658.20
KVx775-33-2	725.50	440.00	572.90
KVx421-2J	720.70	667.00	1027.50
LARS -1	763.60	922.20	527.50
Logofrousso	2.00	0.00	21.00
Melakh	619.20	374.80	434.80
Mouride	720.60	463.60	734.70
Moussa locaL	749.50	377.30	736.80
MT621	0.90	0.70	0.70
N'Diambour	383.20	108.50	503.00
Niaogo	166.30	85.60	460.80
NS 1	78.80	36.20	163.70
NS 1-P29-14B	1.20	0.90	13.60
NS 3	6.20	29.70	54.40
No 2300-P45	4.80	3.20	24.30
No 3076-P22	7.50	24.30	28.60
No 91-P4	0.10	1.20	3.20
Pa local GJ	399.40	296.60	550.60
Pouytenga-3	507.10	331.40	676.60

Appendix 3.6.2 Continued.

	Yield (kg ha^{-1})		
Genotype	Kamboinse	Koupela	Po
Sadore	198.90	103.50	383.90
Sakoula	734.60	431.70	688.00
Sanematenga local	754.70	369.90	610.30
Sanga-2	123.30	149.70	166.80
Sewe GN	645.10	347.80	411.70
SP111-P25a	0.00	0.00	0.00
SP114 P-20	2.50	1.40	9.20
SP115-P-14	4.90	1.90	2.70
SP118-P24	12.20	7.10	20.50
SP130-P19 b	0.40	0.20	6.80
SP131-P21	4.90	1.50	15.80
SP155	640.80	377.50	454.70
SP17-P30b	0.20	0.60	4.10
SP180	1.40	33.10	2.00
SP19 A-P31	2.00	5.50	7.70
SP26-P29	1.20	4.20	21.20
SP369 A-P39b	5.00	2.80	28.80
SP38-P52b	731.40	368.00	637.60
SP5-P51b	1.90	1.20	48.80
SP81C	500.70	367.60	700.80
SP88-P13A	0.30	0.00	5.40
SP9-P49a	0.00	0.00	4.00
Sul 518	777.20	475.70	602.50
Tampouy local	419.40	183.90	248.40
TV1089-P43A	0.90	0.60	0.60
TV286b-P12	0.90	0.90	1.80
TV359-P34	1.30	2.90	21.60
TV365-P41a	2.30	3.40	3.40
TV365-P41b	6.10	1.40	1.10
TV554-P44A	0.10	1.20	10.70
TV709-P7	2.40	98.30	1.80
TVx3236	540.70	495.00	390.30
TVx3236 b	743.40	491.20	611.10
UCR779	772.60	461.10	629.40
Mean	390.70	257.00	360.00
SED	127.20	212.10	141.60
LSD (5%)	249.30	415.71	277.53

SED: Standard error of difference; LSD: Less significant difference.

CHAPTER FOUR

Study of *Striga* resistance mechanisms in cowpea

Abstract

The *Striga* resistance mechanisms of 40 cowpea genotypes against three *Striga* races prevailing in Burkina Faso were studied in *''in-vitro''* experiments from 2008 to 2009. The objective of this research was to identify *Striga* resistance mechanisms among 40 cowpea genotypes. In the first experiment, the effects of cowpea root extracts of 40 genotypes on *Striga* seed germination were studied. The root extracts, which comprised two-week old roots from each cowpea genotype, cut into small pieces were placed in an aluminum foil ring in the centre of a 9-cm petri dish. Glass filter papers, each containing about 30 pre-conditioned *Striga* seeds of three different races were then placed at increased distances from cowpea root extracts: 0-5 mm, 5-10 mm, 10-15 mm, 15-20 mm and 20-25 mm. The three different *Striga* races were from Kamboinse (SR 1), Koupela (SR Kp) and Po (SR 5). In the second experiment, three-day old germinated *Striga* radicles of races SR 1, SR 5 and SR Kp, were placed in contact with a secondary cowpea rootlet on a plate. Ten *Striga* seedlings were placed on ten different cowpea rootlets per cowpea genotype. Records were taken every four days after inoculation for the frequency of *Striga* radicles that did not attach or fix to cowpea rootlets (No *Striga* fixation), the frequencies of *Striga* radicles that had necrosis before (NBP) and after (NAP) the penetration of cowpea roots by *Striga* radicles and the frequency of *Striga* radicles that successfully developed to two leaflet stage (SIV). For most of the cowpea genotypes, the optimum distance for *Striga* seed germination was 20 mm. The highest rate of *Striga* seed germination were obtained with *Striga* race SR Kp. *''In-vitro''* screening parameters ''no *Striga* fixation'', necrosis before and after penetration of cowpea roots by *Striga* radicles and susceptibility ''*in-vitro*'' varied according to the *Striga* race involved. Parameter SIV showed significant correlation with most pot and field parameters regardless of the *Striga* race, suggesting its reliability in predicting field and pot outcomes. This parameter can be used as an indirect screening method for *Striga* resistance. Sources of resistance were found that induce very low germination (0-7.52%) of *Striga* seed germination (IT98K-205-8, KVx61-1 and Pouytenga 3. *Striga* resistance mechanisms NBP, NAP were the most important for all the three *Striga* races used. The resistance mechanism involved with genotypes KVx771-10, IT93K-693-2, KVx61-1 and Koakin local was NBP for SR 1 and SR 5 *Striga* races. For SR Kp, NBP mechanism was operative with genotypes IT81D-994, KVx402-5-2 and Melakh. The mechanism involved in genotype IT98K-205-8 was NAP for all the three *Striga* races.

4.1 Introduction

Striga gesnerioides (Willd.) Vatke is a parasite of cowpea (*Vigna unguiculata* (L.) Walp.) and several other legumes and has been commonly observed in West Africa. This *Striga* spp. is capable of causing complete crop failure in susceptible cowpea varieties if no control measures are implemented (Alonge *et al.*, 2001). Five *S. gesnerioides* races have been reported in the semi-arid areas of West Africa (Singh, 1997). Two of these *Striga* races, namely races SR 1 and SR 5 do occur in Burkina Faso (Singh, 1997; Cardwell and Lane*,* 1995). Most landraces grown in Burkina Faso are susceptible to these two races. Variety KVx61-1, which is resistant to *S. gesneriodes* at Kamboinse and Donsin in the centre of Burkina Faso has been found to be relatively susceptible to *Striga* at Po and Koupela where SR 5 and SR Kp prevail. This shows the differential reaction of the varieties to different *Striga* races. Varieties that confer general resistance to all of these races reported in Burkina Faso would be ideal for dissemination to farmers.

Different mechanisms for *Striga* resistance have been reported. Studies by Lane *et al.* (1991) have shown that the pre-emergence *Striga* resistance mechanisms vary from one cowpea variety to another. Lane *et al.* (1994) reported critical levels of resistance mechanisms involved in this process. These levels include: (a) first level - the ability of cowpea genotypes to stimulate *Striga* seed germination, (b) second level - the penetration of *Striga* radicle into the cowpea roots, and (c) third level - the resistance involves a reduced development of *Striga* on its host, involving reduced *haustoria* size (less than 1 mm) and limited stem development of *Striga*. In cowpea varieties 58-57 and 872, *Striga* seedlings have been observed to die within 3 - 4 days of penetration, accompanied by necrosis of host tissues around the penetration site. The third mechanism was observed in cowpea variety B301. Although Lane *et al.* (1991) and Berner and Williams (1998) developed a methodology that enables measurements of these mechanisms, for most cowpea varieties, particularly those of Burkina Faso, the resistance mechanisms have not been determined.

Artificial field infestation, using *Striga* seeds is prohibited due to the risk of disseminating *Striga* in new areas. ‘*’In-vitro”* techniques using liquid and agar-based nutrient media for growing cowpea under *Striga* infestation were therefore proposed by Lane *et al.* (1991) and

Berner *et al.* (1997). These ‘’*in-vitro’’* techniques allow observation of the underground *Striga* development stages that are not visible under field conditions. However, though they are an appropriate alternative to field experiments, they have never been applied intensively for breeding cowpea in Burkina Faso.

Therefore the objectives of this study were to: i) investigate the stimulation of *Striga* seed germination by different cowpea genotype exudates, ii) identify sources of resistance, and (iii) determine the post-germination resistance mechanisms involved.

4.2 Materials and methods

4.2.1 Cowpea germplasm and *Striga* races

Cowpea germplasm used in this study are indicated in Table 4.1. The germplasm were selected from the field and pot screening trials indicated in chapter 3. Forty cowpea genotypes were selected for *“in-vitro”* screening based on their resistance to *S. gesnerioides* and/or good agronomic characteristics as indicated by the local farmers. The farmers’ preferences included big grain size, white seed and high yield.

The *Striga* inocula involved three races of *S. gesnerioides*. These included seeds from *S. gesnerioides* race 1 (SR 1), and 5 (SR 5) and an isolate from the district of Koupela referred to as SR Kp. The *Striga* seeds were collected from the villages of Kamboinse, Koupela and Po from *Striga* plants growing on a susceptible cowpea landrace during the 2006 rain-fed season. Each *Striga* race was used individually as a separate source of inoculum.

The method of Berner and Williams (1998) was applied for collecting *Striga* seeds. This involved harvesting of mature pods from the *Striga* plant top. Pods were shed and the *Striga* seeds extracted using sieves of 150 µm-mesh size. The *Striga* seeds used were at least six months-old, by which time they had broken the primary dormancy.

4.2.2 *Striga* seed germination study

This experiment was conducted in the laboratory and greenhouse at INERA Kamboinse, Burkina Faso in 2008. *Striga* seed was first disinfected before conditioning. To disinfect,

Striga seeds were mixed at a concentration of 3 mg/ml of 1% sodium hypochlorite solution and 30 ml of the mixture decanted into a petri dish. One milliliter of Tween 80 was then added to the mixture to break the *Striga* seed surface tension and stirred for two minutes. The mixture was allowed to stand for a few minutes, and thereafter floating seeds and debris were discarded. The seeds were cleaned with sterile water.

After the disinfection, the *Striga* seeds were conditioned by placing them in 14 ml of sterile water containing 1 ml of 0.015% benomyl fungicide according to the method of Berner *et al.* (1997). The seeds were then incubated at 27^{o}C for seven days. After incubation, about 25 to 30 preconditioned *Striga* seeds were placed on each of 5 mm glass fibre disks with the aid of a binocular dissecting microscope.

The fibre disks containing *Striga* seeds were then placed in a sterile 9-cm diameter petri dish with two pre-moistened filter-papers at the bottom (Figure 4.1). The disks were arranged in a line from the 1-cm diameter central ring made of aluminum foil to the edge of the petri dish. The *Striga* seed germination stimulant comprised of 1.5 g of root pieces cut from two-week old cowpea genotypes. These root pieces were placed in the ring at the centre of the petri dish. From the ring containing the root pieces, disks 1, 2, 3, 4 and 5 were placed at distances of 5, 10, 15, 20 and 25 mm, respectively, from the ring in a line as shown in Figure 4.1. Each block was assigned *Striga* seeds from a different *Striga* race. Therefore, the three different *Striga* races all appeared in the same petri dish. The experiment had three replications, with each replication comprising of the 40 cowpea genotypes, three blocks of disks with *Striga* seeds, each block having a different *Striga* race (Figure 4.1). The petri dishes were then incubated for 72 hours (three days) after which the number of germinated *Striga* seeds and the total number of *Striga* seeds were recorded using a binocular dissecting microscope.

Table 4.1 Cowpea germplasm characterized according to the grain colour, size and texture.

Trt	Genotype	Colour	Size	Texture	Trt	Genotype	Colour	Size	Texture
1	IT98K-205-8	Wh	M	R	21	Koakin local	Wh	M	R
2	KVx396-4-5-2D	Wh	M	R	22	Sanga-2	Wh	M	R
3	Pouytenga-3	Wh	M	R	23	Djouroum local	Wh	M	Smth
4	KVx421-2J	Br	L	R	24	SP155	Bl	Sml	Smth
5	KVx65-114	Br	M	Smth	25	B12 07a	Br	Sml	Smth
6	N'Diambour	Wh	M	R	26	TV286b-P12	Br	Sml	Smth
7	No 3076 P 22	Bl	Sml	Smth	27	KVx745-11P	Wh	Sml	R
8	Diabiga	Wh	M	R	28	B301	Br	Sml	Smth
9	Donsin local	Wh	M	R	29	IT82 D-849	Br	L	Smth
10	Ife Brown	Br	M	Smth	30	IT91D-994	Wh	L	R
11	KVx61-1	Br	M	R	31	Gorom local	Br	M	R
12	KVx402-5-2	Br	M	R	32	IT93K-693-2	Br	L	R
13	KVx771-10	Wh	L	R	33	IT95K-1381	Wh	M	R
14	Sakoula	Wh	M	R	34	58-57	Wh	Sml	R
15	SP130-P19 b	Br	Sml	Smth	35	IT86D-716	Wh	M	R
16	B07 13	Bl	Sml	Smth	36	Niaogo local	Wh	M	R
17	No 2300	Br	Sml	Smth	37	KVx414-22-2	Wh	L	R
18	KVx397-6-6	Br	M	R	38	KVx3236	Br	Sml	R
19	Melakh	Wh	M	R	39	Moussa local	Wh	M	R
20	Mouride	Wh	M	R	40	Komsare	Br	L	Smth

Tr: treatment number in the experiment; Bl: Black-colour grain; Br: Brown-coloured grain; Wh: White-coloured grain; Sml: Small size-grain; M: Medium-sized grain; L: Large-sized grain; R: Rough-grain; Smth: Smooth grain.

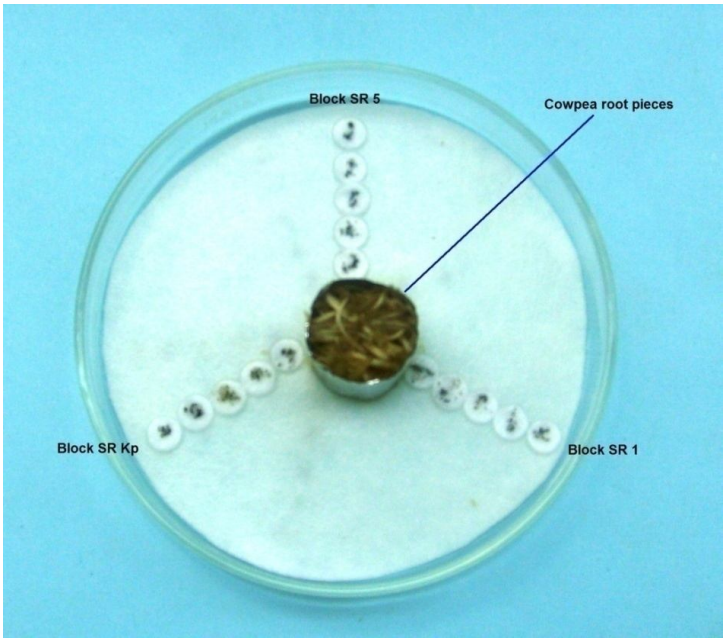

Figure 4.1 Design for testing seed germination of three different *Striga* races for a single cowpea genotype.

4.2.3 Study of the mechanisms of resistance (post germination tests)

The methodology used for screening cowpea genotypes "*in-vitro*" was that proposed by Lane *et al.* (1991), with some modifications which included: i) using single plants per cowpea genotype to constitute a replication, ii) adapting the method to local conditions, by replacing the glass petri dishes and glass fiber filter paper with plastic containers and simple, cheaper filter paper, and iii) studying of the underground processes of *Striga* parasitism by growing the cowpea host in sterile sandy medium in pots for three days, then transferring it into a large and disinfested glass/plastic tray as shown in Figure 4.2. Ten secondary roots per tray were selected, and a single *Striga* seedling was placed near the selected cowpea rootlets. The whole system, which included the tray with a moist filter paper laid at the bottom, the cowpea host plant and *Striga* seedling, was placed in a sterile plastic bag with an opening at the top. The cowpea aerial plant parts were allowed to grow through the opening at the top, while the remaining lower cowpea parts, the *Striga* seedling and plastic bag were covered with aluminum foil to exclude light. The whole system was then incubated for 72 hours in a growth chamber maintained between 27-30°C. Light was provided by a series of tungsten bulbs placed at 70 cm high from the tray. The bulbs provided power of 1536 watts light daily for 16 hours per day. Thereafter, a modified liquid medium of Lane *et al.* (1991) was used to provide nutrients (Appendixes 4.6.1, 4.6.2 and 4.6.3) to the cowpea seedlings up to the optimum number of days that *Striga* required to emerge from the soil (i.e. in field, 30 to 35 days after planting).

Each set of experiment comprised three replicates of a single plant for each of the 40 cowpea genotypes. Three experiment sets, each comprising of 40 cowpea genotypes were conducted. Each set was infested with a different race of *Striga*.

Records were taken every four days for at least five times. The records taken included the following parameters: the frequency of *Striga* radicles which failed to attach or fix, the frequency of *Striga* radicles showing necrosis before (NBP) and after (NAP) penetrating cowpea root cortex, and the frequency of *Striga* seedlings that successfully developed up to 2-3 leaf stage (or susceptibility ‘*in-vitro*’’ (SIV)).

Figure 4.2 ‘’*in-vitro”* screening of cowpea genotypes for *Striga* resistance in a growth chamber at Kamboinse 2009.

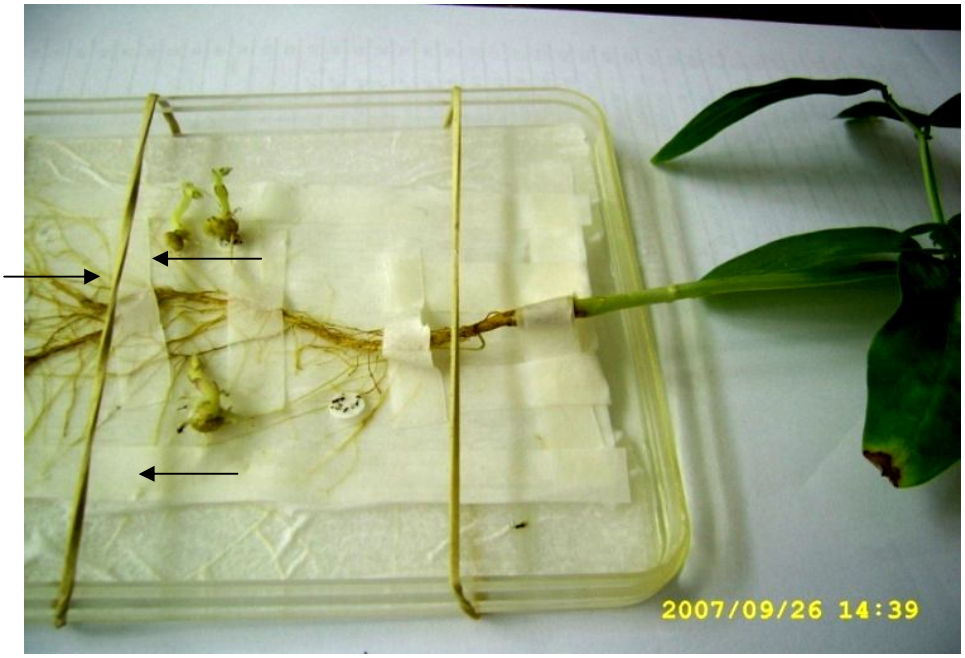

Figure 4.3. ‘’*in-vitro”* test of cowpea genotypes using plastic tray and liquid nutrient media: *Striga* seedling (black arrows) well developed and attached to a susceptible cowpea genotype in plastic plate.

4.2.4. Data analysis

For both the germination test and post-germination studies, a combined analysis of the different distances from the stimulation source across the three *Striga* races was done.

Data from the two experiments were analysed using the residual maximum likelihood (REML) procedure in GENSTAT 12th edition (Payne *et al.,* 2009) following the model*:*

$$Y_{ij} = \mu + G_i + B_j + \varepsilon_{ij},$$

Where, Y: the observed effect comprising; μ: overall mean; $G_{i:}$ genotypic main effects; $B_{j:}$ block or replication effects; $\varepsilon_{ij:}$ experimental error (environmental effects).

The model for genotype x germination distances and genotype x *Striga* race interactions were:

$$Y_{ij} = \mu + G_i + B_j + (GE) + \varepsilon_{ij,}$$

Where; Y: variety mean; μ: overall mean; G_i: genotypic main effects, and B_j: block effects; ε_{ij}: experimental error; G x E: genotype - environment interactions.

The correlation studies involved *Striga* resistance mechanism (SIV) involved in this chapter and *Striga* resistance parameters studied in the previous chapter three (Field *Striga* density (DS) as shoot m^{-2} and yield) and cowpea dry biomass (g) in pots.

4.3 Results

4.3.1 *Striga* seed germination test according to distance from a stimulation source

For SR 1, within 72 hours of testing, most of the cowpea genotypes had induced *Striga* seed germination except IT98K-205-8, KVx61-1 and Pouytenga 3. There were significant differences ($P<0.01$) amongst the cowpea genotypes in the stimulation of *Striga* seed germination. The highest *Striga* seed germination rates were observed for genotypes TV286-P12, SP155 and B12 07a (Table 4.2). All the susceptible controls induced less *Striga* seed germination rates than the resistant controls (Table 4.2).

For SR 5, within 72 hours of testing, cowpea genotypes differed significantly (P<0.01) in their stimulation of *Striga* seed germination only (Table 4.2). The lowest mean germination rates of 0.29 % (IT98K-205-8), 0.39% (KVx61-1) and 0.79% (KVx65-114) were observed for IT98K-205-8, KVx61-1 and KVx65-114, respectively. The highest mean germination proportions of 28.94%, 23.33%, 20.00% were observed for genotypes TV286 P12, Komsare and Mouride, respectively, and these were higher than those of the susceptible controls (Table 4.2). The susceptible controls induced less *Striga* seed germination rates than the resistant controls (Table 4.2), for SR 5.

Within the three days (72 hours) of testing, for SR Kp, most of the cowpea varieties had induced *Striga* seed germination. The cowpea genotypes were significantly different (P<0.01) in their stimulation of *Striga* seed germination. The mean germination rates were low for KVx61-1 (2.37%), KVx421-2J (2.58%), Pouytenga 3 (5.52%) and IT98K-205-8 (7.52%). Genotypes TV286 P12, Komsare, and SP155 had the highest *Striga* seed germination rates of 43.48%, 32.51% and 29.00%, respectively. Except for genotype KVx396-4-5-2D all the susceptible controls induced less *Striga* seed germination rates than the resistant controls (Table 4.2).

Table 4.2 Mean[†] germination rate (%) of *Striga* seeds over five germination distances from cowpea root pieces induced by cowpea genotypes under *''in-vitro''* screening.

Genotypes		SR1	[a]SR1	SR5	[a]SR5	SR Kp	[a]SRKp
IT98K-205-8		0.00	2.24	0.29	2.30	7.52	3.38
KVx61-1		0.00	2.24	0.39	2.32	2.37	2.68
Pouytenga-3		0.00	2.24	9.17	3.64	5.52	3.11
No 3076-P22		0.19	2.28	6.33	3.28	6.41	3.35
KVx421-2J		0.24	2.29	2.45	2.70	2.58	2.72
Diabiga		0.26	2.29	6.42	3.29	7.69	3.50
KVx65-114		0.50	2.34	0.79	2.40	5.67	3.21
NS 1 P 14		1.04	2.45	1.61	2.54	3.76	2.90
N'Diambour		1.57	2.54	9.46	3.56	21.13	4.55
Sakoula		2.83	2.77	13.45	4.20	19.92	4.87
Donsin local		2.85	2.73	8.71	3.61	16.64	4.58
Ife Brown		3.10	2.72	11.32	3.82	17.96	4.31
KVx745-11P		3.19	2.81	3.00	2.77	12.46	3.85
IT86D-716		3.41	2.87	7.54	3.45	13.86	3.97
KVx414-22-2		3.45	2.84	8.92	3.49	11.01	3.74
IT91D-994		3.50	2.85	2.46	2.69	9.20	3.73
KVx402-5-2		3.87	2.95	9.17	3.51	7.65	3.51
TVx3236		4.53	3.07	12.60	4.04	26.02	5.47
IT95K-1381		4.58	3.00	3.06	2.76	10.48	3.69
Melakh		5.01	3.09	14.79	4.39	12.64	3.99
Sanga 2		5.22	3.14	1.95	2.62	14.18	4.09
Mouride		5.24	3.13	20.00	4.94	15.47	4.40
KV 771-10		5.85	3.16	9.55	3.57	12.90	3.89
Koakin local		6.61	3.25	6.47	3.22	22.62	4.74
58-57		6.97	3.29	11.42	3.75	22.47	4.62
IT93K-693-2		8.19	3.43	10.53	3.65	12.77	3.88
SP130-P19b		8.22	3.45	13.63	4.01	14.78	4.18
B07 13		8.65	3.51	14.41	4.22	25.39	5.15
KVx397-6-6		10.03	3.61	8.05	3.34	18.81	4.38
Komsare		11.25	3.74	23.33	5.20	32.51	5.79
Gorom local		11.64	3.97	8.35	3.44	15.08	4.12
Djourom local		13.05	3.94	16.69	4.38	31.86	5.67
TV286-P12		15.07	4.14	28.94	5.61	43.48	6.73
SP155		16.08	4.34	19.46	4.86	29.94	5.53
B12 07a		18.81	4.38	16.52	4.36	27.86	5.28
Controls							
B301	(**R**)	4.97	3.13	12.79	4.21	14.20	4.34
IT82 D-849	(**R**)	7.97	3.58	14.14	4.34	23.38	5.23
KVx396-4-5-2D	(**S**)	4.01	2.92	5.86	3.16	21.02	4.52
Niaogo local	(**S**)	0.92	2.41	8.83	3.57	8.34	3.53
Moussa local	(**S**)	3.09	2.82	2.39	2.68	9.81	3.61
Mean		5.40	3.05	9.63	3.60	15.93	4.22
P value			<0.001		<0.001		<0.001
CV (%)			24.30		27.80		24.70
LSD (5%)			1.04		1.40		1.46

([†]): Means of germination rates of the five germination distances from the stimulation source**.** [a]: parameters transformed using Square root (X + 5); SR: *Striga* race; CV: coefficient of variation; LSD: Least significant difference;(R): Resistant control; (S): Susceptible control.

Figure 4.4 shows the *Striga* germination percentage for the different distances from the stimulation source for all the three *Striga* races used in the study. Most *Striga* seeds germinated at 20 mm from the stimulation source for *Striga* races SR 5 and SR Kp. The percentage of *Striga* seed germination for *Striga* races SR 5 and SR Kp increased from distances 5 to 20 mm from the stimulation source and declined therafter, while for SR 1 it increased gradually from 5 to 15 mm and from 20 to 25 mm. For this latter *Striga* race, the *Striga* germination percentage was still increasing with the distance beyond 20 mm from the stimulation source. On average, *Striga* seed germination rates were highest with *Striga* race SR Kp and lowest with *Striga* race SR 1. The maximum *Striga* seed germination percentage was observed at 20 mm for *Striga* races SR 5 and SR Kp and around 25 mm for *Striga* race SR 1 (Figure 4.4).

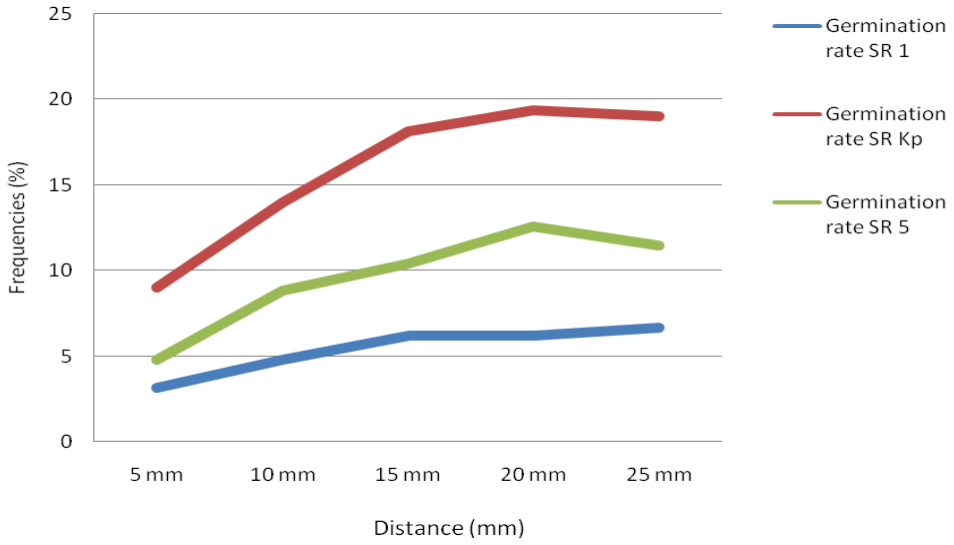

Figure 4.4 *Striga* seed germination rates for five different distances from the stimulation sources, with three different *Striga* races.

4.3.2 Study of the mechanisms of resistance to *Striga gesnerioides*

4.3.2.1 Race SR 1

There were no significant differences (P>0.05) amongst the cowpea genotypes for the parameters ‘’No fixation’’, NBP, and NAP (Table 4.3). However, the genotypes differed

significantly (P<0.01) for SIV. The proportion of *Striga* seedlings that developed beyond two leaf stage varied from 0.00 to 0.32, while the overall proportion mean for this parameter was 0.05.

Varieties KVx771-10 (67%), IT93K-693-2 (74%), KVx61-1 (83%) and HTR (78%) had the highest level of NBP, whereas varieties Pouytenga 3, IT98K-205-8 (48%) and Mouride (47%) had the highest NAP.

Table 4.3 Mean frequencies of *Striga* resistance mechanisms (No Fixation, NBP, NAP, SIV) for cowpea genotypes with *Striga* race SR 1, Kamboinse 2008.

Variety	NoFixt	NBP	NAP	SIV	[a] No Fixt	[a] NBP	[a] NAP	[a] SIV
15 most resistant								
Pouytenga 3	0.00	0.50	0.50	0.00	0.71	1.00	1.00	0.71
IT98K-205-8	0.27	0.26	0.48	0.00	0.87	0.86	0.99	0.71
Mouride	0.13	0.40	0.47	0.00	0.79	0.94	0.98	0.71
KVx397-6-6	0.03	0.53	0.43	0.00	0.73	1.01	0.96	0.71
No 3076 P22	0.03	0.54	0.43	0.00	0.73	1.02	0.96	0.71
No 2300	0.00	0.57	0.43	0.00	0.71	1.03	0.96	0.71
KVx745-11P	0.07	0.53	0.40	0.00	0.75	1.01	0.94	0.71
KV 771-10	0.00	0.67	0.33	0.00	0.71	1.08	0.91	0.71
KVx421-2J	0.10	0.57	0.33	0.00	0.77	1.02	0.91	0.71
IT91D-994	0.21	0.46	0.33	0.00	0.83	0.97	0.89	0.71
IT93K-693-2	0.00	0.74	0.26	0.00	0.71	1.11	0.87	0.71
KVx402-5-2	0.07	0.70	0.23	0.00	0.75	1.08	0.84	0.71
SANGA-2	0.10	0.72	0.18	0.00	0.77	1.10	0.82	0.71
KVx61-1	0.00	0.83	0.17	0.00	0.71	1.15	0.81	0.71
HTR	0.08	0.78	0.13	0.00	0.76	1.13	0.79	0.71
Resistant checks								
B301	0.04	0.83	0.13	0.00	0.74	1.15	0.79	0.71
IT82 D-849	0.07	0.63	0.30	0.00	0.75	1.06	0.88	0.71
58-57	0.00	0.73	0.27	0.00	0.71	1.11	0.87	0.71
Susceptible checks								
KVx396-4-5-2D	0.00	0.72	0.24	0.04	0.71	1.10	0.85	0.74
Moussa local	0.00	0.42	0.52	0.07	0.71	0.95	1.00	0.75
Niaogo local	0.00	0.59	0.26	0.15	0.71	1.05	0.87	0.80
10 most susceptible								
TV286b Profil 12	0.22	0.48	0.20	0.10	0.84	0.98	0.82	0.77
Ife Brown	0.00	0.67	0.23	0.11	0.71	1.08	0.85	0.78
KVx61-1	0.13	0.38	0.38	0.13	0.78	0.93	0.93	0.79
B12 07a	0.00	0.60	0.27	0.13	0.71	1.04	0.86	0.79
Gorom local	0.00	0.73	0.13	0.13	0.71	1.10	0.79	0.79
IT86D-716	0.00	0.52	0.34	0.13	0.71	1.01	0.92	0.79
Komsare	0.00	0.67	0.20	0.13	0.71	1.08	0.83	0.79
Sakoula	0.00	0.73	0.10	0.17	0.71	1.11	0.78	0.82
Diabiga	0.00	0.37	0.37	0.27	0.71	0.93	0.93	0.88
SP155	0.00	0.58	0.10	0.32	0.71	1.04	0.77	0.91
Mean	0.05	0.64	0.26	0.05	0.74	1.06	0.86	0.74
P value					0.40	0.22	0.19	0.00
CV (%)					9.90	11.80	14.00	6.90
LSD (5%)					0.12	0.20	0.20	0.08

[a]: Statistics of parameters transformed using square root (X + 0.5); SR: *Striga* race; CV: coefficient of variation; LSD: Least significant difference; GR: Germination rate; NoFixt: No fixation; NBP: Necrosis before the penetration of cowpea roots by *Striga haustoria*; NAP: Necrosis after the penetration of cowpea roots by *Striga haustoria*, SIV: Successful growth of *Striga* seedling beyond two leaf stage;

4.3.2.2 Race SR Kp

Significant differences (P<0.01) were observed for all the parameters recorded (Table 4.4). The proportion of ‘’No *Striga* fixation’’ varied from 0.00 to 0.37 for the different varieties. The overall mean proportion for *Striga* seedlings that did not attach for all genotypes was 0.10. *Striga* seedlings showing NBP ranged from 0.10 to 0.83 with an overall mean proportion for all the varieties of 0.50. The proportion of *Striga* seedlings that showed NAP varied from 0.33 to 0.73 and the mean proportion for all the genotypes was 0.30. *Striga* seedlings that developed SIV varied from 0.00 to 0.53 with a mean proportion across the genotypes of 0.10.

The highest NPBwas observed for varieties IT81D-994 (83%), KVx402-5-2 (73%) Melakh (67%), whereas varieties Mouride (73%), IT93K-693-2 (67%), IT98K-205-8 (50%) induced high levels of NAP.

Table 4.4 Mean frequencies of *Striga* resistance mechanisms (No Fixation, NBP, NAP, SIV) for cowpea genotypes with *Striga* race SR Kp, Kamboinse 2008.

Variety	NoFixt	NBP	NAP	SIV	[a] NoFixt	[a] NBP	[a] NAP	[a] SIV
15 most resistant								
Mouride	0.07	0.20	0.73	0.00	0.75	0.83	1.11	0.71
IT93K-693-2	0.03	0.30	0.67	0.00	0.73	0.89	1.08	0.71
HTR	0.10	0.29	0.61	0.00	0.78	0.88	1.05	0.71
No 2300-P45	0.10	0.40	0.50	0.00	0.78	0.95	1.00	0.71
IT98K-205-8	0.03	0.47	0.50	0.00	0.73	0.98	1.00	0.71
IT95K-1381	0.03	0.47	0.50	0.00	0.73	0.98	0.99	0.71
Ife Brown	0.07	0.50	0.43	0.00	0.75	0.99	0.96	0.71
Melakh	0.07	0.67	0.27	0.00	0.75	1.08	0.87	0.71
KVx402-5-2	0.03	0.73	0.23	0.00	0.73	1.11	0.85	0.71
IT91D-994	0.00	0.83	0.17	0.00	0.71	1.16	0.82	0.71
SP130 P19	0.03	0.43	0.50	0.03	0.73	0.97	1.00	0.73
KVx 771-10	0.33	0.23	0.40	0.03	0.91	0.85	0.95	0.73
KVx397-6-6	0.03	0.63	0.30	0.03	0.73	1.06	0.89	0.73
KVx61-1	0.03	0.63	0.30	0.03	0.73	1.06	0.89	0.73
No 3076-P22	0.07	0.55	0.31	0.07	0.76	1.02	0.90	0.75
Resistant checks								
58 57	0.00	0.43	0.57	0.00	0.71	0.96	1.03	0.71
B301	0.37	0.23	0.40	0.00	0.92	0.85	0.93	0.71
IT82D-849	0.27	0.53	0.13	0.08	0.87	1.00	0.79	0.76
Susceptible checks								
KVx396-4-5-2D	0.00	0.40	0.37	0.23	0.71	0.94	0.93	0.85
Moussa local	0.10	0.20	0.43	0.27	0.77	0.83	0.95	0.87
Niaogo local	0.03	0.43	0.27	0.27	0.73	0.96	0.88	0.86
10 most susceptible								
TV286b-P12	0.27	0.10	0.40	0.23	0.87	0.78	0.95	0.85
N'Diambour	0.23	0.50	0.03	0.23	0.85	1.00	0.73	0.86
Pouytenga	0.06	0.43	0.25	0.25	0.75	0.96	0.86	0.86
B12 07a	0.08	0.61	0.07	0.24	0.76	1.05	0.75	0.86
KVx65-114	0.07	0.33	0.33	0.27	0.75	0.91	0.91	0.87
Sakoula	0.00	0.41	0.31	0.28	0.71	0.95	0.90	0.88
KVx414-22-2	0.00	0.47	0.17	0.37	0.71	0.98	0.82	0.93
KVx61-1	0.03	0.27	0.33	0.37	0.73	0.87	0.91	0.93
SP155	0.00	0.57	0.03	0.40	0.71	1.03	0.73	0.95
Komsare	0.00	0.33	0.13	0.53	0.71	0.91	0.80	1.02
Mean	0.08	0.46	0.32	0.14	0.76	0.97	0.90	0.79
P value					0.01	0.01	0.00	0.00
CV (%)					0.12	11.00	10.70	9.80
LSD (5%)					9.40	0.17	0.16	0.13

[a]: Statistics of parameters transformed using square root (X + 0.5); SR: *Striga* race; CV: coefficient of variation; LSD: Least significant difference; GR: Germination rate; NoFixt: No fixation; NBP: Necrosis before the penetration of cowpea roots by *Striga haustoria*; NAP: Necrosis after the penetration of cowpea roots by *Striga haustoria*, SIV: Successful growth of *Striga* seedling beyond two leaf stage;

4.3.2.3 Race SR 5

Significant differences (P<0.01) were observed amongst the cowpea genotypes for all the parameters recorded with the exception of NBP (Table 4.5). *Striga* seedlings that did not fix to cowpea rootlets varied from 0.00 to 0.60, with an overall mean proportion for all the varieties of 0.20. The proportion of *Striga* seedlings that showed necrosis after the penetration (NAP) of cowpea rootlets by *Striga* radicles varied from 0.00 to 0.73 and the overall mean proportion across the varieties was 0.20. The *Striga* seedlings that developed up to 2-leaf stage (SIV) ranged from 0.00 to 0.40 with an overall mean proportion of 0.10.

The highest NBP was observed for varieties IT91D-994 (78%), KVx414-22-2 (72%) and KVx61-1 (70%), while varieties IT93K-693-2 (73%), Mouride (57%) and KVx421-2J (50%) resulted in the highest NAP.

Table 4.5 Mean frequencies of *Striga* resistance mechanisms (No fixation, NBP, NAP, SIV), for cowpea genotypes with *Striga* races SR 5, Kamboinse 2008.

Variety	NoFixt	NBP	NAP	SIV	[a] NoFixt	[a] NBP	[a] NAP	[a] SIV
15 most resistant								
IT93K-693-2	0.07	0.20	0.73	0.00	0.75	0.83	1.10	0.71
Mouride	0.07	0.37	0.57	0.00	0.75	0.93	1.03	0.71
KVx421-2J	0.07	0.43	0.50	0.00	0.75	0.96	0.99	0.71
No 3076 P22	0.13	0.53	0.33	0.00	0.80	1.02	0.91	0.71
KV 771-10	0.30	0.37	0.33	0.00	0.89	0.92	0.90	0.71
SANGA-2	0.07	0.63	0.30	0.00	0.75	1.06	0.89	0.71
SP130-P19 b	0.33	0.37	0.30	0.00	0.90	0.92	0.89	0.71
HTR	0.27	0.49	0.24	0.00	0.87	0.99	0.86	0.71
KVx61-1	0.07	0.70	0.22	0.00	0.76	1.09	0.84	0.71
IT91D-994	0.04	0.78	0.18	0.00	0.74	1.13	0.83	0.71
KVx402-5-2	0.30	0.52	0.18	0.00	0.89	1.01	0.82	0.71
KVx414-22-2	0.14	0.72	0.14	0.00	0.80	1.10	0.80	0.71
IT98K-205-8	0.53	0.33	0.14	0.00	1.02	0.91	0.80	0.71
SP155	0.56	0.38	0.07	0.00	1.02	0.92	0.75	0.71
Melakh	0.60	0.40	0.00	0.00	1.05	0.95	0.71	0.71
Resistant checks								
B301	0.20	0.40	0.40	0.00	0.83	0.95	0.94	0.71
58 57	0.17	0.52	0.32	0.00	0.82	1.01	0.90	0.71
IT82 D-849	0.07	0.87	0.07	0.00	0.75	1.17	0.75	0.71
Susceptible checks								
KVx396-4-5-2D	0.17	0.50	0.11	0.22	0.81	1.00	0.78	0.85
Moussa local	0.00	0.57	0.23	0.20	0.71	1.02	0.85	0.83
Niaogo local	0.17	0.50	0.17	0.17	0.82	1.00	0.82	0.81
10 most susceptible								
TV286b P12	0.17	0.50	0.23	0.10	0.82	1.00	0.86	0.77
B12 07a	0.27	0.47	0.17	0.10	0.87	0.98	0.81	0.78
Ife Brown	0.07	0.39	0.41	0.13	0.75	0.94	0.95	0.79
Donsin local	0.21	0.58	0.03	0.18	0.83	1.03	0.73	0.82
Djouroum local	0.11	0.38	0.29	0.22	0.78	0.92	0.87	0.85
N'Diambour	0.00	0.77	0.00	0.23	0.71	1.12	0.71	0.85
Komsare	0.27	0.34	0.10	0.28	0.88	0.92	0.77	0.88
IT95K-1381	0.17	0.43	0.10	0.30	0.81	0.96	0.77	0.89
IT86D-716	0.10	0.27	0.27	0.37	0.78	0.88	0.88	0.93
Diabiga	0.07	0.43	0.10	0.40	0.75	0.97	0.77	0.95
Mean	0.18	0.49	0.24	0.09	0.82	0.99	0.85	0.76
P value					0.00	0.14	0.04	0.00
CV (%)					11.40	12.10	13.70	7.10
LSD (5%)					0.15	0.19	0.19	0.09

[a]: Statistics of parameters transformed using square root (X + 0.5); SR: *Striga* race; CV: coefficient of variation; LSD: Least significant difference; GR: Germination rate; NoFixt: No fixation; NBP: Necrosis before the penetration of cowpea roots by *Striga haustoria*; NAP: Necrosis after the penetration of cowpea roots by *Striga haustoria*, SIV: Successful growth of *Striga* seedling beyond two leaf stage;

4.3.3 Genotype x *Striga* race interactions

Mean squares for the genotypes were highly significant (P<0.01) for all the recorded parameters (Table 4.6). On the other hand, the environments (that is, the *Striga* races) were significant (P<0.01) for all the parameters with the exception of NAP, which was not significant (P>0.05). The mean squares for the genotype x *Striga* race interaction were highly significant (P<0.01) for no fixation only.

Table 4.6 Mean squares of genotype x *Striga* race interaction for *Striga* resistance parameters (No Fixation, NBP, NAP, SIV) ''*in-vitro*'' across three different *Striga* races at Kamboinse (2009).

Source	DF	No fixation	NBP	NAP	SIV
Total	350	0.03	0.07	0.05	0.02
Treatments	116	0.05**	0.10 **	0.07 **	0.04 **
Genotypes (G)	38	0.04**	0.10 **	0.12 **	0.07 **
Striga race (SR)	2	0.57**	1.06 **	0.18 NS	0.24**
Block	6	0.02	0.12	0.08	0.02
Interactions (G x SR)	76	0.04**	0.07 NS	0.05 NS	0.01 NS
Error	228	0.02	0.05	0.04	0.01

DF: Degrees of freedom; NoFixt: No fixation; NBP: Necrosis before the penetration of cowpea roots by *Striga haustoria*; NAP: Necrosis after the penetration of cowpea roots by *Striga haustoria*, SIV: Successful growth of *Striga* seedling beyond two leaf stage;

4.3.4 Correlation studies

The correlation coefficients were highly significant (P<0.01) between successful growth of *Striga* seedling beyond two leaf stage (SIV) ''*in-vitro''* with field yield (r = -0.42) and *Striga* dry biomass (r = 0.40) for race SR 1 (Table 4.7). For race SR 5, there were positive, significant (P<0.001) correlation coefficients between SIV with *Striga* dry biomass (r = 0.51) and *Striga* vigour (r = 0.62). There were no significant (P>0.05) correlation coefficients for SR Kp for SIV with any of the parameters as indicated in Table 4.7.

Table 4.7 Correlations between *''in-vitro'' Striga* resistance parameters, pot and field *Striga* resistance parameters with SR 1.

	SIV *''in-vitro''*		
	SR 1	SR 5	SR Kp
Yield (field) kg ha^{-1}	- 0.42 **	0.19 NS	0.11 NS
Striga density in field (shoots m^{-2})	0.09 NS	0.32 NS	0.23 NS
Striga dry biomass in pot (g)	0.4 0**	0.51 **	0.24 NS
Striga vigour in pot score 1-9	0.28 NS	0.62 **	0.29 NS

(**): analysis of variance significant at P = 0.01; NS: ANOVA not significant at P=0.05; SIV *''in-vitro''* successful growth of *Striga* seedling beyond two leaf stage "*in-vitro*"; SR 1: *Striga* race 1; SR 5: *Striga* race 5; SR Kp: *Striga* race at Koupela.

4.4 Discussion and conclusion

Varieties IT98K-205-8, KVx61-1 and Pouytenga 3 did not induce any *Striga* race SR 1 germination. For SR 5, IT98K-205-8, KVx61-1 and KVx65-114 induced each less than 0.80% of *Striga* seed germination. For SR Kp, though cowpea genotypes induced higher germination *Striga* rates than with SR 1 and SR 5, KVx61-1, KVx421-2J, Pouytenga 3 and IT98K-205-8 were the most tolerant as their mean germination rates were low (2-8%). Lane *et al.* (1991) had found that there were no cowpea genotypes that did not induce *Striga* seed germination. However in our study, cowpea genotypes IT98K-205-8, KVx61-1 and Pouytenga 3 did not induce *Striga* seed germination with SR 1. These same varieties with the exception of Pouytenga 3 showed field resistance as well. It is possible that these varieties are not totally immune. For example, genotype Pouytenga 3 showed a moderate resistance from the results of the field resistance in chapter 3. It could be suggested that the level of inoculum (30 *Striga* seedlings per cowpea genotype) used in this current study was not high enough to identify *Striga* seed germination compared to the high levels found in a field and in pots. Therefore the experiment needs to be confirmed with additional tests.

Some cowpea genotypes consistently demonstrated *Striga* race-specificity and these included Pouytenga 3, KVx65-114 and KVx421-2J. These genotypes were resistant to one *Striga* race only, SR 1, SR 5 and SR Kp respectively. Other genotypes such as IT98K-205-8, and KVx61-1 had broad resistance (SR 1, SR 5 and SR Kp) to *Striga* seed germination. The resistance to *Striga* seed germination in cowpea implied that the varieties had

mechanisms to prevent *Striga* germination, and can therefore be used over time in an integrated strategy to control *S. gesnerioides* in cowpea. Matusova *et al.* (2005) hypothesized that host root exudates are responsible for *Striga* seed germination induction and defined exudates as strigolactones or sesquiterpene lactones. It can therefore be postulated that the resistance to *Striga* seed germination may be due to the inhibition or the low production of such substances by these cowpeas. However, relatively high germination rates were observed for some genotypes such as B301 and IT82D-849 known to be resistant in field or pots as compared to susceptible genotypes. This suggests that the mechanism associated with the field resistance for such genotypes might not be due to *Striga* seed germination. Post-germination mechanisms should play a key role in that resistance to *Striga*.

The optimum distance at which *Striga* seed germination was induced was observed at 20 mm for *Striga* races SR 5 and SR Kp and 25 mm for SR 1. This finding was in agreement with those of Lane *et al.* (1991) and Dube and Olivier (2001) who estimated the distance to vary between 20 and 30 mm. Although the same trend for germination distance from stimulation sources for all three *Striga* races was observed, the mean *Striga* germination rates were low, intermediate and high for SR 1, SR 5 and SR Kp respectively. Low *Striga* germination rates for SR 1 may originate from the high selection pressure that has been applied since the 1980's (Aggarwal and Ouedraogo, 1989) for selecting genetic materials with resistance to SR 1, which is the most prevalent *Striga* race. This could have contributed to the high frequency of the resistance gene to *Striga* seed germination by cowpea for SR 1. However, though *Striga* race SR 5, was reported by Cardwell and Lane (1995), less effort has been made in selecting sources of resistance to this race. Consequently most cowpea genotypes showed increased *Striga* seed germination rates, resulting in the intermediate levels of seed germination observed. On the other hand SR Kp is a relatively new race, reported in 2003 (unpublished data). Subsequently selection has not yet been undertaken for the resistance to SR Kp, therefore resulting in the low frequency of the resistance genes in the materials tested, thus contributing to the high germination in the population of cowpea screened for *Striga* germination rate.

Striga germination rates also increased with increasing distances (5-15 mm) from the stimulation source (Figure 4.4) irrespective of the *Striga* race involved. The trend was similar for races SR 5 and Kp with the germination rate increasing with distance up to 20

mm and decreasing beyond this point. For race SR 1, the germination rate remained almost unchanged between 15 and 20 mm from the stimulation source, followed by a new increase of *Striga* seed germination rate. This result was in contrast with findings reported for other crops. For instance, with sorghum infested with *S. asiatica,* Fate *et al.* (1990) showed that *Striga* germination rates decreased with increasing distances. The same trend was observed by Olupot *et al.* (2003) who used three different germination distances (3, 9 and 15 mm) from *S. asiatica* stimulation source (susceptible sorghum). It is assumed that the concentration of *Striga* seed germination stimulants are higher closer to the *Striga* seeds, which results in high germination rates. However, our results agreed with Olupot *et al.* (2003) findings with cowpea. Though, cowpea was involved as a trap crop with a different *Striga* species in their experiment, they reported that *Striga* seed germination rates were increasing with distance when cowpea was involved as stimulation source (Olupot *et al.*, 2003). The same authors suggested that such ability in cowpea could be due to the presence of factors inhibiting *Striga* seed germination, which are diluted with increasing distances, resulting in a balance more and more favourable to germination stimulants.

Different *Striga* resistance mechanisms were assessed as criteria of resistance to *S. gesnerioides*. On average, regardless of the cowpea genotype involved, the most common mechanism of resistance was due to the necrosis before the penetration (NBP). The NBP of cowpea roots by *Striga* haustoria accounted for 60%, 50% and 50% of the *Striga* resistance mechanisms observed for SR 1, SR 5 and SR Kp, respectively. For the mechanism ‘’No Fixation’’, the average rate of seedling that did not fix to cowpea roots was low for all *Striga* races: SR 1 (5%), SR 5 (8%) and SR Kp (18%).

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Varieties KVx771-10, IT93K-693-2, KVx61-1 and Koakin local exhibited a high level of resistance to SR 1 race through NBP. On the other hand, genotypes Pouytenga 3, IT98K-205-8 and Mouride had a high level of resistance for necrosis after the penetration (NAP) of cowpea roots with SR 1. With *Striga* race SR 5, varieties IT93K-693-2, KVx61-1, Koakin local and Sanga 2 had a high level of resistance through NBP, whilst genotypes Pouytenga 3, and IT98K-205-8 had a high level of resistance through NAP. With SR Kp, varieties IT81D-994, KVx402-5-2 and Melakh had a high level of resistance through NBP, whereas varieties Mouride, IT93K-693-2, and IT98K-205-8 had a high level of resistance through NAP.

The genotype x *Striga* race interaction (G X SR) was highly significant for resistance mechanism ''No Fixation'' only (P<0.001). Since the genotype effects was significant for the same mechanism, it could be inferred that the selection for ''No Fixation'' can be made for the resistance (best performers) in each site in terms of low rates of *Striga* fixations. For NBP, NAP and SIV, though the genotypes effects were highly significant (P<0.001), the G X SR was not signicant (P>0.05). This implies that a selection for broad resistance to *Striga* can be made for best performers for the resistance with regard to the different parameters (that is, high rates for NBP and NAP and low rates for SIV). For all mechanisms, the *Striga* race effects were highly significant irrespective of cowpea genotype, indicating that the Striga race reacted differently, which is supported by the field and pot results.

Negative, but significant correlations were observed for SR 1 between SIV and field yield suggesting that highly susceptible variety reactions ''*in-vitro''* would be expected to have low yield in the field. On the other hand, the same varieties which were highly susceptible *"in-vitro"* would have high *Striga* dry biomass in pot. The *Striga* dry biomass in pots was a more relevant parameter than DS in field trial in explaining the variation observed with SIV *''in-vitro''*. With SR 5, cowpea varieties which had high *Striga* vigour in pots would be the most susceptible varieties *''in-vitro''* as indicated by the positive significant correlation coefficients.

Striga resistance parameters such as SIV can also be used as predictors for pot resistance parameters. For example, for *Striga* race SR 1, the ''*in-vitro'' Striga*-resistant parameter SIV was a good predictor of field yield. Since ''*in-vitro''* screening poses no risk for disseminating *Striga* and results are obtained within a short period, it provides a quick and effective way of screening for *Striga* resistance. However, field evaluation would still be important for evaluation of yield and other agronomic trait.

It can be concluded that:

- genotypes IT98K-205-8, KVx61-1 and Pouytenga 3 did not induced *Striga* seed germinations for SR 1 and induced very low *Striga* germinations for SR 5 and SR Kp;

- genotypes KVx771-10, IT93K-693-2, KVx61-1 and Koakin local (with SR 1 and SR 5) and genotypes IT81D-994, KVx402-5-2 and Melakh (with SR Kp) induced mostly NBP, whilst genotype IT95K-205-8 induced mostly NAP for all three *Striga* races;

- necrosis before the penetration of cowpea roots by *Striga* radicles was the most frequent resistance mechanism for cowpea genotypes;

- *Striga* growth beyond 2-3 leaflet stage was a measurement from which the resistance could be ascertained.

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4.6 Appendices

4.6.1 Composition of the liquid nutrient media

The nutrient solution used) for testing cowpea genotype mechanisms of resistance to *S. gesnerioides* ''*in-vitro''* is equivalent to 0.5% that of Lane *et al.* (1991).

The liquid nutrient media was that of Lane *et al* (1991) modified. The liquid media in its macro-nutrients was adjusted for both cowpea and *Striga* growth to a suitable optimum concentration of 0.5% the nutrient media of Lane *et al.* (1991); the rest was unchanged (0.2 times the stated concentrations of Fe-ETA and the micro-nutrients. These modified media enabled the completion of *Striga* growth beyond 2-3 leaf stage (Figure 4.3) and pod formation in the growth chamber. The composition the adjusted liquid media is shown in appendixes 4.6.2 and 4.6.3.

4.6.2 Macro-element composition and concentration

Chemical formula	Molecular weight	mg l^{-1}	Mother solution (g/100 ml)	Quantity of solution to add per liter of water
$Ca(NO_3)_2$	82	12.306	0.1231	10 ml
KNO_3	50	25.273	0.2527	10 ml
KH_2PO_4	68	6.848	0.0681	10 ml
$MgSO_4$	60	11.43	0.1143	10 ml
Fe-EDTA	-	0.33	0.0033	10 ml

4.6.3 Minor nutrient solution composition and concentrations

Chemical formula	Mg.l^{-1}	Mother solution (mg/100 ml)	Quantity mother solution to take for 1L of water (final solution)
H_3BO_3	$2.85\ 10^{-2}$	$2.85\ 10^{-4}$	1 ml
$CuSO_4\ 5H_2O$	$0.2\ 10^{-2}$	$0.2\ 10^{-4}$	1 ml
KCl	$5.25\ 10^{-2}$	$5.25\ 10^{-4}$	1 ml
$MnSO_4\ 4H_2O$	$4.05\ 10^{-2}$	$4.05\ 10^{-4}$	1 ml
$(NH_4)6Mo_7O_{24}\ 4H_2O$	$0.01\ 10^{-2}$	$0.01\ 10^{-4}$	1 ml
ZnSO4 7H2O	$0.11\ 10^{-2}$	$0.11\ 10^{-4}$	1 ml

CHAPTER FIVE

Combining ability study of *Striga gesnerioides* resistance in cowpea, using *''in-vitro''* and pot screenings

Abstract

Striga gesnerioides is a cowpea root parasite which can cause complete yield loss when susceptible genotypes are used. In Burkina Faso, the existence of different *Striga* races with apparent variable aggressiveness renders the breeding for *Striga* resistance very complex. The objective of the present study was to determine the additive, non-additive gene effects and relationships governing *Striga* resistance in different *Striga* races (SR) affecting Burkina Faso cowpea germplasm. The methodology comprised pot and *"in-vitro"* infestation of F_1 populations derived respectively from a full and a half-diallel cross mating design between ten parents. Griffing's method I model I and Hayman's approach for analyzing data were used. The results showed that, the additive-dominance model was adequate for the characters hundred grain weight screened with SR 1 and SR Kp, grain weight with SR 1, *Striga* emergence dates (DSE) with SR 1 and SR 5 and *Striga* flowering date (SF) with SR 5. Complete dominance effect were operative with cowpea dry biomass (CDB) with SR 5. Overdominance effects prevailed with the parameter hundred grain weight screened with SR 1, whilst partial dominance effects were operative with the rest of the parameters. Genes with dominant and positive effects were present in IT93K-693-2, B301 and KVx771-10, whilst parents KVx396-4-5-2D, Moussa local and Niaogo local had genes with recessive and negative effects for SVIG (SR1), DSE (SR1 and SR 5) SF (SR 5) and SH (SR 1). For parameters hundred grain weight and *Striga* emergence date with SR 5, genes with recessive and negative effects were involved in the *Striga* resistance. However, genes with recessive and positive effects were involved in grain weight (SR 1), hundred grain weight (SR 5 and SR Kp). *Striga* resistance mechanistic studies *"in-vitro"*, indicated that when SR 1 was involved as *Striga* race, genes with additive effects were important for parameters *Striga* germination rate (GR) and, necrosis before (NBP) and after (NAP) the penetration of cowpea roots by *Striga* haustoria. Genes with dominant effects were responsible for the resistance to *Striga* growth (to 2-3 leaf stage (SIV)) with SR 1 and SR Kp, suggesting that backcross breeding, progeny test, and bulk methods were appropriate for improving cowpea for this parameter.

5.1 Introduction

Cowpea (*Vigna unguiculata* (L.) Walp.) is an important food legume and an integral part of traditional cropping systems in the semi-arid regions of the tropics and especially in Burkina Faso. Cowpea grains are consumed as food and the haulms are fed to livestock as nutritious fodder. Cowpea, being the sole crop that provides 50% of protein to most staple food preparations (Marconi *et al.,* 1992), is gradually being regarded as a cash crop in the country (Ouédraogo *et al.,* 1996). However its production is currently hindered greatly by severe occurrence of *Striga* in the areas of high cowpea cultivation. High infestations by *Striga gesnerioides* (Willd.) Vatke can reduce pod grain number and result in yield losses ranging between 70% and 100% (Muleba *et al.,* 1997).

Diagnostic surveys conducted in diverse regions in Burkina Faso (PRONAF 2003) identified the need for improved varieties resistant to *S. gesnerioides*, drought, diseases and insects. In the prioritization of cowpea production constraints, farmers ranked the development of new varieties resistant to *Striga gesnerioides* among the top three priorities. Over the years, research activities have been carried out to develop new cowpea varieties to suit farmer/consumer needs, but the improved variety KVx396-4-5-2D, and the best two landraces, Moussa local, and Gorom local released are susceptible to at least one strain of *Striga.* Recently, the occurrence of site-specific *Striga* races, such as SR Kp in East-Burkina Faso, coupled with persistent drought conditions render *S. gesnerioides* more devastating.

Five *Striga* races were reported in West and Central Africa, and these are races 1, 2, 3 and 5 (Singh, 1997). Of these *Striga* races, 1 and 5 are prevalent in Burkina Faso (Cardwell and Lane 1995). Recently, Gorom local, a variety conferring resistance to *Striga* races 1 and 5 has been observed to induce *Striga* emergence in East-Burkina Faso, suggesting the possible existence of a new race or races.

New *Striga*-resistant varieties, which include KVx771-10 and IT93K-693-2, were identified that confer resistance to three races of *S. gesnerioides* prevailing in Burkina Faso. This coupled with the unknown status of the newly occurring *Striga* race SR Kp render the urgent need to understand the gene action involved in the resistance in order to define an

appropriate breeding strategy. Combining ability studies have not yet been performed for cowpea germplasm with genotypes including material with diverse genetic back-ground such as landraces and cowpea wild relatives. The combining ability studies covered the following: (i) the general combining ability (GCA), which is the average performance of a line in a series of crosses, and (ii) the specific combining ability (SCA), which is the deviation from the performance predicted on the basis of the GCA. Such studies can be useful in determining the appropriate breeding procedure to adopt.

Striga resistance mechanisms were found in cowpea varieties B301 and 58-57 using ‘’*in-vitro*’’ screening (Lane *et al.,* 1991). The resistance mechanism in B301 involved necrosis of *Striga* plants after penetration of the cowpea root cortex (Lane *et al.,* 1991). On the other hand, for variety 58-57, the resistance mechanism involves necrosis before *Striga* can penetrate the cowpea root cortex (Lane *et al.,* 1991). Though *Striga* resistance sources are available, the gene action involved and the genes underlying such resistance mechanisms in most of the cowpea varieties are unknown. This study was therefore aimed at providing a better understanding of the gene action in *Striga* resistance parameters and mechanisms of three *Striga* races prevailing in Burkina Faso, using *Striga*-infested pots and “*in-vitro*” conditions. The specific objectives of the research were to study the general and specific combining abilities of cowpea lines and the adequacy for the additive-dominance model: i) in cowpea resistance to *Striga*, using infested pots and three different inocula of *Striga* races prevailing in Burkina Faso, and ii) for cowpea resistance mechanisms ‘’*in-vitro”*, with the three different *Striga* races that are prevalent in Burkina Faso.

5.2 Material and methods

5.2.1 Cowpea germplasm and *Striga* races

Ten promising cowpea lines IT86D-716, IT81D-994, KVx396-4-5-2D, IT93K-693-2, KVx771-10, B301, KVx745-11P, Moussa local, Niaogo local and No 2300 were selected as parents from the field, pot and ‘’*in-vitro”* screening trials (chapter three and four) for *Striga* resistance. Parents B301, IT93K-693-2, KVx771-10, KVx745-11P and No 2300 were resistant to moderately resistant, while KVx396-4-5-2D, IT86D-716, Moussa and Niaogo local were moderately resistant to highly susceptible to *Striga* (Tables 5.1 and 5.2). *Striga* seeds originated from three different *Striga* hot-spots of Burkina Faso (Table 5.3).

The lines were crossed in a 10 x 10 full diallel mating design in the 2007 off-season (October 2007 to March 2008) in a greenhouse at INERA in the research station of Kamboinse in Burkina Faso. The resulting F_1 hybrids were evaluated in a greenhouse from June to October 2008 in artificially infested pots. *Striga* races originated from three different *Striga* hot-spots of Burkina Faso (Table 5.3). Unlike SR 1 and SR 5, SR Kp had not yet been reported.

Table 5.1 *Striga* vigour for 10 cowpea parents involved in a 10 x 10 diallel cross and screened with three different *Striga* races (SR 1, SR 5 and SR Kp), in pot trials, Kamboinse 2009.

	Race		
Genotype	SR 1	SR Kp	SR 5
B301	I	I	I
IT81D-994	HR	MR	I
IT93K-693-2	I	I	I
KV 771-10	I	I	I
KVx745-11P	HR	HS	HR
No 2300 P45	MR	HR	I
KVx396-4-5-2D	HS	MR	MR
Moussa locaL	MR	VS	S
IT86D-716	S	S	HR
Niaogo local	HS	MS	MS

1: Immune (I); HR: highly resistant; R: resistant; MR: moderately resistant; MS: moderately susceptible; S: susceptible; VS: very susceptible; HS: highly susceptible (HS); 9: Highly susceptible + dead plants; (HS); SR 1: *Striga* race 1; SR 5: *Striga* race 5; SR Kp: *Striga* race Kp.

Table 5.2 *Striga* resistance mechanisms of the parents for parameters % no fixation, frequencies of necrosis for *Striga* seedlings before (NBP) and after (NAP) the penetration and frequency of successfully developed *Striga* seedlings ''*in-vitro*'' (SIV), screened with three different *Striga* races (SR 1, SR 5 and SR Kp) Kamboinse 2009.

	Race SR 1				Race SR 5				Race SR Kp			
Genotype	No fixat.	NBP	NAP	SIV	No fixat.	NBP	NAP	SIV	No fixat.	NBP	NAP	SIV
B301		+++		+++				+++				+++
IT91D-994		+		+++		+++		+++		++	++	+++
IT93K-693-2		+++		+++			++	+++		++	++	+++
KV 771-10		+++		+++				+++				+++
No 2300		+	+	+++			+	+++	+++			++
KVx745-11P		+		+++				+++	+	+++		+++
KVx396-4-5-2D		+++								+	++	
Moussa local		+	+				+	+	+++	+		+
IT86D-716		+				+						
Niaogo local		+				+			+++	+	++	

For NBP and NAP: 41-60%=Resistant (+); 61-1; 80% = Very Resistant (++); 81-100% = Highly Resistant (+++);
For No fixation and SIV: 0-20% = Highly Resistant (+++); 21-40% = Very Resistant (++); 41-60% = Resistant (+).

Table 5.3 *Striga* seed collection area and sources of different races of *Striga gesnerioides* prevailing in Burkina Faso and used as screening inocula.

Striga races	*Striga* seed collect area	Sources
Striga gesnerioides race 1 (SR 1)	Centre of Burkina Faso	(Atokple *et al.,* 1995; Lane *et al.*, 1997)
Striga gesnerioides race 5 (SR 5)	Southern Burkina Faso	(Lane *et al.*, 1997)
Striga gesnerioides race Kp (SR Kp)	Eastern Burkina Faso	Not yet reported (newly discovered)

5.2.2 Evaluation of the F_1 hybrids and parents in *Striga* infested pots

The 90 F_1 hybrids, which included reciprocals, and the 10 parents, were planted in *Striga* infested pots in a greenhouse, in a 10 x 10 lattice square design, with three replications. Three sets of the same experiment were carried out, each infested with 15,000 seeds m^{-2} of a different *Striga* race. Each pot was an experimental unit consisting of a single F_1 plant. Two insecticide sprays against aphids and thrips were applied at flowering and pod formation stages to ensure successful flowering and crosses of the cowpea genotypes. As in the pot screening trials (chapter three), the pot screening for *Striga* resistance was carried out according to the method by Musselman and Ayensu (1983). One thousand *Striga* seeds per pot (equivalent to 15,000 seeds m^{-2}) were used according to recommendations by Musselman and Ayensu (1983). Pots and potting mix (2 sand: 1 clay by volume) were sterilized at over 100^{o}C, using humid heating prior to the screening. After soil infestation with the one year-old *Striga* seeds, the pots were watered to field capacity for three weeks to precondition *Striga* seeds to break their dormancy and ensure optimum germination. The 90 F_1s and parents were planted three weeks after pot inoculation with *Striga* seeds. The pots were kept weed-free through hand-weeding. Half a gram fertilizer comprising 14N: 23P: 14K units were applied per 10 l pot before *Striga* inoculation.

5.2.3 Data collection

The records taken included *Striga* vigour (SVIG), which was assessed using a scale of 1 - 9 classes, where: 1 = immune or presence of *Striga* shoots with height 0.5 cm; 2 = highly resistant (*Striga* shoots emerged above soil level and with *Striga* shoot height 2.1-3 cm); 3 =

resistant (shoots height 3.1-5 cm); 4 = moderately resistant (*Striga* height 5.1-10 cm); 5 = moderately susceptible (flowering *Striga* shoots with height 10.1-15 cm); 6 = susceptible (*Striga* height 15.1-20 cm); 7 = very susceptible (*Striga* height 20.1-25 cm); 8 = highly susceptible (flowering *Striga* shoots with heights > 25 cm and no dead cowpea); and 9 = highly susceptible (shoots with heights > 25 cm and presence of dead cowpea plants). The other records taken were: *Striga* emergence date (DSE), *Striga* flowering date (SF), *Striga* shoot height (SH), cowpea grain weight per pot (CGW), cowpea dry biomass per pot (CDB) and cowpea hundred grain weight per pot (HGW).

5.2.4 "*In-vitro*" assessment of F_1 hybrids for *Striga* resistance mechanisms

An "*in-vitro*" method proposed by Lane *et al.* (1991) and described in section 4.2.3 was adapted and used for screening the F_1 hybrids. The F_1 hybrids were derived from a 10 x 10 half diallel mating design using the same parents indicated in section 5.2.1. The experiment had three replications. Data were recorded every four days after *Striga* and cowpea roots were put in contact and over 24 days. Records were taken on each of the ten individual *Striga* seedlings placed each on different healthy cowpea rootlets of the same plant.

5.2.5 Data collection

Records were taken for the successful germinated *Striga* seed rate (GR), the frequencies of *Striga* radicles developing necrosis before (NBP) and after (NAP) penetrating cowpea root cortex, the frequency for ''*in-vitro*'' successful development of *Striga* seedlings up to 2-3 leaf stage or susceptibility *''in-vitro''* (SIV). Germination rates were calculated based on the ratio of successfully germinated *Striga* seeds over the total number of *Striga* seeds placed close to the cowpea roots. For each replication, the final germination rate was the mean of five disks per cowpea genotype per replication. The frequency or rate for each mechanism of resistance was obtained by the ratio of the number of necrosis for *Striga* seedlings divided by the number of *Striga* radicles used for the infestation. The final frequency or rate for each resistance mechanism was the mean rate from the analysis of variance table.

5.2.6 Data analysis

The analysis of variance was done using Hayman method (Griffing, 1956; Hayman, 1954). The graphical approach of Hayman (1954) was applied to test (i) the adequacy of the ''dominance-additive'' model, (ii) the degree of dominance (prevalence of partial, complete or overdominance), (iii) the direction of the dominance (prevalence of recessive genes over dominant genes). The adequacy of ''dominance-additive'' model was tested from the value of the regression coefficient (b_{Wr}) of regression of the covariance of parents (Wr) on the variance of their off-springs (Vr) (Hayman, 1954).

The Griffing's method for diallel analysis was based on the following model

$X_{ij} = \mu + g_i + g_j + S_{ij}$,

where μ = the general mean; g_i and g_j, = the general combining ability (GCA) effect of the i^{th} and the j^{th} parent, respectively; and S_{ij} = the specific combining ability (SCA) effect of the cross i x j.

The equation for the model proposed by Hayman and Jinks (Hayman, 1954; Jinks and Hayman, 1953) was:

$V_i = \mu + a_i + d_i$ for the parents, and $C_{ij} = \mu + ½(a_i + a_j) + ½(d_i + d_j) + h + h_i + h_j + S_{ij}$ for each F_1 cross,

where: μ = the mean of random inbred for all parents; a_i and a_j = the deviation of homozygous loci in parents i and j; d_i = the deviations of heterozygous loci in parent i and parent j; h = average heterosis in all crosses; h_i = average heterosis contributed by parent i; h_j = average heterosis contributed by parent j; S_{ij} = specific heterosis when parent i is crossed with parent j; and H_{ij} =heterosis = $h + h_i + h_j + S_{ij}$.

To estimate the narrow sense heritability value, the GCA and SCA effects, the statistical programme "Dial" for the analysis of full and half diallel designs was used (Ukai, 1998). The narrow sense heritability (h^2) was calculated by the statistical programme ''Dial'' using the following formula:

$h^2 = A(G+E)^{-1}$, where A is the additive variance; G is the genetic variance and E is the variance of the environment.

The ratio GCA/SCA was calculated to determine the importance of each component in the gene action.

5.3 Results

5.3.1 Combining ability effects for *Striga* resistance parameters using pot experiments

5.3.1.1 Gene action with *Striga* race SR 1

The mean squares of GCA and SCA effects, the effects of the mean dominance (b1), the effects of the dominance due to parent (b2) and the residual dominance (effects of epistasis and failure of assumptions) (b3) are shown in Table 5.4 for all the parameters recorded.

The GCA effects were highly significant (P<0.01) for all the parameters with the exception of *Striga* flowering (SF) date, which was non-significant (P>0.05). On the other hand, the SCA effects were only significant for *Striga* emergence date (DSE), *Striga* height (SH), cowpea grain weight (CGW), cowpea dry biomass (CDB), and hundred grain weight (HGW) (P<0.05). On partitioning of the SCA effects, the mean dominance effects (b1) were only significant (P<0.01) for DSE, SH and HGW. The mean squares for the dominance effects due to parents (b2) were only significant (P<0.01) for SH. The residual dominance effects (b3), that is effects due to epistasis or failure of assumptions were significant (P<0.05) for DSE, CGW, CDBand HGW. For all the parameters, the mean squares for maternal or reciprocal effects were non-significant (P>0.05).

The narrow sense heritability was important for SVIG (39.20%), DSE (53.80%), SH (33.40%) and HGW (52.7%). For the rest of the parameters the heritability was less than 25%. The regression slope b_{Wr} was significant (>0.50) for SVIG (0.54), DSE (0.86), SH (0.91), CGW (0.50) and HGW (0.60). The graphs of the regression of the covariance of parents Wr on off-springs Vr for SVIG, DSE, SH, CGW and HGW are shown in figures 5.1, 5.2, 5.3, 5.4 and 5.5 respectively. The correlation coefficients (r_{Wr}) were significant for the same parameters SVIG (66.90%), DSE (-76.30%), SH (90.90%) and CGW (79.10%). The intercepts (a_{W1r}) of the regression of unit slope (W_1r) were significant (a_{W1r} >0) for SVIG (0.16), DSE (38.57), SH (10.10), CGW (0.38) whilst a_{W1r} was negative for HGW (-0.40).

For SVIG (Figure 5.1), DSE (Figure 5.2), SH (Figure 5.3) genotypes B301, IT93K-693-2 and KVx771-10 were close to the origin of the graph in the regression line Wr on Vr, whilst genotypes Moussa local, Niaogo local, IT86D-716 and KVx396-4-5-2D were mostly at further positions from the origin of the graph.

For CGW (Figure 5.4), genotypes Moussa local and No 2300 were close to the origin of the graph in the regression line Wr on Vr, whilst KVx771-10, B301 and IT81D-994, KVx745-11P and Niaogo local had an intermediate position on the same graph. Genotype KVx396-4-5-2D, IT86D-716 and IT93K-693-2 were at furthest positions from the origin of the graph.

For HGW (Figure 5.5), genotypes B301 and No 2300 were closer to the origin of the graph in the regression line Wr on Vr. Genotypes IT93K-693-2, KVx771-10, B301 and IT81D-994, KVx745-11P, Moussa local and Niaogo local were at an intermediate position on the same graph, whilst genotype KVx396-4-5-2D and IT86D-716 were at furthest positions from the origin of the graph.

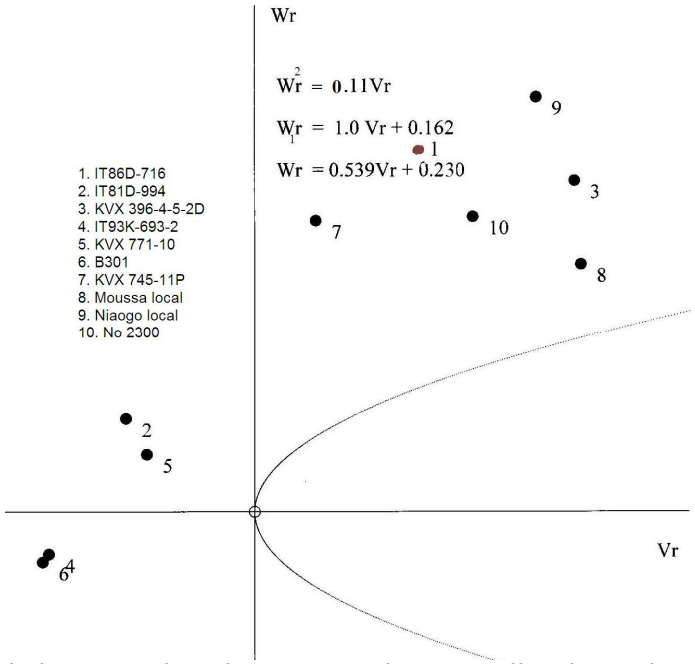

Figure 5.1 Wr/Vr graph the regression of parent covariance on off-spring variance (Wr/Vr) for *Striga* vigour (SVIG) in pots with SR 1 as *Striga* race, 2009.

Table 5.4 Mean squares of *Striga* race SR 1 resistance parameters of a full diallel analysis involving ten parents under *Striga*-infested pots in greenhouse conditions, 2008.

			Mean squares													
Source		DF	SVIG		DSE		SF		SH		CGW		CDB		HGW	
Replication		2	155.00		1909.47		1216.90		170.21		26.81		6283.15		24.52	
a (GCA)		9	16.2	**	38.03.04	**	3702.38	NS	616.93	**	211.85	**	6993.65	**	212.36	**
b (SCA)		9	1.84	NS	376.79	*	2941.96	NS	127.19	*	27.53	**	3447.94	*	25.61	**
	b1	1	0.01	NS	936.33	*	982.83	NS	610.90	**	57.70	NS	340.75	NS	126.13	**
	b2	9	1.56	NS	375.17	NS	746.48	NS	307.91	**	18.55	NS	3647.90	NS	15.02	NS
	b3	35	1.96	NS	361.22	*	3562.49	NS	66.90	NS	28.97	**	3485.30	*	25.47	**
c		9	1.17	NS	357.17	NS	3281.35	NS	45.14	NS	21.13	NS	3215.30	NS	18.35	NS
d		36	2.10	NS	321.11	NS	3056.35	NS	47.84	NS	17.68	NS	1647.97	NS	9.45	NS
Error		198	2.48		231.44		2823.38		86.85		15.54		2020.58		10.35	
Total		299														

a: additive gene effects (or general combining ability (GCA)); b: non additive gene effects (or specific combining ability (SCA)); b1: observed dominance deviation; b2: further dominance deviation due to parents; b3: Residual dominance effects which may be due to epistasis; c: maternal effects; d: reciprocal effects. *: F statistic is significant at p <0.05; **: F statistic is highly significant at p <0.01; NS: F statistic is not significant; DF: degrees of freedom; SVIG: *Striga* vigour (1-9); DSE: *Striga* emergence date (days); SF: *Striga* flowering date (days); SH: *Striga* height (mm). CGW: cowpea grain weight (single F_1 plant); CDB: cowpea dry biomass (g); HGW: cowpea hundred grain weight (g);

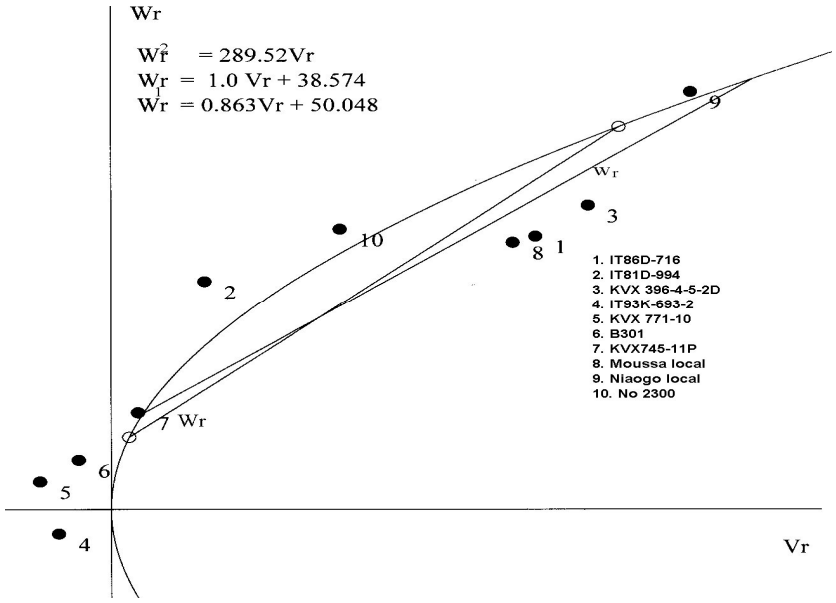

Figure 5.2 Graph of the regression of parent covariance on off-spring variance (Wr/Vr) for *Striga gesnerioides* emergence (days, DSE) screened in pot with SR 1 as *Striga* race, 2009.

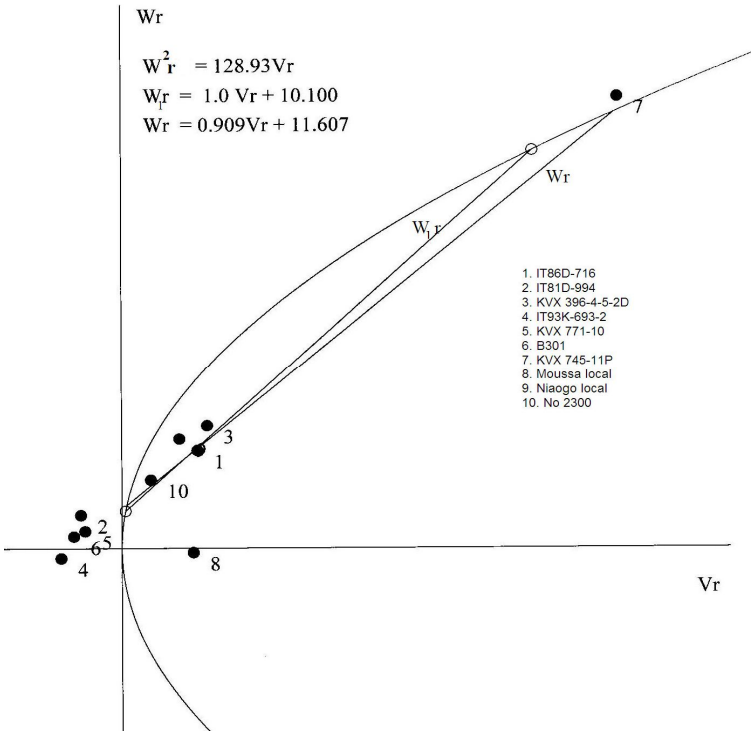

Figure 5.3 Wr/Vr graph the regression of parent covariance on off-spring variance (Wr/Vr) for *Striga* height (cm, SH)) in pots with SR 1 as *Striga* race, 2009.

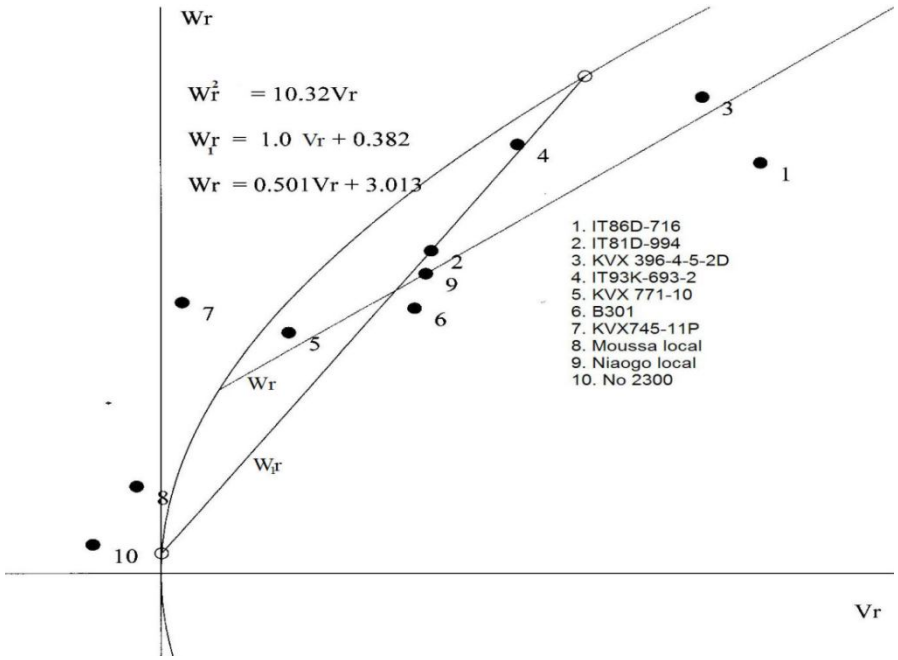

Figure 5.4 Graph of the regression of parent covariance on off-spring variance (Wr/Vr) for cowpea grain weight (g, CGW)) screened in pots with SR 1 as *Striga* race, 2009.

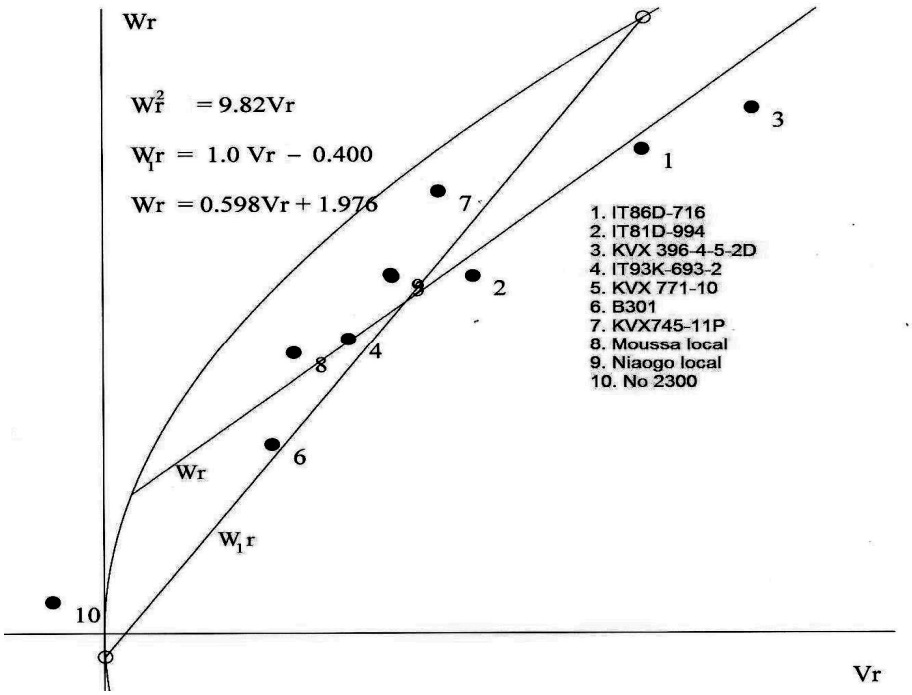

Figure 5.5 Graph of the regression of parent covariance on off-spring variance (Wr/Vr) for hundred grain weight (g, HGW) screened in pots with SR 1 as *Striga* race, 2009.

5.3.1.2 Gene action with *Striga* race SR 5

Mean squares for the effects of GCA and SCA, the mean dominance (b1), the dominance due to parent (b2) and the residual dominance (effects of epistasis and failure of assumptions) (b3) are shown in Table 5.5 for all the parameters recorded.

The GCA effects were highly significant (P<0.01) for all the parameters with the exception of cowpea dry biomass (CDB), which was non-significant (P>0.05). On the other hand, the SCA effects were significant for *Striga* emergence date (DSE, P<0.05), *Striga* flowering date (SF, P<0.01), *Striga* height (SH, P<0.01), and cowpea grain weight (CGW, P<0.01). The SCA effects for *Striga* vigour (SVIG), CDBand HGW were non-significant (P>0.05). On partitioning the SCA effects, the mean dominance effects (b1) was not significant (P>0.05) for all the parameters. However, the mean squares for the dominance effects due to parents (b2) were significant for DSE (P<0.05), SF, SH and CDB (P<0.01) while not significant (P>0.05) for SVIG, CGW and HGW. The residual dominance effects (b3), that is effects due to epistasis or failure of assumptions were significant for DSE (P<0.05), SF, SH, and CGW (P<0.01) and non-significant (P>0.05) for SVIG, CDBand HGW. For all the parameters, the mean squares for maternal or reciprocal effects were non-significant (P>0.05).

The narrow sense heritability was important for SVIG (48.00%), DSE (61.40%), SF (55.40%), SH (62.00%) and HGW (46.20%).

The graphs of the regression of the covariance Wr on the variance of the off-springs Vr for DSE and SF, SH and CDBare represented in Figures 5.6, 5.7, 5.8 and 5.9 respectively. The regression slope b_{Wr} was significant (>0.50) for DSE (0.75), SF (0.91), SH (0.73) and CDB (1.03). The correlation coefficients (r_{Wr}) were important for same parameters DSE (-68.10%), SF (-78.30%), SH (50.90%) and CDB (99.40%). The intercepts (a_{W1r}) of the regression of unit slope (W_1r) were significant (a_{W1r} >0) for DSE (18.78), SF (10.62), SH (41.16) and was almost zero for CDB (0.02).

For DSE (Figure 5.6), SF (Figure 5.7) and SH (Figure 5.8), genotypes IT93K-693-2, KVx771-10 and B301 were nearer to the origin of the graph in the regression line Wr on Vr except for KVx771-10 with SH. Moussa local ranked at an intermediate position on the same graph except for SF (extreme position), whilst Niaogo local ranked further from the origin of the graph. For CDB (Figure 5.9), all genotypes were closer to the origin of the graph Wr on Vr except for genotype KVx745-11P which was furthest from the origin of the graph Wr on Vr.

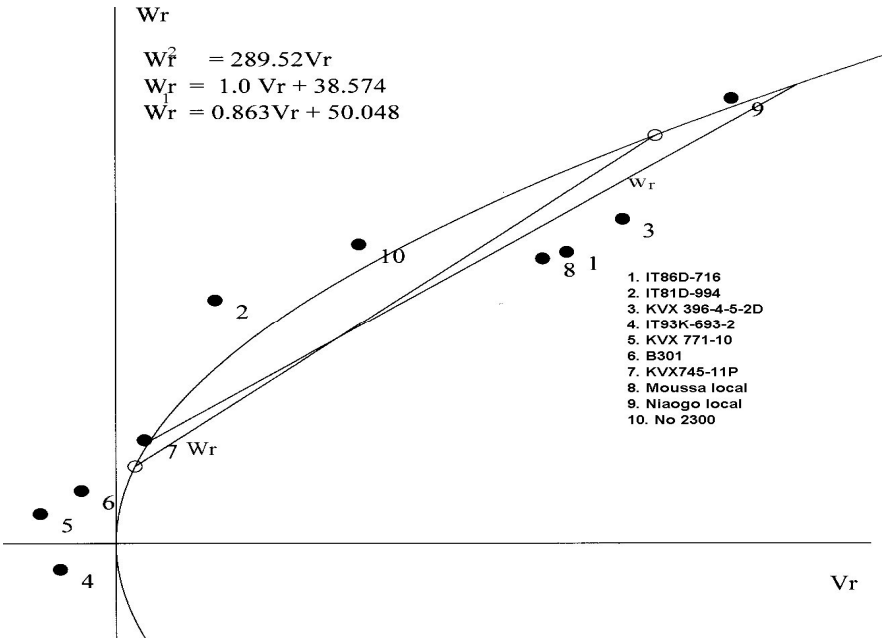

Figure 5.6 Wr/Vr graph the regression of parent covariance on off-spring variance (Wr/Vr) for *Striga gesnerioides* emergence (days, DSE) in pot with SR 5 as *Striga* race, 2009.

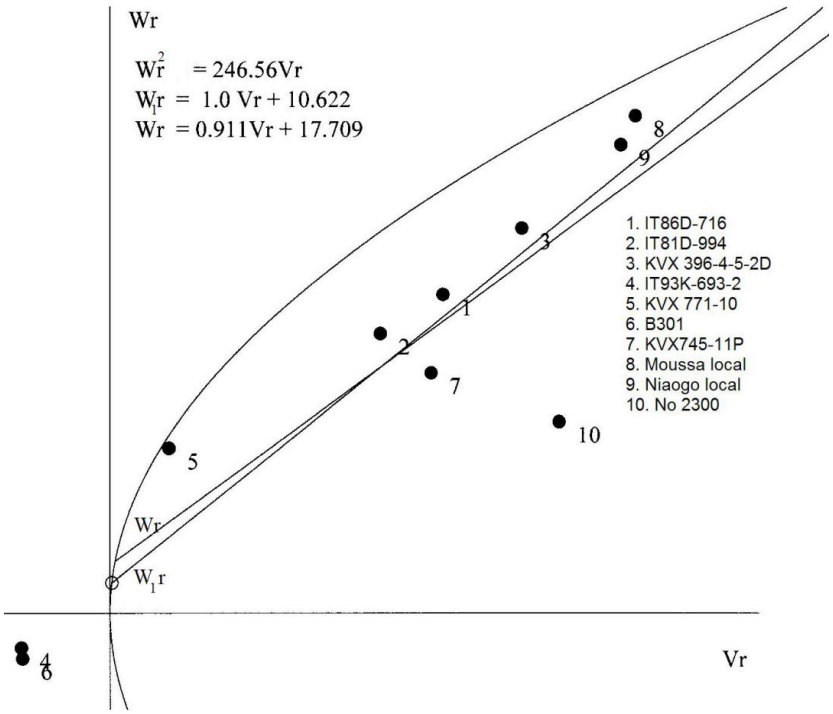

Figure 5.7 Graph of the regression of parent covariance on off-spring variance (Wr/Vr) for *Striga* flowering date (SF) screened in pot with SR 5 as *Striga* race, 2009.

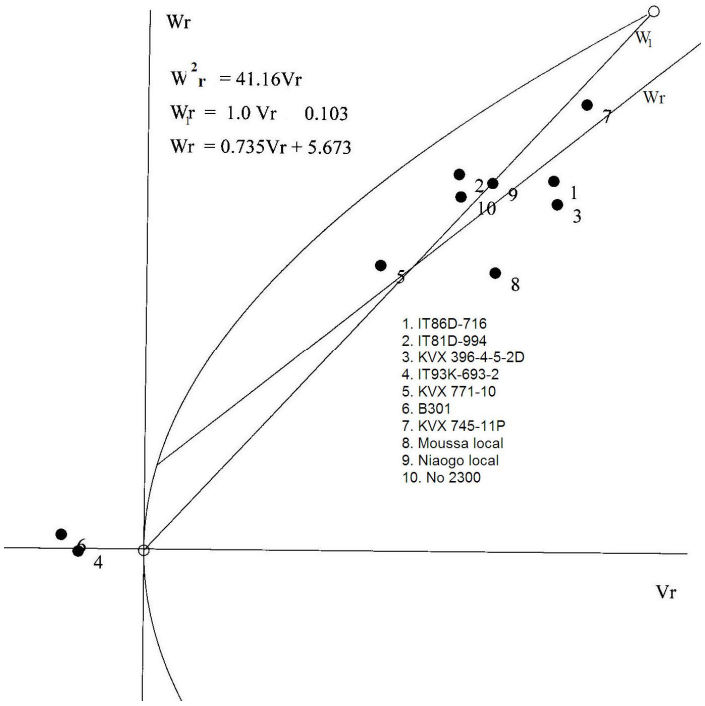

Figure 5.8 Graph of the regression of parent covariance on off-spring variance (Wr/Vr) for *Striga* height (cm, SH) in pots with SR 5 as *Striga* race, 2009.

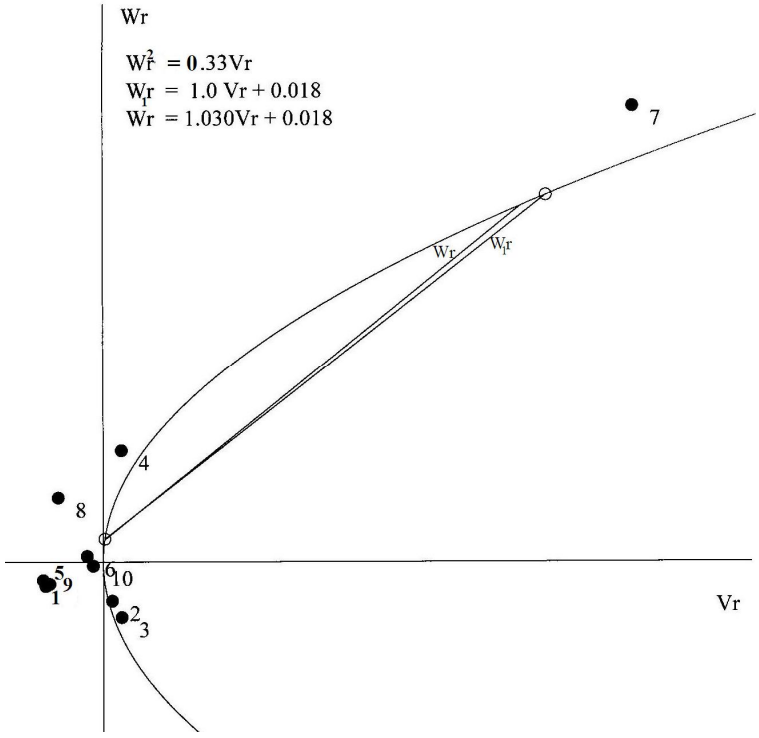

Figure 5.9 Graph of the regression of parent covariance on off-spring variance (Wr/Vr) for cowpea dry biomass (CDB) with SR 5 as *Striga* race, 2009

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Table 5.5 Mean squares of *Striga* race SR 5 resistance parameters of a full diallel analysis involving ten parents under *Striga*-infested pots in greenhouse conditions, 2008.

			Mean squares													
Source		DF	SVIG		DSE		SF		SH		CGW		CDB		HGW	
Replication		2	334.63		2948.54		1234.28		479.01		109.68		154		204.63	
a (GCA)		9	38.93	*	6049.08	**	3165.33	**	966.11	**	136.94	**	0.52	NS	153.87	**
a (SCA)		9	3.95	NS	438.83	*	373.32	**	74.79	**	44.24	**	0.34	NS	17.19	NS
	b1	1	1.47	NS	65.83	NS	13.23	NS	27.91	NS	76.13	NS	0.41	NS	7.51	NS
	b2	9	3.76	NS	561.26	*	545.95	**	104.89	**	24.00	NS	0.94	**	21.34	NS
	b3	35	4.07	NS	418.02	*	339.21	**	68.40	**	48.54	**	0.19	NS	16.41	NS
c		9	1.72	NS	54.96	NS	238.25	NS	18.81	NS	18.56	NS	0.12	NS	8.61	NS
d		36	1.96	NS	306.91	NS	211.60	NS	50.95	NS	9.09	NS	0.18	NS	15.03	NS
Error		198	3.80		280.74		167.87		38.80		22.55		0.32		14.72	
Total		299														

a: additive gene effects (or general combining ability, (GCA)); b: non additive gene effects (or specific combining ability (SCA)); b1: observed dominance deviation; b2: further dominance deviation due to parents; b3: Residual dominance effects which may be due to epistasis; c: maternal effects; d: reciprocal effects. *: F statistic is significant at p <0.05; **: F statistic is highly significant at p <0.01; NS: F statistic is not significant; DF: degrees of freedom; SVIG: *Striga* vigour (1-9); DSE: *Striga* emergence date (days); SF: *Striga* flowering date (days); SH: *Striga* height (mm). CGW: cowpea grain weight (single F_1 plant); CDB: cowpea dry biomass (g); HGW: cowpea hundred grain weight (g); GCA: general combining ability; SCA: specific combining ability.

5.3.1.3 Gene action with *Striga* race SR Kp

Mean squares for the effects of GCA and SCA, the mean dominance (b1), the dominance due to parent (b2) and the residual dominance (effects of epistasis and failure of assumptions) (b3) for the *Striga* race SR Kp are shown in Table 5.6 for all the parameters recorded.

The GCA effects were significant (P<0.01) for *Striga* emergence date (DSE), *Striga* height (SH), cowpea grain weight (CGW), hundred grain weight (HGW) and for *Striga* vigour (SVIG, P<0.05), and non-significant (P>0.05) for *Striga* flowering date (SF) and cowpea hundred grain weight (HGW). On the other hand, the SCA effects were significant only for SH (P<0.01), and CGW (P<0.05). On partitioning the SCA effects, the mean square for dominance (b1) was significant on for HGW (P>0.01), whereas the mean squares for the dominance effects due to parents (b2) were non-significant (P>0.05) for all the parameters. The residual dominance effects (b3), that is effects due to epistasis or failure of assumptions were significant only for SH (P<0.01), and CGW (P<0.05). For all the parameters, the mean squares for maternal or reciprocal effects were non-significant (P>0.05). The narrow sense heritability was important (>33.33%) for SH (40.10%), CGW (57.80%) and HGW (98.00%).

The regression slope b_{Wr} was significant (>0.50) for HGW (0.65) only (Figure 5.10). The correlation coefficient (r_{Wr}) was important for the same parameters HGW (76.40%). The intercept (a_{W1r}) of the regression of unit slope (W_1r) was significant for HGW (0.50). For HGW, KVx745-11P, IT81D-994, Moussa local, Niaogo local and No 2300 were close to the origin of the graph Wr on Vr, whilst IT93K-693-2 and KVx771-10 were furthest on the same graph (Figure 5.10). Genotypes B301, KVx396-4-5-2D and IT86D-716 were at an intermediate position on the same graph.

Table 5.6 Mean squares of *Striga* race Kp resistance parameters of a full diallel analysis involving ten parents under *Striga*-infested pots in greenhouse conditions, 2008.

			Mean squares													
Source		DF	SVIG		DSE		SF		SH		CGW		CDB		HGW	
Replication		2	201.72		6754.2		5296.48		75.37		39.44		305.28		78.01	
a (GCA)		9	3.90	*	16179.08	**	6606.17	NS	372.54	**	255.81	**	276.80	NS	63.02	**
b (SCA)		9	0.79	NS	4249.35	NS	3737.93	NS	62.82	**	22.36	*	273.83	NS	13.83	NS
	b1	1	0.48	NS	4459.59	NS	1932.09	NS	6.45	NS	0,92	NS	40.98	NS	70.13	**
	b2	9	0.48	NS	2062.05	NS	1190.76	NS	48.98	NS	26.16	NS	70.51	NS	5.95	NS
	b3	35	0.87	NS	4805.79	NS	4444.51	NS	67.99	**	22.00	*	332.76	NS	14.25	NS
c		9	0.56	NS	8683.26	NS	3075.83	NS	10.54	NS	5.87	NS	336.27	NS	11.23	NS
d		36	0.63	NS	5549.20	NS	5856.45	NS	42.37	NS	7.98	NS	333.16	NS	10.22	NS
Error		198	1.99		5588.97		4778.47		36.34		13.81		299.00		10.35	
Total		299														

a: additive gene effects or general combining ability (GCA); b: non additive gene effects or specific combining ability (SCA); b1: observed dominance deviation; b2: further dominance deviation due to parents; b3: Residual dominance effects which may be due to epistasis; c: maternal effects; d: reciprocal effects. *: F statistic is significant at p <0.05; **: F statistic is highly significant at p <0.01; NS: F statistic is not significant; DF: degrees of freedom; SVIG: *Striga* vigour (1-9); DSE: *Striga* emergence date (days); SF: *Striga* flowering date (days); SH: *Striga* height (mm). CGW: cowpea grain weight (single F_1 plant); CDB: cowpea dry biomass (g); HGW: cowpea hundred grain weight (g)

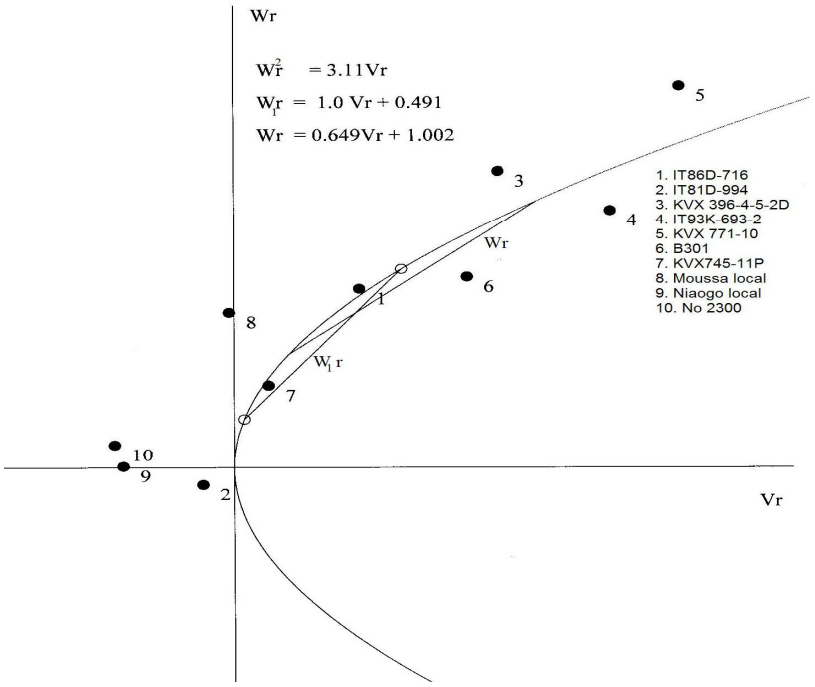

Figure 5.10 Wr/Vr graph of hundred grain weight (g, HGW) screened in pots with SR Kp as *Striga* race, 2009.

5.3.2 Gene action of *Striga* resistance mechanisms *''in-vitro''*

5.3.2.1 *Striga* seed germination rates

Results of the *"in-vitro"* diallel analysis for GR are presented in Table 5.7. The mean squares for the GCA effects for GR were highly significant (P<0.01) for races SR 1 and SR 5 and non-significant for SR Kp. On the other hand, the SCA effects were only significant (P<0.05) for race SR 5. The narrow sense heritability estimates for GR were 32.9%, 1.1%, and 15.3% with races SR 1, SR 5 and SR Kp, respectively. The GCA/SCA ratios involving the three races were 1.00, -0.25 and 0.53 for race SR 1, SR 5 and SR Kp, respectively.

Table.5.7 Mean squares of resistance parameter *Striga* seed germination rate (GR) across three different *Striga* races SR 1, SR 5 and SR Kp and using a half diallel involving ten parents under ‘*in-vitro*’-infested conditions, 2008.

		GR					
Source	DF	SR 1		SR 5		SR Kp	
Replication	2	0.13		0.15		0.06	
GCA	9	0.02	**	0.11	**	0.02	NS
SCA	35	0.01	NS	0.11	*	0.01	NS
Error	88	0.01		0.06		0.01	
Total	134						

DF: Degrees of freedom; GR: *Striga* seed germination rate (frequency); (*) and (**) : the probability is respectively significant at 5% and at both 5% and 1%; NS: the analysis of variance was not significant; SR 1, SR 5 and SR Kp are experiments screened respectively with inoculums of *Striga* race 1, 5 and Kp; GCA: General combining ability; SCA: Specific combining ability.

5.3.2.2 Necrosis before cowpea root cortex penetration by *Striga* radicles

Mean squares for the GCA and SCA effects for NBP for the three races used are presented in Table 5.8. The GCA effects for NBP were significant (P<0.05) only for race SR 1, while the SCA effects for the same race were non-significant (P>0.05). For races SR 5 and SR KP, both the GCA and SCA effects were not significant (P>0.05). The narrow sense heritability estimates for SR 1, SR 5 and SR Kp were 4.40%, 16.8% and 4.40%, respectively. The GCA/SCA ratios were respectively 0.62, 0.49, and 0.35 for SR 1, SR 5 and SR Kp, respectively.

Table 5.8 Mean squares of resistance parameter frequency of necrosis before the penetration of cowpea roots by *Striga* radicles (NBP) across three different *Striga* races SR1, SR 5 and SR Kp, using a half diallel involving ten parents under ‘*in-vitro*’-infested conditions, 2008.

		NBP					
Source	DF	SR 1		SR 5		SR Kp	
Replication	2	0.05		0.48		1.48	
GCA	9	0.02	*	0.05	NS	0.05	NS
SCA	35	0.01	NS	0.02	NS	0.04	NS
Error	88	0.01		0.02		0.06	
Total	134						

DF: Degrees of freedom; NBP: Frequency of necrosis *Striga* before the penetration into cowpea rootlets
(*) and (**) : the probability is respectively significant at 5% and at both 5% and 1%; NS: the analysis of variance was not significant; SR 1, SR 5 and SR Kp are experiments screened respectively with inoculums of *Striga* race 1, 5 and Kp; GCA: General combining ability; SCA: Specific combining ability.

5.3.2.3 Necrosis after cowpea root cortex penetration by *Striga* radicles

For NAP, the GCA effects were highly significant (P<0.01) for races SR 1 and SR Kp (Table 5.9). The mean squares for the GCA effects for SR 5 and the SCA effects for all the three races were not significant (P>0.05). Narrow sense heritability estimates were 16.90%, 2.30% and 20% for races SR 1, SR 5 and SR Kp, respectively. The GCA/SCA ratios for SR 1, SR 5 and SR Kp were 0.60, 0.23 and 0.77, respectively.

Table 5.9 Mean squares of resistance parameter frequency of necrosis after the penetration of cowpea roots by *Striga* radicles (NAP) for three different *Striga* races SR1, SR 5 and SR Kp, using a half diallel involving ten parents under *''in-vitro''*-infested conditions, 2008.

		NAP					
Source	DF	SR 1		SR 5		SR Kp	
Replication	2	1.00		2.00		0.44	
GCA	9	0.18	**	0.04	NS	0.09	**
SCA	35	0.08	NS	0.05	NS	0.03	NS
Error	88	0.06		0.05		0.03	
Total	134						

DF: Degrees of freedom; NAP: Frequency number of necrosis *Striga* after the penetration into cowpea rootlets;
(**) : the probability is respectively significant at 5% NS: the analysis of variance was not significant; SR 1, SR 5 and SR Kp are experiments screened respectively with inoculums of *Striga* race 1, 5 and Kp. GCA: General combining ability; SCA: Specific combining ability; GCA: General combining ability; SCA: Specific combining ability.

5.3.2.4 *''In-vitro''* susceptibility (SIV) or successful growth of *Striga* seedling beyond two leaflets

Results for *'in-vitro''* susceptibility (SIV) or successful growth of *Striga* seedling beyond two leaflets are presented in Table 5.10. Mean squares for the GCA effects were non-significant (P>0.05) for all the three races. The SCA effects, on the other hand, were significant (P<0.05) for races SR 1 and SR Kp and non-significant (P>0.05) for race SR 5.

The narrow sense heritability estimates for races SR 1, SR 5, and SR Kp were 5.9%, 12.3% and 10.60%, respectively. The GCA/SCA ratios were 0.25, 0.44 and 0.27 for race SR 1, SR 5 and SR Kp, respectively.

Table 5.10 Mean squares of resistance parameter frequency of *Striga* growth to 2-3 leaflet stage (SIV) across three different *Striga* races SR1, SR 5 and SR Kp, using a half diallel involving ten parents under ‘*’in-vitro’’*-infested conditions, 2008.

		SIV					
Source	DF	SR 1		SR 5		SR Kp	
Replication	2	0.11		0.21		0.05	
GCA	9	0.06	NS	0.03	NS	0.02	NS
SCA	35	0.06	*	0.02	NS	0.01	*
Error	88	0.03		0.02		0.01	
Total	134						

DF: Degrees of freedom; SIV: frequency of *Striga* growth to 2-3 leaflet stage; (*): the probability is respectively significant at 5% NS: the analysis of variance was not significant; SR 1, SR 5 and SR Kp are experiments screened respectively with inoculums of *Striga* race 1, 5 and Kp; GCA: General combining ability; SCA: Specific combining ability; GCA: General combining ability; SCA: Specific combining ability.

5.4 Discussion and conclusion

The results from this study showed that various types of gene action were involved in pot and ‘*’in-vitro’’* resistance traits and mechanisms respectively. Additive and/or non-additive gene effects were involved.

With pot-screening, the GCA effects were significant for parameters SVIG, DSE, SH, CGW, and HGW for all the three *Striga* races used. The GCA effects were significant for parameters SF and CDBwith SR 5 and SR 1, respectively. This implied that additive gene action was important for these parameters. On the other hand, non-additive gene action as indicated by SCA effects was also observed for some of the parameters. The non-additive gene effects involved either dominance or epistasis and in some instances both were observed for the same parameters. For the characters, in which additive gene effects were operative with no epistasis, progress can be made through the selection of parents in breeding. However, where non-additive gene effects including epistasis were operative, prediction of the breeding outcome would be difficult as non-additive gene effects are not heritable for pure line cultivars. The narrow sense heritability measures the breeding value that is passed on to the progenies. Regardless of the *Striga* race involved in pot trials, the narrow sense heritability was greater than 23%, 40% and 46% for SVIG, SH and HGW respectively. These rates measure the breeding progress that can be expected during selection using the type of protocol employed here.

There were no maternal and reciprocal effects, suggesting that there were no genetic implication in using a parent as male or female when crossing cowpea for these characters. Therefore, seeds of F_1 and reciprocal crosses can be bulked and used in studying these parameters. This also implies that no genes originating from the cytoplasm were involved in the inheritance of the characters studied. These results were in agreement with the findings of Atokple *et al.* (1995) on the interactions of cowpea and *S. gesnerioides*. The gene effects induced in the resistance parameters for the three *Striga* races based on GCA and SCA effects are summarized in Table 5.11.

Table 5.11 Summary of the gene effects induced in the resistance parameters for the three *Striga* races based on GCA and SCA effects

Parameters	SR 1	SR 5	SR Kp
SVIG	Additive	Additive	Additive
DSE	Additive, dominance, epistasis	Additive, dominance, epistasis	Additive
SF	NS	Additive, dominance, epistasis	NS
SH	Additive, dominance	Additive, dominance, epistasis	Additive, epistasis
CGW	Additive, epistasis	Additive, epistasis	Additive, epistasis
CDB	Additive, epistasis	Dominance	NS
HGW	Additive, dominance, epistasis	Additive	Additive, dominance

NS: Analysis of variance not significant

For all parameters, based on the graphical analysis, with a regression of unit slope b_{Wr}>0.50, a regression coefficient of approximately 50.00% or more indicated that the additive model was adequate to describe the data (Jinks and Hayman, 1953; Christie and Shattuck, 1992; Dalbholkar, 1992; Sharma, 1995). Therefore, the additive model was adequate for SVIG, DSE, SH, CGW and HGW for SR1, DSE, SF, SH and CDBfor SR 5 and HGW for SR Kp. This implied that the selection of parents can contribute to the progress in accumulating genes for resistance to *Striga* with regard to these parameters.

Partial dominance was operative with parameters SVIG, DSE, SH, CGW and HGW with SR 1; DSE, SF, SH and CDBwith SR 5; and HGW with SR Kp in that the intercept of the regression line of unit slope W_1r was positive and closer to 1 (Sharma, 1995; Ukai, 1998). Overdominance was found to be operative with parameter HGW with SR1 because the

intercept of the regression of unit slope W_1r was negative. Complete dominance was operative with parameter CDBwith SR 5 in that, the regression line of unit slope W_1r was almost zero. Dominance effects (that is, partial dominance, complete dominance or overdominance) can not be transferred to the progenies and might slow progress in selection. However, such gene action would have been useful in hybrid production. Nonetheless, the self-pollinating nature of cultivated cowpea renders difficult the production of hybrid cowpea. However, with some perennial cowpea wild relatives, the occurrence of high rates of cross pollinations (unpublished data) are new fields for hybrid production in cowpea. A summary of the gene effects induced in the resistance parameters for the three *Striga* races based on the graphical analysis of Jinks and Hayman (1953) is shown in Table 5.12.

Table 5.12 Summary of the gene effects induced in the resistance parameters for the three *Striga* races based on the graphical analysis of regression of the covariance of parents (Wr) and the regression of unit slope (W_1r) on their progenies (Vr).

Parameters	SR 1	SR 5	SR Kp
SVIG	Additive, dominance (PD)	NS	NS
DSE	Additive, dominance (PD)	Additive, dominance (PD)	NS
SF	NS	Additive, dominance (PD)	NS
SH	Additive, dominance (PD)	Additive, dominance (PD)	NS
CGW	Additive, dominance (PD)	NS	NS
CDB	NS	Additive, dominance (CD)	NS
HGW	Additive, dominance (OD)	NS	Additive, dominance (PD)

CD: complete dominance effects; OD: overdominance effects; PD: Partial dominance effects. NS: graphical analysis not significant.

Where genotype coordinates are close to the origin in the graph of the Wr on Vr with significant correlation coefficients, genes with dominant effects are mostly involved (Sharma, 1995; Ukai, 1998). For grain weight (GW) and hundred grain weight (with *Striga* races SR 1 and SR Kp), HGW (with race SR Kp), parents IT81D-994, KVx745-11P and Moussa local had genes with mostly dominant and positive effects. The recessive genes for the same characters prevailed in IT86D-716, KVx396-4-5-2D, IT93K-693-2 and KVx771-10. This shows that in addition to accumulating grain quality, insect and disease resistances

(already present in genotypes IT86D-716, KVx396-4-5-2D) and *Striga* resistance, yield can be improved by using these varieties.

For SVIG, DSE and SH, genotypes B301, IT93K-693-2 and KVx771-10 possessed genes with mostly dominant effects because they were closer to the origin of the graph in the regression of Wr on Vr. With the same parameters, Moussa local, Niaogo local, IT86D-716 and KVx396-4-5-2D had genes with mostly recessive effects since they were at the furthest positions from the origin of the regression of Wr on Vr. These parents also have good grain characteristics, resistance to cowpea aphid-borne mosaic virus, tolerance to insects (landraces Moussa and Niaogo), and could therefore be used to obtain *Striga*-resistant lines, which are adapted to local conditions through pedigree or Backcross breeding. The rest of the parents, KVx745-11P, IT81D-994 and No 2300 would fit in a group with incomplete resistance genes. Such varieties can provide genetic material in breeding for horizontal resistance.

The investigations on *Striga* resistance mechanisms, using the same three *Striga* races revealed that only additive genes were important with *Striga* race SR 1 for parameters GR, NBP. Dominant gene effects were important with parameters SIV for *Striga* races SR 1 and SR Kp. This observation was important, since the parameter SIV reflected more the resistance/susceptibility status *''in-vitro''.* This mechanism can be seen as equivalent to pre-emergence resistance to *Striga* in the soil. Except for parameter GR, NBP and NAP, SIV showed significant effects for GCA. A post-penetration failure of *Striga* growth can be attributed to biochemical processes such as antibiosis. Such mechanisms were observed with cowpea variety B301 (Lane *et al.,* 1994). The same mechanisms were noticed by Hood *et al.* (1998) on *Striga asiatica* with non-host plants and considered as non-host resistance. This was assumed to be durable due to the lack of chemical signals or nutrients produced by the host as a prerequisite for further development of *Striga* (Hood *et al.,* 1998). The parameters NBP and NAP are dependent on the occurrence of GR, whilst NAP is also dependent on NBP. This may result in errors, or cause a failure of the assumption about the independent distribution of genes controlling NBP and NAP among the parents.

In conclusion, the objective of this study was to determine the combining ability effects of Burkina Faso cowpea germplasm for *Striga* resistance, using pot and ‘*'in-vitro''* screening

techniques and three different races of *Striga gesnerioides* prevailing in Burkina Faso. From this study, it was inferred that:

- from the pot screening, regardless of the *Striga* race used, additive genes were predominant in the inheritance of *Striga* resistance with regard to parameters DSE, SH, CGW and HGW. Allelic interactions (complete dominance, partial dominance and overdominance) and non-allelic interactions (epistasis and failure of some assumption) were present with some parameters;

- with SR 1, genes with dominance effects (important SCA effects) were observed for genotypes B301, IT93K-693-2 and KVx771-10 (SVIG, DSE, SH), genotypes Moussa local No 2300 (CGW) and genotypes B301 and 2300 (HGW). Genes with partial dominance effects were involved with genotypes KVx771-10, B301 and IT81D-994, KVx745-11P and Niaogo local (CGW), genotypes IT93K-693-2, KVx771-10, B301 and IT81D-994, KVx745-11P, Moussa local and Niaogo local (HGW). Genes with recessive effects were involved with genotypes Moussa local, Niaogo local, IT86D-716 and KVx396-4-5-2D (SVIG, DSE, SH), genotypes KVx396-4-5-2D, IT86D-716 and IT93K-693-2 (CGW) and genotypes KVx396-4-5-2D, and IT86D-716 (HGW);

- with SR 5, genes with dominance effects (important SCA effects) were involved for genotypes IT93K-693-2 and B301 (DSE, SF and SH), KVx771-10 (DSE and SF) and for all genotypes except KVx745-11P (CDB). Genes with partial dominance effects were involved with genotype Moussa local (DSE, SF and SH), Niaogo local (DSE) genotype. Genes with recessive effects were involved Niaogo local (SF and SH) and KVx745-11P (CDB);

- with SR Kp, genes with dominance effects (important SCA effects) were involved for genotypes KVx745-11P, IT81D-994, Moussa local, Niaogo local and No 2300 (HGW). Genes with partial dominance effects were involved with genotypes B301, KVx396-4-5-2D and IT86D-716 (HGW). Genes with recessive effects were involved for IT93K-693-2 and KVx771-10 (HGW);

- with ‘*’in-vitro’’* screening, the parameters in which additive genes were involved varied according to the *Striga* race involved. Parameters GR (SR 1 and SR Kp), NBP (SR 5),

NAP (SR 1 and SR Kp) and SIV (SR 5 and SR Kp), additive genes were predominant, with high narrow sense heritability values. For these parameters, the selection of parents can contribute to a selection progress;

- additive genes were mostly involved in *Striga* resistance traits and mechanisms. This implies that selection of parents can contribute to accumulating Striga resistance in progenies. Where SCA effects were significant, hybrid production could be profitable by exploiting heterosis, but the self-pollinating nature of cowpea may render this task difficult.

- the comparison of data from Griffing and Hayman methods resulted in the following conclusions: (i) the analysis of variance for a diallel cross using Hayman method gave all information provided by Griffing method in terms of the significance of GCA, SCA and reciprocal effects; however, (ii) the analysis of variance using Hayman method gave additional information which was not provided by Griffing method, such as the maternal effects and the sub-components of the SCA (epistasis, observed dominance effects and the dominance deviation effects due to parents); the graphical analysis provided only by Hayman method was useful in discriminating cowpea genotypes for *Striga* resistance and for the degree of dominance effects.

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CHAPTER SIX

Segregation pattern and allelic relationships of the resistance to *Striga gesnerioides* in new developed cowpea lines

Abstract

Different genes for *Striga* resistance, such as *Rsg 1, Rsg 2, Rsg 3* and *994-Rsg* were reported to confer resistance to *S. gesnerioides* in cowpea. Altogether, genes *Rsg 1* and *Rsg 2* can confer resistance to the five *Striga* races reported in West and Central Africa. For most of these genes, the allelic relationships are known for some *Striga* races, while for others, the allelic relationships are not known. In addition, the occurrence of new races requires that allelic relationships be reconsidered. The objective of the present study was to investigate the segregation patterns of F_2 populations derived from crosses resistant x susceptible (for segregation pattern) and resistant x resistant cowpea genotypes (for allelic relationships) from newly identified *Striga*-resistant genotypes that confer *Striga* resistance to the *Striga* races prevailing in Burkina Faso. In 2007, crosses were made in a greenhouse to generate F_1 populations which were advanced to the F_2 generation. The F_2 populations were planted in artificially *Striga*-infested benches. Three different *Striga* races, SR 1, SR 5 and SR Kp that prevail in Burkina Faso were used as inocula. The results showed that the segregation patterns in F_2 populations involving resistant x susceptible parents were governed by a single dominant gene regardless of the *Striga* race (SR) used. The allelic relationships study showed two types of segregation patterns. In the first group there was no segregation for *Striga* resistance in the F_2 populations implying that allelic or closely linked genes were involved in the *Striga* resistance. In the second type, the F_2 populations of resistant x resistant crosses, segregated into ratios 15 resistant: 1 susceptible for *Striga* resistance, which implied that the resistance genes in the two parents were different. The gene for *Striga* resistance in parental lines IT93K-693-2, and KVx771-10, which showed resistance across all *Striga* races in previous studies, was allelic with B301. This suggested that they possessed the gene *Rsg1* (present in B301), which has been shown to confer resistance to four *Striga* races (1, 2, 3 and 5). Gene *994-Rsg* was not allelic to *Rsg3* though both confer resistance to SR 1 and 5 of Burkina Faso. The resistance gene in the new variety KVx771-10 segregated differently with *Rsg 1, Rsg 2 and Rsg 3,* suggesting that a new gene may be involved in the resistance to *Striga* Therefore, IT93K693-2, and KVx771-10 could be used as donor parents in breeding cowpea for *Striga* resistance in Burkina Faso.

6.1 Introduction

Cowpea (*Vigna unguiculata* (L.) Walp.) is one of the most adapted legume crops in Burkina Faso in arid-areas and therefore a source of food and income (Ouedraogo *et al.,* 1996). At the same time, cowpea has become a source of diversification of crops in the more humid zones, in that it is an important source of proteins (Ehlers *et al.*, 1997), which complements cereal-based diets. However, cowpea production has been compromised by the effect of insects, diseases and weeds, when susceptible genotypes are grown. *Striga gesnerioides* (Willd.) Vatke is one of the cowpea root parasitic weeds that contribute to yield loss and all the methods developed by farmers have proved ineffective in controlling it.

The resistance to *S. gesnerioides* race 1 in cowpea genotype Gorom local (SuVita2) was shown to be singly inherited with the resistance gene being dominant over susceptibility (Agarwal and Ouedraogo, 1989). In other independent studies, Atokple *et al.* (1995) showed that *Striga* resistance in B301, IT82D-849 was governed by a single dominant gene. Fasoula and Fasoula (1997) have shown that segregation ratios of 15 resistant: 1 susceptible meant that two non-allelelic genes were involved. This suggested that iso-epistasis was therefore involved since the genes responsible for the resistance to *Striga* in each of the resistant parents were different, but functionally, they played the same role (Fasoula and Fasoula, 1997). More recently, Omo-Ikerodah *et al.* (2009) reported non-allelic relationships occurring between two cowpea genotypes (TVU 1509 and Sanzi) and both conferring the resistance to flower thrips.

The knowledge of the allelic relationships between sources of resistance should be taken into account for developing more durable *Striga*-resistant genotypes (Dubé and Olivier, 2001). Different genes with dominant effects were involved in the resistance to *S. gesnerioides* in the genotypes B301, IT82D-849 and Gorom local (or Suvita-2), which were named *Rsg1, Rsg2,* and *Rsg3* respectively (Atokple *et al.,* 1995). Gene *Rsg3* was introduced in genotypes KVx61-1 and KVx745-11P using Gorom local as a source of resistance, and conferred resistance to SR 1 of Burkina Faso. Gene *994-Rsg* was found in cowpea genotype IT81D-994 and also conferred resistance to the race SR 1 of *S. gesnerioides* in Burkina Faso (Ouedraogo *et al.,* 2001). Boukar *et al.* (2004) found that IT93K-693-2, though possessing the *Striga* resistance gene *Rsg1* conferred resistance to

all five *Striga* races reported in cowpea. The relationship between *Rsg1, Rsg2,* and *Rsg3* and the resistance present in genotype IT81D-994 is unknown (Ouedraogo *et al.,* 2001).

The classical pedigree breeding method has been effective in breeding characters that are governed by a single or few genes, such as *Striga* specific resistance genes in cowpea (Aggarwal and Ouédraogo, 1989; Muleba *et al.,* 1997). However, the presence of different *Striga* races coupled with the lack of good agronomic characteristics makes it urgent to breed for adapted lines with multiple genes for *Striga* resistance. The objective of this study was to determine the inheritance of newly identified genotypes for *Striga* resistance in F_2 populations of resistant x susceptible and resistant x resistant cowpea genotypes.

The specific objectives of the study were to i) investigate segregation patterns when F_2 populations derived from crosses resistant x susceptible cowpea genotypes are involved, and ii) determine allelic relationships between newly identified and already known sources of resistance to *S*. *gesnerioides*.

6.2 Material and methods

6.2.1 Germpalsm and crosses

Genotypes used in this study were IT93K-693-2 (*Rsg-1*) and B301 (*Rsg-1*), KVx771-10, KVx745-11P and IT81D-994 (resistant), KVx396-4-5-2D, IT86D-716 and Moussa local (susceptible). Besides their reactions to *S. gesnerioides*, the lines were also selected on the basis of farmers' preferred traits whenever possible (big sized, white-coloured and rough texture of grain).

Single crosses to generate resistant x resistant and resistant x susceptible combinations were made in 2007 off-season (October 2007 to March 2008) at INERA at the research station of Kamboinse, Burkina Faso. The resulting F_1 single cross hybrids were self-pollinated to generate F_2s from June to October 2008, and from February to December 2008, the F_2s were planted and assessed in artificially infested benches (Figure 6.1) with three different *Striga* races.

6.2.2 Evaluation of the different F_2 populations

Four, five and three F_2 populations were screened respectively with *Striga* races SR 1, SR 5 and SR Kp. The F_2s were planted in *Striga*-infested benches in a greenhouse. The population size varied from 25 to 41 plants (for the allelic relationships study) and from 22 to 47 plants for the study of the segregation pattern of F_2s derived from crosses between resistant and susceptible genotypes. Each F_2 population was an independent trial. A screening technique proposed by Muleba *et al.* (1997) was used. *Striga* seeds were applied at 10 g m^{-2} on the upper layers of the soil in the benches (Figure 6.1). The benches were 3 m long, 1 m wide and 0.30 m deep. The soil media comprised a mixture of sand and soil (1:1 v/v) previously sterilized at 100^{o}C for 16 h. The method of Atokple *et al.* (1995) was used to classify individual F_2s as resistant or susceptible as follows: at harvest, each cowpea root was pulled out and *Striga* attachments to cowpea roots were assessed. Thus cowpea individuals showing no *Striga* shoots or with minute *Striga* shoots or *Striga* shoots less than 0.5 cm height were considered as being resistant. Cowpea individuals that promoted further development of *Striga* plants were termed as being susceptible. For each F_2 population, plants were classified as resistant or susceptible: at harvest, the F_2 plants were dug from the soil and the roots were washed and examined for the attachment of *Striga* seedlings or shoots. This method was meant to ensure even distribution of *Striga* seeds and uniform infestation and produce heavy *Striga* loads on susceptible genotypes (Figure 6.2).

Figure 6.1 *Striga*-inoculated benches used for screening F_2 populations showing cowpea seedlings two weeks after planting, at Kamboinse in 2009.

Figure 6.2 Susceptible check at harvest showing heavy infestation of matured *Striga* shoots in benches, with race Kp: (Left) infested plants - arrows show *Striga* plants; (Right): *Striga*-free plants at Kamboinse in 2009.

6.2.3 Data analysis

A 15R: 1S Mendelian ratio was tested for allelic relationships among the different sources of resistance. The model was based on the following assumptions:

(i) If two genes A and Bconfer the resistance and each of the homozygous parent carry different resistance genes, then the parents can be AAbb and aaBBrespectively. A cross between them generates F_1 progenies of combinations AaBb which are resistant because of the presence of A and Bgenes.

(ii) Segregation in the F_2 generations gives 9A_B_: 3A_bb : 3aaB_: 1aabb. This is the normal Mendelian ratio. Resistant progenies in this case are expected to be 9A_B_: 3A_bb: 3 aaB_, whilst susceptible progenies are those with aabb, giving a ratio of 15R: 1S.

(iii) If the genes are allelic, then a cross between two resistant individuals would generate all resistant progenies in the F_1 and F_2 generations.

In the inheritance studies, the Mendelian segregation ratio 3 resistant: 1 susceptible for simple gene segregation was also tested in the F_2 populations. The decision to make was to reject the null hypothesis ''H_o'', when the calculated chi-square was greater than the theoretical chi-square and to accept it, when the calculated chi-square was less than the theoretical chi-square. The computer package Genstat version 12.1 (Payne *et al.,* 2009) was used to perform the chi-square test of goodness of fit.

6.3 Results

6.3.1 Inheritance studies

Figure 6.3 shows F_2s, with high infestation levels derived from two susceptible parents (Niaogo local x KVx396-4-5-2D) with few healthy F_2 plants (left) and many susceptible F_2 plants (right) from benches at Kamboinse in 2008.

The F_2 populations of the four crosses involving resistant x susceptible are shown in Table 6.1. The results of the chi-square test for goodness of fit are also presented in Table 6.1. The segregation ratios of all F_2 progenies were 3 resistant: 1 susceptible across all the three *Striga* races used (Chi-square value not significant).

With SR 1 F2 population of crosses KVx396-4-5-2D x IT93K-693-2, IT93K-693-2 x Moussa local (and reverse cross) and B301 x KVx396-4-5-2D segregate into 3 resistant: 1susceptible. With SR 5, F2 population of crosses KVx396-4-5-2D x IT93K-693-2, Moussa local x IT93K-693-2, KVx396-4-5-2D x B301 (and reverse cross), Moussa local x B301 segregate into 3 resistant: 1susceptible. With SR Kp, F2 population of cross KVx396-4-5-2D x IT93K-693-2, IT93K-693-2 x Moussa local (an reverse cross) segregate into 3 resistant: 1susceptible as well.

Figure 6.3 Assessment of *Striga* resistance in F_2s: Susceptible F_2 plants (left) and healthy F_2 plants (right) in benches (arrows show *Striga* plants), at Kamboinse in 2009.

Table 6.1. Segregation ratio of F_2 progenies derived from crosses between *Striga*-resistant and susceptible cowpea genotypes screened with three different *Striga* races.

Striga races	Female	x	Male	Type	Test ratio	Plants nb.	Observed		Expected		χ2 value	χ2
							R	S	R	S		
SR 1	KVx396-4-5-2D	X	IT93K-693-2	S x R	3R: 1S	38	30	8	28.5	9.5	0.32	NS
	IT93K-693-2	X	Moussa local	R x S	3R: 1S	32	20	12	24	8	2.67	NS
	Moussa local	X	IT93K-693-2	S x R	3R: 1S	34	26	8	25.5	8.5	0.04	NS
	B301	X	KVx396-4-5-2D	R x S	3R: 1S	23	21	2	17.25	5.75	3.26	NS
	Pooled data					31.75	24.25	7.50	23.81	7.94	0.03	NS
SR 5	KVx396-4-5-2D	X	IT93K-693-2	S x R	3R: 1S	34	31	3	25.5	8.5	0.19	NS
	Moussa	X	IT93K-693-2	S x R	3R: 1S	25	23	2	18.75	6.25	0.19	NS
	KVx396-4-5-2D	X	B301	S x R	3R: 1S	30	23	7	22.5	7.5	0.40	NS
	B301	X	KVx396-4-5-2D	R x S	3R: 1S	39	32	7	29.25	9.75	0.32	NS
	Moussa local	X	B301	S x R	3R: 1S	27	23	4	20.25	6.75	0.29	NS
	Pooled data					31.00	26.40	4.60	23.25	7.75	1.71	NS
SR Kp	IT93K-693-2	X	KVx396-4-5-2D	R x S	3R: 1S	34	27	7	25.5	8.5	0.35	NS
	IT93K-693-2	X	Moussa local	R x S	3R: 1S	41	31	10	30.8	10.3	0.01	NS
	Moussa local	X	IT93K-693-2	S x R	3R: 1S	36	30	6	27.0	9.0	1.33	NS
	Pooled data					55.5	44	11.5	41.65	13.9	0.55	NS

S: susceptible (emerged and vigourous *Striga* radicles, with height > 1 cm above soil)
R: resistant (no emerged *Striga*, or minus *Striga* with height ≤ 1 cm)
NS: the calculated χ2 is not significantly different from theoretical χ^2: With, DF=1, p (0.05)= 3.84; p(0.01)=6.64.

6.3.2 Allelic relationships

The results of the F_2 progenies from crosses between resistant sources screened at Kamboinse using SR 1, SR 5 and SR Kp are presented in Table 6.2. The results presented are those of F_2 progenies that showed no segregation.

There was no segregation for F_2 progenies for crosses IT93K693-2 x B301 when screened with all the races (SR 1, SR 5 and SR Kp). F_2 populations from the crosses IT93K693-2 x IT82D-849, and IT82D-849 x B301 did not segregate for *Striga* resistance with races SR 1 and SR Kp. Likewise, F_2 progenies from IT93K693-2 x KVx61-1 showed no segregation for *Striga* resistance for races SR 1 and SR 5. The other crosses that did not show segregation for resistance in the F_2 population were IT81D-994 x IT93K693-2 (for SR 1), and IT82D-849 x KVx61-1 (for SR 5).

Table 6.3 shows the F_2 progenies from the crosses involving resistant genotypes that segregated differently for *Striga* resistance. For race SR 1, all the F_2 progenies that showed segregation resulted in a ratio of 15 resistant: 1 susceptible. Segregation was observed for progenies involving the following crosses: KVx61-1 x B301, KVx745-11P x B301, KVx745-11P x IT93K-693-2, IT81D-994 x B301, IT81D-994 x KVx745-11P, KVx771-10 x IT82D-849 and KVx771 10 x KVx61-1

Similarly, the F_2 progenies that segregated for SR 5 and SR Kp all resulted in the ratio 15 resistant: 1 susceptible. For SR 5, the F_2 progenies that segregated were derived from crosses between; KVx61-1 x B301, IT81D-994 x KVx745-11P, KVx771-10 x KVx61-1 and KVx771-10 x IT93K-693-2. Crosses IT93K-693-2 x IT81D-994, KVx61-1 x IT93K-693-2, KVx745-11P x B301 and IT82D-849 x KVx61-1 resulted in segregation of the F_2 progenies for resistance to *Striga* with race SR Kp.

Table 6.2 F_2 progenies showing no segregation from crosses between *Striga*-resistant cowpea genotypes screened with three different *Striga* races, Kamboinse 2009.

	Crosses				Nb. of	Observed	
	Female	x	Male	Type	plants	R	S
SR 1	IT93K-693-2	X	B301	R X R	38	38	0
	B301	X	IT93K-693-2	R X R	28	28	0
	IT93K-693-2	X	KVx61-1	R X R	27	27	0
	KVx61-1	X	IT93K-693-2	R X R	38	38	0
	IT82D-849	X	B301	R X R	41	41	0
	IT93K-693-2	X	IT82D-849	R X R	24	24	0
	IT81D-994	X	IT93K-693-2	R X R	28	28	0
SR 5	IT93K-693-2	X	B301	R X R	60	60	0
	B301	X	IT93K-693-2	R X R	40	40	0
	IT93K-693-2	X	KVx61-1	R X R	32	32	0
	IT82D-849	X	KVx61-1	R X R	51	51	0
SR Kp	IT93K-693-2	X	B301	R X R	38	38	0
	B301	X	IT93K-693-2	R X R	28	28	0
	IT82D-849	X	B301	R X R	41	41	0
	IT93K-693-2	X	IT82D-849	R X R	24	24	0

R: resistant individual; S: Susceptible; Segregation into ratios 15 resistant: 1 susceptible for *Striga* resistance.

Table 6.3 F_2 populations with allelic or closely linked genes (no segregations for different *Striga* resistance genes) in all three *Striga* races (1, 5 and Kp) at Kamboinse , 2008-2009.

Striga	*Striga* resistance genes involved					
races	*Rsg 1*	*Rsg 2*	*Rsg 3*	*994-Rsg*	F_2 crosses	Ratios
1	x				IT93K693-2 x B301	No segreg.
1	x		x		IT93K693-2 x KVx61-1	No segreg.
1	x	x			IT93K693-2 x IT82D-849	No segreg.
1	x			x	IT81D-994 x IT93K693-2	No segreg.
1	x	x			IT82D-849 x B301	No segreg
5	x		x		IT93K693-2 x KVx61-1	No segreg.
5	x	x			IT93K693-2 x IT82D-849	No segreg.
5	x	x			IT82D-849 x B301	No segreg.
Kp	x	x			IT93K693-2 x B301	No segreg.
Kp	x	x			IT93K693-2 x IT82D-849	No segreg.

No segreg. : there was no segregation for *Striga* resistance

Table 6.4 Segregation ratios of F_2 progenies derived from crosses between *Striga*-resistant cowpea genotypes screened with three *Striga* races, Kamboinse 2009.

Striga	Crosses					Number	Observed		Expected			p value
race	Female	x	Male	Type	Test ratio	of plants	R	S	R	S	χ2 value	5%
SR 1	IT81D-994	X	B301	R X R	15R: 1S	20	17	3	18.75	1.25	2.61	0.11 NS
	IT81D-994	X	KVx745-11P	R X R	15R: 1S	45	40	5	42.19	2.81	1.81	0.18 NS
	KVx61-1	X	B301	R X R	15R: 1S	47	44	3	44.06	2.94	0.00	0.97 NS
	KVx745-11P	X	IT93K-693-2	R X R	15R: 1S	22	19	3	20.63	1.38	2.05	0.15 NS
	KVx745-11P	X	B301	R X R	15R: 1S	38	37	1	35.63	2.38	0.85	0.36 NS
	KVx771-10	X	KVx61-1	R X R	15R: 1S	35	31	4	32.81	2.19	1.60	0.21 NS
	KVx771-10	X	IT82D-849	R X R	15R: 1S	22	19	3	20.63	1.38	2.05	0.15 NS
	Pooled data					32.71	29.57	3.14	30.67	2.05	0.62	0.43 NS
SR 5	IT81D-994	X	KV X 745-11P	R X R	15R: 1S	42	38	4	39.38	2.63	0.77	0.37 NS
	KVx61-1	X	KVx771-10	R X R	15R: 1S	22	21	1	20.63	1.38	0.11	0.73 NS
	KVx771-10	X	KVx61-1	R X R	15R: 1S	25	22	3	23.44	1.56	1.41	0.46 NS
	KVx61-1	X	B301	R X R	15R: 1S	49	43	6	45.94	3.06	3.01	0.09 NS
	KVx771-10	X	IT93K-693-2	R X R	15R: 1S	28	25	3	26.25	1.75	0.95	0.46 NS
	Pooled data					33.20	29.80	3.40	31.13	2.08	0.89	0.34 NS
SR Kp	IT81D-994	X	IT93K-693-2	R X R	15R: 1S	46	43	3	43.13	2.88	0.01	0.94 NS
	IT93K-693-2	X	IT81D-994	R X R	15R: 1S	34	31	3	31.88	2.13	0.38	0.54 NS
	IT82D-849	X	KVx61-1	R X R	15R: 1S	32	28	4	30.00	2.00	2.13	0.14 NS
	KVx61-1	X	IT93K-693-2	R X R	15R: 1S	31	28	3	29.06	1.94	0.62	0.43 NS
	Pooled data					35.75	32.50	3.25	33.52	2.24	0.49	0.49 NS

NS: p value (5%) is significant; R: resistant individual; S: susceptible individual

Table 6.5 F_2 populations with non-allelic genes involved in the cross of *Striga*-resistant x *Striga*-resistant (segregations into ratios 15 resistant: 1 susceptible for different *Striga* resistance genes) across three *Striga* races (1, 5 and Kp) at Kamboinse, 2008-2009.

Striga races	*Striga* resistance genes involved				Cross	Ratios
	Rsg 1	*Rsg 2*	*Rsg 3*	*994-Rsg*		
1	x		x		KVx61-1 x B301	15 R: 1S
1	x		x		KVx745-11P x B301	15 R: 1S
1	x		x		KVx745-11P x IT93K-693-2	15 R: 1S
1	x			x	IT81D-994 x B301	15 R: 1S
1			x	x	IT81D-994 x KVx745-11P	15 R: 1S
1	?	?	?	x	KVx771-10 x IT82D-849	15 R: 1S
1	?	?	x	?	KVx771-10 x KVx61-1	15 R: 1S
5	x		x		KVx61-1 x B301	15 R: 1S
5			x	x	IT81D-994 x KVx745-11P	15 R: 1S
5	?	?	x	?	KVx771-10 x KVx61-1	15 R: 1S
5	x	?	?	?	KVx771-10 x IT93K-693-2	15 R: 1S
Kp	x		x		KVx61-1 x IT93K-693-2	15 R: 1S
Kp	x			x	IT93K-693-2 x IT81D-994	15 R: 1S
Kp		x	x		IT82D-849 x KVx61-1	15 R: 1S
Kp			x	x	IT81D-994 x KVx745-11P	15 R: 1S

6.4 Discussion and conclusion

6.4.1 Inheritance of the resistance to *Striga gesnerioides*

Genotype KVx396-4-5-2D which is the most adapted (Tignegre, 2000) and high yielding improved genotype was susceptible to all the three *Striga* races of *S. gesnerioides* that occur in Burkina Faso. Likewise, genotype Moussa local is the most adapted landrace that is preferred by farmers for its grain quality, but it was also susceptible to all the three *Striga* races used in this study. Genotypes IT93K-693-2 and B301 were resistant to all the three races of *S. gesnerioides* used.

According to Boukar *et al.* (2004) genotype IT93K-693-2 has the resistance gene *Rsg1* and conferred resistance to all five *Striga* races reported, including SR 4 of Benin, to which B301, though having *Rsg1* is relatively susceptible. Crosses KVx396-4-5-2D x IT93K-693-2, Moussa local x IT93K-693-2, KVx396-4-5-2D x B301 segregated into ratios 3 resistant: 1 susceptible. This suggested that a single dominant gene governed the resistance to *Striga* in these crosses. These results are in agreement with the findings of Aggarwal and Ouedraogo (1989), Atokple *et al.* (1995) and Ouedraogo *et al.* (2001), who reported that both varieties had *Striga* resistance gene *Rsg1*. Therefore, gene *Rsg1* present in IT93K-

693-2 and B301 was a dominant gene and conferred resistance to all the three *Striga* races (SR 1, SR 5 and SR Kp). Since cowpea is a self-pollinating crop, the presence of a single and dominant gene suggested that pedigree breeding and Backcross breeding could contribute to improving *Striga* resistant genotypes.

6.4.2 Allelic relationships between different sources of resistance to *Striga gesnerioides*

With SR 1, the lack of segregation for different combinations of crosses (Table 6.3) implied that though cowpea genotypes B301, IT82D-849, KVx61-1, IT81D-994 and IT93K-693-2 are functionally different for the *Striga* resistance gene, they are the same in terms of conferring resistance to SR 1. *Striga* resistance genes *Rsg1, Rsg2, Rsg3* and *994-Rsg* were present in genotypes B301, IT82D-849, KVx61-1 and IT81D-994 respectively, which all conferred resistance to SR 1. Gene *Rsg3* was closely linked to the resistance gene *Rsg1* present in IT93K-693-2 as shown by the reaction of the cross IT93K-693-2 x KVx61-1. Gene *Rsg2* was closely linked to the resistance gene *Rsg1* in the cross IT82D-849 x B301. Gene *994-Rsg* was also closely linked to the resistance gene *Rsg1* present in IT93K-693-2 in the cross IT81D-994 x IT93K-693-2. Table 6.3 shows the F_2 populations of *Striga*-resistant x *Striga*-resistant genotypes, with the allelic or closely linked genes involved (no segregations for different *Striga* resistance genes) across three *Striga* races. This confirms the observation by Atokple *et al.* (1995) that when the genes responsible for *Striga* resistance in each of the crosses are allelic or very tightly linked, they do not segregate independently.

Irrespective of the *Striga* race, the F_2 populations from the cross between B301 and IT93K-693-2 (both resistant to all three races) and their reciprocal crosses did not segregate for *Striga* resistance, since both have the same resistance gene *Rsg1*. Except for the brown colour of its grain, genotype IT93K-693-2 has good grain characteristics, compared to B301 which has small, brown and smooth type of grain. It is therefore a new potential parent for improving cowpea for *Striga* resistance and adaptation for Burkina Faso in a Backcrossing breeding programme.

The cross IT82D-849 x B301 did not segregate for resistance to SR 1 and SR Kp, suggesting that gene *Rsg 1* present in B301 and *994-Rsg* present in IT81D-994 are tightly linked and confer the resistance to SR 1 and SR Kp. This result confirmed Atokple *et al.* (1995) findings, in which AFLP markers linked to genes for resistance to SR 1 and SR 3 in genotypes B301 and IT82D-849 were found which mapped to linkage group LG1. The other AFLP markers which are linked to the genes for resistance to SR 1 present in Gorom local and IT81D-994 were mapped to linkage group LG6.

With SR 1, there was segregation of 15 resistant: 1 susceptible in the F2 populations of crosses involving resistant x resistant genotypes: (KVx61-1 x B301), (KVx745-11P x B301), (KVx745-11P x IT93K-693-2), (IT81D-994 x B301), (IT81D-994 x KVx745-11P), (KVx771-10 x IT82D-849), (KVx771-10 x KVx61-1), (KVx61-1 x B301), (IT81D-994 x KVx745-11P), (KVx771-10 x KVx61-1), (KVx771-10 x IT93K-693-2), (KVx61-1 x IT93K-693-2), (IT93K-693-2 x IT81D-994), (IT82D-849 x KVx61-1) and (IT81D-994 x KVx745-11P) (Table 6.5). The segregation suggested that the resistance gene *Rsg3* in KVx745-11P was different from *994-Rsg* present in IT81D-994. The crosses KVx61-1 x B301 and KVx745-11P x B301 segregated into 15 resistant: 1 susceptible implying that gene *Rsg1* in B301 was different from *Rsg3* in KVx61-1

With race SR 5, the F_2 progenies of crosses IT81D-994 x KVx745-11P, KVx61-1 x KVx771-10, KVx61-1 x B301 segregated into ratios 15 resistant: 1 susceptible. This suggests that genes conferring resistance to SR 5 were different for each combination of parents. For the first time 994-*Rsg* in IT81D-994 and *Rsg3* in KVx745-11P segregated differently for the resistance to SR 5. The allelic relationships between *Rsg1* and *Rsg2, Rsg3* and the gene conferring the resistance in IT81D-994 were unknown for SR 5 (Ouedraogo *et al.* 2001). The *Striga* resistance gene *Rsg3* in KVx61-1 was found to be different from *Rsg1* in B301. The results of this work showed that the gene *994-Rsg* in genotype IT81D-994 and *Rsg3* segregated differently for the resistance to SR 5, which means that the two genes were different.

The F_2 populations of crosses KVx771-10 x IT93K-693-2, KVx771-10 x IT82D-849 (SR 1) and KVx771-10 x KVx61-1 (SR 5) segregated into different ratios, suggesting that KVx771-

10 could have a new *Striga*-resistant gene that is different from *Rsg 1, Rsg2* and *Rsg3* (Table 6.5). In addition, the F_2 progenies of cross KVx61-1 x IT82D-849 segregated into 15 resistant: 1 susceptible suggesting that *Rsg3* and *Rsg2* were independent genes. This result confirmed those of Atokple *et al.* (1995) who, through pot screening, found two resistant sources, IT82D-849 and Gorom local which had *Striga* resistance genes *Rsg2* and *Rsg3* respectively. Ouedraogo *et al* (2001), also reached the same conclusions by using molecular markers associated with *Rsg2* and *Rsg3*.

In conclusion, the objective of this investigation was to study the inheritance and allelic relationships of the resistance to the most prevailing races of *S. gesnerioides* of Burkina Faso. The following can be concluded:

- the gene for resistance to *S. gesnerioides* in each of the crosses was singly inherited and dominant in cowpea suggesting that pedigree breeding and backcross breeding would be the appropriate improvement methods to adopt;

- A new source with non-allelic genes for resistance was identified in genotype KVx771-10, providing an opportunity for breeding for durable resistance to *S. gesnerioides*. Genotype KVx771-10 may have a new *Striga*-resistant gene that is different from *Rsg1, Rsg2* and *Rsg3* (Table 6.5). Pyramiding the different *Striga* resistant genes in farmers' preferred varieties can be a way to improve resistance;

- gene *Rsg1* conferred resistance to *Striga* races SR 1, SR 5 and SR Kp. Gene *Rsg2* conferred *Striga* resistance to SR 1, SR 5 and incomplete resistance to SR Kp. Gene *Rsg3* conferred *Striga* resistance to SR 1 and incomplete resistance to races SR 5 and SR Kp. Gene *994-Rsg* conferred *Striga* resistance to SR 1, SR 5 and incomplete resistance to SR Kp;

- genotype KVx771-10 and IT93K-693-2 conferred the resistance to all three *Striga* races and segregated when crossed to B301 (gene *Rsg1*), IT82D-849 (gene *Rsg*2) and KVx61-1 (gene *Rsg3*) implying that the gene for *Striga* resistance in genotype KVx771-10 could be new;

- the study also confirmed that the genes for *Striga* resistance between B301 (*Rsg1*) and IT82D-849 (*Rsg2*) were allelic.

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CHAPTER 7

Overview

7.1 Introduction

This chapter aims at providing an overview of the research findings, the breeding implications of such findings and the associated challenges. The research objectives of this research were to:

· determine the production system, farmers' awareness of *Striga gesnerioides* (Willd.) vatke and their varietal preferences for cowpea cultivars through a participatory rural appraisal (PRA), and a participatory variety selection (PVS),

· identify new adapted sources of resistance to the prevailing races of *S. gesnerioides*, by screening Burkina Faso cowpea germplasm,

· determine the resistance mechanisms involved in such sources of resistance of *S. gesnerioides*,

· study the combining ability of *Striga* resistance genes and the resistance mechanisms, and

· determine inheritance and allelic relationships between genes from genetic materials derived from Burkina Faso germplasm selected for *Striga* resistance.

7.2 Main findings

Specific research investigations were conducted in Burkina Faso from 2006 to 2009 in order to achieve these above objectives. The specific research chapters were supported by a general literature review research which highlighted the following:

- Cowpea (*Vigna unguiculata* (L.) Walp.) is a very important staple in semi-arid areas of West Africa including Burkina Faso, where most cowpea production is undertaken. The production at farmers' level is 300 kg ha^{-1} which is below the potential of 7000 kg ha^{-1} achieved in USA (Ehlers and Hall, 1997).

- *Striga gesnerioides* establishes a parasitic relationship with its host cowpea and therefore competes with the host for nutrients and water, which result in severe yield loss when susceptible genotypes are grown. Five *Striga* races were reported on cowpea in Africa (Singh, 1997) of which *Striga* race 1 (SR 1) and *Striga* race 5 (SR 5) occur in Burkina Faso (Cardwell and Lane 1995). Field and pot methods were used for screening cowpea genotypes for *Striga* resistance. The dissemination of *Striga seeds* to new areas has inspired scientists on the need for alternative and less risky screening methods such as ‘*’in-vitro”* resistance tests (Lane *et al.* 1991). However, this method has never been applied to an extended number of genotypes or for breeding populations such as F_1s. The correlation study between ‘*’in-vitro”* screening, pot and field resistance parameters has not been formally established, which could provide a predictive tool for field or pot trial outcomes.

- In cultivated cowpea, the resistance genes were found to be governed by a single dominant gene (Aggarwal and Ouedraogo, 1989; Atokple *et al.*, 1995), while a suitable combination of the four non-allelic genes (*Rsg1, Rsg2, Rsg3 and 994-Rsg*) together conferred resistance to all five *Striga* races prevailing in Africa. Most cowpea landraces are *Striga*-susceptible and the available resistance sources lacked good agronomic characteristics or grain quality, which suggested that breeding approaches for developing adapted and *Striga*-resistant genotypes of cowpea could include wild relatives, cohabiting with cultivated cowpeas

- The literature review outcomes were used as the basis for elaborating the hypotheses of specific research projects to achieve the above objectives. The breeding priorities for cowpea in *Striga*-prone areas of Burkina Faso were investigated using participatory research methods. Constraints in cowpea production included poor access to fertilizers, agro-chemicals and irrigation, especially for cowpeas. In addition, the decline in rainfall over time coupled with degraded soils and *Striga* damage were reported by the farmers as the major constraints in all three regions.

- At all sites, except in the north of Burkina Faso, farmers’ preferences for cowpea were big sized-grain and white-coloured testa for their own consumption and the market. In

the north of Burkina Faso, farmers preferred cowpea grain with brown-coloured testa for consumption. Cowpea is increasingly becoming a source of income as well.

- Field and pot screening showed a differential reaction of some genotypes such as KVx61-1 and IT82D-849 for *Striga* resistance over the three different sites used and for the three races. Genotypes KVx771-10, IT93K-693-2, KVx775-33-2, Melakh, and IT81D-994 are potential sources of resistance to all three *Striga* races, and have acceptable yield. Improved genotypes KVx396-4-5-2D and IT86D-716 were high yielding, but susceptible to *Striga*. Moussa local was the farmers' preferred variety across all sites but *Striga* susceptible. Most cowpea landraces with farmers' preferred traits were moderately to highly susceptible to *S. gesnerioides* across all sites. Most wild cowpea species, though showing *Striga* resistance, had undesirable shattering characteristics.

- Different cowpea genotypes were identified with different mechanisms of resistance to *Striga.* The reaction of cowpea genotypes varied according to the *Striga* races involved. Varieties KVx61-1, IT98K-205-8 and Pouytenga 3 were found to be resistant by either inhibiting *Striga* seed germination for *Striga* race SR 1 or for inducing low *Striga* seed germination with *Striga* races SR 5 and SR Kp. The optimum distance for *Striga* seed germination from a stimulation source in the soil was approximately 20 mm. Genotypes IT98K-205-8, Pouytenga 3 were very low *Striga* seed germination stimulators for SR 5 and SR Kp and did not stimulate seed germination of race SR 1. Genotypes KVx771-10, IT93K-693- and B301 were resistant to all three *Striga* races and had high abilities for frequency of *Striga* radicle necrosis before (NBP) and after (NAP) it can penetrate cowpea root cortex. Therefore they were proposed as donor parent for *Striga* resistance improvement. *Striga* race Kp could be a new race. The study of the post-germination resistance mechanisms revealed also that parameter *Striga* radicles successfully developed to two leaflet stage (SIV) was consistently correlated to some parameters of *Striga* resistance in field and pot screenings. With SR 1 for instance, the higher the susceptibility ''*in-vitro"*, the lower was the yield under field conditions.

- The methodology proposed by Lane *et al.* (1991) for screening cowpea *''in-vitro''* was simplified and an adapted liquid media for growing both cowpea and *Striga ''in-vitro''* was explored. In general, *Striga* seed germination rate was not influenced by the cowpea genotype resistance status or the *Striga* races involved.

- Further studies focused on understanding the gene action involved in *Striga* resistance mechanisms and traits. A diallel cross was used to investigate the combining ability of *S. gesnerioides* resistance in cowpea, using ‘*'in-vitro''* and pot screenings. Pot trials showed that additive genes were mostly involved in the resistance of parameters *Striga* emergence date (DSE), *Striga* height (SH), cowpea grain weight (CGW), cowpea hundred grain weight (HGW) (for all *Striga* races involved) and *Striga* vigour (SVIG) (for SR 5 and SR Kp). Regardless of the *Striga* race used as inocula, additive genes were predominant in the inheritance of *Striga* resistance with regard to parameters DSE, SH, CGW and HGW. Allelic interactions (complete dominance, partial and overdominance) and non-allelic interactions (epistasis and failure of some assumptions) were operative with some parameters. There were no maternal and reciprocal effects in cowpea for the investigated parameters.

- With ‘*'in-vitro''* screening, the mechanisms in which additive genes were involved varied according to the *Striga* race. For the parameters *Striga* germination rates (GR) (for SR1 and SR Kp), frequency of *Striga* radicles that had necrosis before the penetration of cowpea roots by *Striga* radicles (NBP) (for SR 5), frequency of *Striga* radicles that had necrosis after the penetration of cowpea roots by *Striga* radicles (NAP) (for SR 1 and SR Kp) and frequency of *Striga* radicles that successfully developed to two leaflet stage (SIV) (for SR5 and SR Kp), additive genes were predominant, with high narrow sense heritability values.

- The segregation pattern and allelic relationships for the resistance to *S. gesnerioides* showed that the genes for resistance to *S. gesnerioides* were singly inherited in cowpea and character ‘'resistance'' was dominant over character ‘'susceptible'' for all three *Striga* races.

- The allelic relationships between different resistant sources revealed that a new gene may be involved in the resistance to *S. gesnerioides* in genotype KVx771-10. This gene conferred resistance to all three *Striga* races, including SR Kp. Gene *994-Rsg* in IT81D-994 and *Rsg3* segregated differently for the resistance to SR 5.

7.3 Breeding implications of the findings

There is a need to breed *Striga*-resistant, locally adapted and farmers' preferred varieties to address the presence of different races of the parasitic weed. The low input use calls for a need to improve the farming systems for genotypes adapted to low input conditions. Such approaches should be included in an integrated control programme involving trap cropping, rotation and intercropping.

The development of *Striga*-resistant cultivars for Burkina Faso will require genotypes with adaptation to the major abiotic and biotic constraints and suitability for farmers and the market preferred grain traits. At all sites, farmers' preferences were big sized-grain and white-coloured testa for their own consumption and the market. In Northern Burkina Faso, farmers preferred brown cowpea grain testa for their own consumption. Cowpea production can be improved if farmers have access to more agricultural inputs, particularly improved *Striga*-resistant genotypes, with the preferred grain characteristics, and training facilities.

The selection for *Striga* resistance should consider *Striga* race specificity to propose either site-specific or multiple *Striga* race-resistant genotypes. Genotypes KVx771-10 and IT93K-693-2 were the most *Striga*-resistant genotypes. These genotypes are potential recurrent parents for *Striga* resistance breeding. A research was implemented to study the *Striga* resistance mechanisms in cowpea. This research showed that the resistance mechanism ''*Striga* growth beyond two-leaf stage'' (SIV) can be a reliable predictive criterion for field and pot experiments. It can be recommended for selecting *Striga* resistant genotypes when carrying out pot or field experiments are not possible.

The genetic study covered the combining ability study of *S. gesnerioides* resistance in cowpea, using *''in-vitro''* and pot screenings. With pot-screening, parameters DSE, SH,

CGW, HGW (for all *Striga* races involved), and SVIG (for SR5 and SR Kp), additive genes were mostly involved. With ‘’*in-vitro”* screening for parameters GR (SR1 and SR Kp), NBP (SR 5) NAP (SR 1 and SR Kp) and SIV (SR 5 and SR Kp), additive genes were predominant, with high narrow sense heritability values. For these characters, in which additive gene effects were predominant, the selection of parents can contribute in making progress in terms of improvement.

Genotypes KVx745-11P, IT81D-994 and wild cowpea relative No 2300 fitted in a group with incomplete resistance genes. Such genotypes can provide genetic materials in breeding for horizontal resistance. There were no maternal and reciprocal effects, therefore, seeds of F_1 and reciprocal crosses can be bulked and be used in a half-diallel as it was done in this study for the study of *Striga* resistance mechanisms.

The genetic study also investigated the segregation patterns and the allelic relationships of the resistance to *S. gesnerioides* in F_2 populations. The gene for resistance to *S. gesnerioides* was singly inherited in cowpea suggesting that pedigree breeding and Backcross breeding was the appropriate improvement methods to adopt.

Gene *Rsg1* present in IT93K-693-2 and B301 is a dominant gene and confers resistance to all three *Striga* races. A new gene for *Striga* resistance conferring resistance to all three races could be involved in the resistance to *Striga* with KVx771-10. The incorporation of *Striga*-resistant genes in farmers’ preferred varieties is the most sustainable way to address vulnerability of cowpea to *Striga*.

7.4 Challenges

Though there are good perspectives for improving cowpea, the following points are challenges that need to be addressed:

· Incorporation of farmers’ preferred traits in the breeding objectives (taste, oil absorption by fried pastes, cooking time).

· Existence of several *Striga*-races necessitates the use of gene pyramiding for resistance to all *Striga* races.

· The resistance sources do not have farmers' desired characteristics.

· The restrictions on *Striga* research in the field require that reliable methods applicable to field conditions be developed.

· The costs of most laboratory consumables and small equipment renders it necessary that the protocol for implementing experiments be adapted by using cheaper and available materials to enable their wide use.

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