

GENETIC ANALYSIS OF RESISTANCE OF COWPEA [*Vigna unguiculata* (L.) Walp.]

TO *Alectra vogelii* Benth. IN BURKINA FASO

BY

DIENI ZAKARIA

(10496572)

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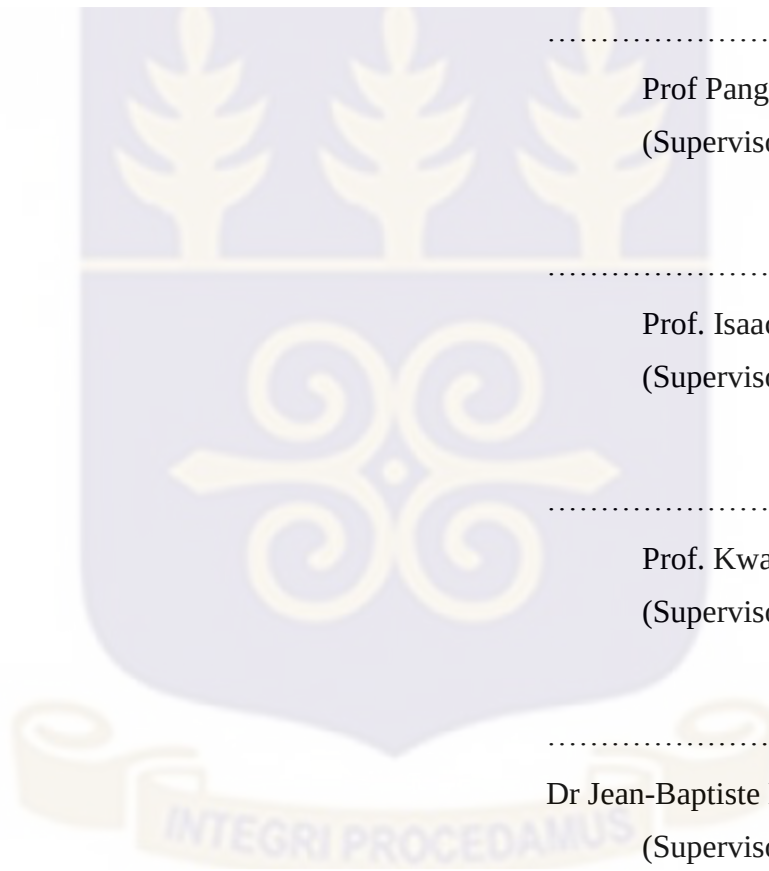
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DECLARATION

I hereby declare that except for references to works of other researchers, which have been duly cited, this work is my original research and that neither part nor whole has been presented elsewhere for the award of a degree.

.....

DIENI Zakaria
(Student)



.....

Prof Pangirayi Tongoona
(Supervisor)

.....

Prof. Isaac K. Asante
(Supervisor)

.....

Prof. Kwadwo Ofori
(Supervisor)

.....

Dr Jean-Baptiste D. L. Tignegre
(Supervisor)

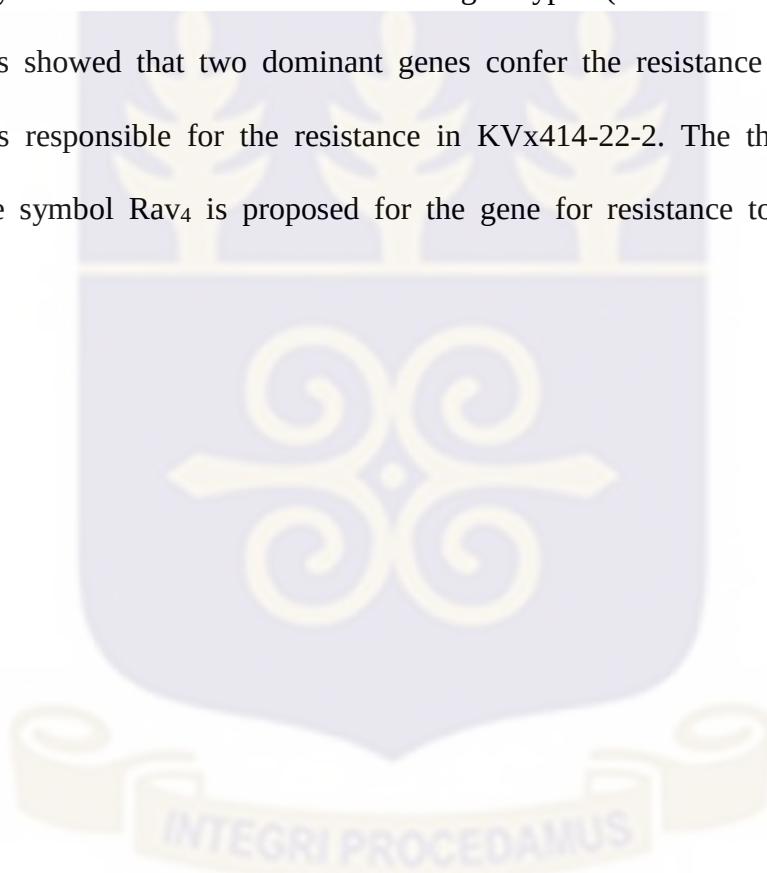
.....

Dr Daniel Dzidzienyo
(Supervisor)

ABSTRACT

Alectra vogelii is a parasitic weed of the *Schrophulariaceae* family causing severe damage to cowpea in Southern, Eastern and Western Africa. Total yield losses occur in heavily infested fields. In Burkina Faso, *A. vogelii* has recently been observed to heavily infest fields causing damage. The objectives of the study were to: (i) identify farmers' varietal preferences and assess their opinion on the parasitic weed *A. vogelii*; (ii) identify sources of resistance to *A. vogelii* in cowpea germplasm from Burkina Faso; (iii) determine gene action involved in cowpea resistance to *A. vogelii* and (iv) determine the genetic inheritance and the allelic relationship of the resistance genes. A participatory rural appraisal (PRA) was conducted in three districts to assess farmers' awareness of the parasitic weed *A. vogelii*, and identify their preferred varietal traits. One hundred and twenty cowpea genotypes from INERA-Kamboinse germplasm were screened in a screen house for their response to three ecotypes of *A. vogelii*. Twenty five genotypes were selected from this list for field assessment. A gene action study was conducted with a 9x9 half diallel cross, the inheritance and the allelic relationship of the resistance genes were studied. The PRA revealed that farmers from western Burkina Faso knew *A. vogelii* as a parasitic weed better than those from eastern Burkina Faso. *A. vogelii* was ranked the third most important biotic constraint to cowpea production after *Striga gesnerioides* and insects. Farmers' preferred traits were large sized grains with rough texture and white colour. Erect and prostrate short cycle cowpea varieties were also preferred varietal types. Varieties B301, Komcalle, IT98K-205-8, IT99K-573-2-1 and K VX414-22-2 showed resistance to all the three ecotypes of *Alectra*; these varieties except B301 also possess farmers' preferred grain qualities. Djouroum local and Pouytenga-9 were the best landraces for *Alectra*-resistance. Significant genotype by environment interaction with differential reactions of cowpea genotypes to *A. vogelii* ecotypes were observed. The combining ability study

showed significant effects of general combining ability (GCA) for days to flowering, days to *Alectra* shoot emergence, 100 seeds weight and severity of *Alectra* damage. Specific combining ability (SCA) was not significant for days to *Alectra* shoot emergence and 100 seeds weight. Additive gene effects were more important for all the traits except days to flowering suggesting that good selection progress can be achieved with proper choice of parents. Non additive gene effects were also involved in the expression of some parameters. The inheritance and allelic relationship study involved two *Alectra* resistant genotypes (B301 and KVx414-22-2). The segregation ratios showed that two dominant genes confer the resistance in B301. A single dominant gene is responsible for the resistance in KVx414-22-2. The three genes were all independent. The symbol Rav_4 is proposed for the gene for resistance to *Alectra vogelii* in KVx414-22-2.



DEDICATION

I dedicate this thesis to: my lovely wife Limata and our son Labado Abdoul Hakim; my father and mother.



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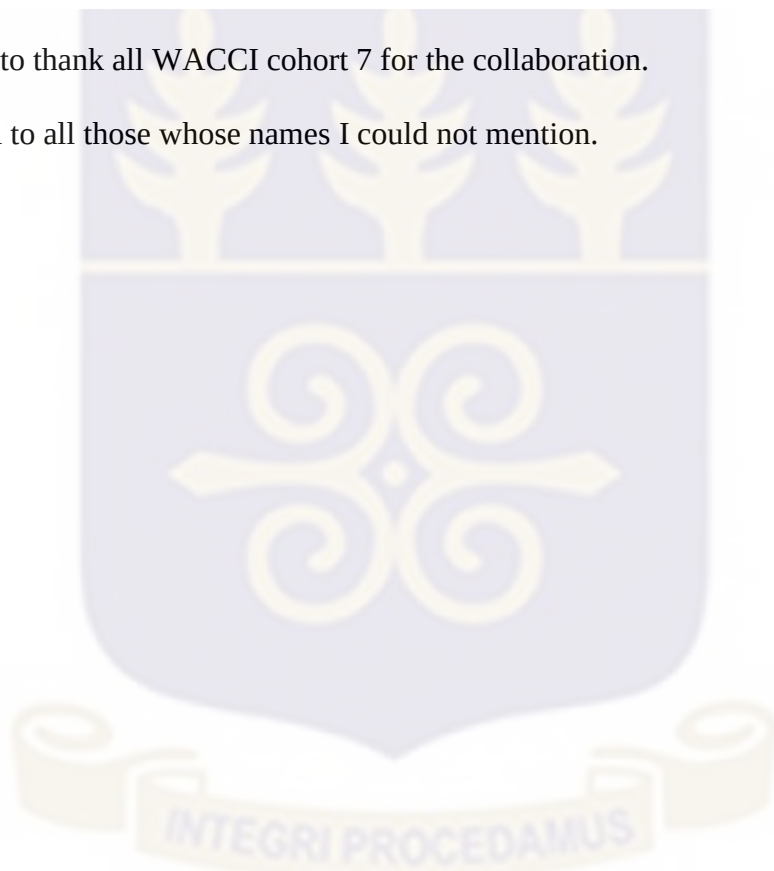


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LIST OF ABBREVIATIONS

AATF: African Agricultural Technology Foundation

ADB: *Alectra* Dry Biomass

AEC: Average Environment Coordinate

AFLP: Amplified Fragment Length Polymorphism

AGRA: Alliance for Green Revolution in Africa

AMMI: Additive Main effects and Multiplicative Interaction

cDNA: complementary Deoxyribonucleic

CREAF-K: Centre de Recherches Environnementales, Agricoles et de Formation de Kamboinse

DAEMG: Days to *Alectra* shoots Emergence

DTF: Days to cowpea first Flowering

DNA: DeoxyriboNucleic Acid

FAO: Food and Agriculture Organization of the United Nations

FGD: Focus Group Discussion

GCA: General Combining Ability

GGE: Genotype and Genotype by environment Interaction

GPS: Générale des Prestations et Services

GY: Grain Yield

HSW: 100 Seed Weight

MET: Multi-environment trials

IITA: International Institute of Tropical Agriculture

INERA: Institut de l'Environnement et de Recherches Agricoles

MAB: Marker-Assisted Breeding

MABC: Marker-Assisted Backcrossing

MAS: Marker-Assisted Selection

MAT: Days to cowpea maturity

PCA: Principal Component Analysis

PRA: Participatory Rural Appraisal

PRONAF: Projet Niébé pour l'Afrique (Project for African Cowpea)

PVS: Participatory Variety Selection

QTL: Quantitative Trait Loci

RAPD: Random Amplified Polymorphism

RFLP: Restricted Fragment Length Polymorphism

SCA: Specific Combining Ability

SNP: Single Nucleotide Polymorphism

SP/CPSA: Secretariat Permanent de la Coordination des Politiques Sectorielles Agricoles

SP-IPM: The Systemwide Program on Integrated Pest Management

SSR: Simple Sequence Repeat

SVP: Singular Value Partitioning

USA: United State of America



CHAPTER ONE

1.0 GENERAL INTRODUCTION

Cowpea (*Vigna unguiculata* (L) Walp.) is a legume crop grown all over the world. It is well adapted to arid and semi-arid zones where most cowpea grain is produced. Cowpea production increases through the years with some fluctuations. A total land area of 123,168,78 hectares (ha) were planted with cowpea in the world with an estimated production of 6,991,174 metric tons in 2016 (FAOSTAT, 2016). Compared to the average production (5,283,894 t) of the last decade, an increase of 8.22% was observed. West African production (5,833,904 t) accounts for about 83% of the world production. However, cowpea average yield is low in the largest production area; where more than 85% of the total land area sown with the crop is found. Nevertheless, cowpea remains one of the most important grain legumes grown in West Africa. The three largest West African countries in cowpea production are Nigeria (3,027,596 t), Niger (1,987,100 t) and Burkina Faso (603,635 t) (FAOSTAT, 2016). Burkina Faso produced nearly 13% of the total West African cowpea production in 2016 (FAOSTAT, 2016).

In Burkina Faso, cowpea is the fourth most important food crop produced after sorghum, pearl millet and maize and the first grain legume crop. It is produced across the three agro-ecological zones found in the country. Cowpea production is more important in the Sahelian, the central east and the northern regions in Burkina Faso. In these areas, cowpea serves both as a food and cash crop. Cowpea average yield in Burkina Faso is less than 500 kg ha⁻¹ (FAOSTAT, 2016) even though it has recently increased with the release of high yielding varieties Tiligre, Nafi, Komcalle and Gourgou in 2012 and Yiisyande and Niizwe in 2013. The yields in Burkina Faso are far lower than the potential that can be more than 4 000 kg ha⁻¹ (Ehlers & Hall, 1997).

Cowpea (*V. unguiculata*) is well appreciated by farmers because of its multiple-uses. It is an important source of protein for small holder farmers. Indeed, cowpea is used for both human and animal consumption (Ehlers & Hall, 1997; Singh *et al.*, 2003; Horn *et al.*, 2015). Cowpea grain protein content is ranged from 24.5% to 33.9% with an average of 28.4% (Nell *et al.*, 1992). Timko and Singh (2008) asserted that for millions of people in the developing countries, cowpea provides an important source of dietary protein that nutritionally complements their staples food made with cereals and tubers. Many dishes are cooked, the grains are directly boiled or processed into flour for couscous, akara, spaghetti, bread and juice productions. Fresh pods and leaves are used as vegetables for human consumption (Ehlers & Hall, 1997). Cowpea also serves as an excellent source of protein for animal feeding. Its haulms are an alternative source of protein to animals in arid areas (Nell *et al.*, 1992; Singh *et al.*, 2003). For this reason, dual purpose (grain and fodder) varieties are preferred by livestock farmers. Substantial income is also generated from cowpea production (Horn *et al.*, 2015). Cowpea grains trade offers a big economic exchange network between west and central African countries. Within this market area, traders' profit margin can reach up to \$22 /t with Kano's Dawanau market in Nigeria being the largest cowpea market in the world (Langyintuo *et al.*, 2003). The Nigerian market constitutes the main potential market for the excess production of Burkina Faso (Soule, 2002; SP/CPSA, 2002; GPS, 2014). A large part (90%) of the total production is self-consumed, mainly in the urban markets (SP/CPSA, 2002; GPS, 2014). Sometimes a kilogram of cowpea can be sold for nearly \$1 in the national market (GPS, 2014). The income generated by cowpea grain trade in Burkina Faso was evaluated at 2.1% of the total revenue of agriculture (31% of GDP) of the country (Dabat *et al.*, 2012).

Cowpea also protects the soil from erosion at the vegetative stage of growth in the field (Kariaga, 2004; Garba & Dalhatu, 2015). Furthermore, cowpea plays an important role in restoring soil

fertility. It is used either in association with cereals or in crop rotation system or both. Through these practices, cowpea provides an important quantity of nitrogen to the other plants and the soil as well thanks to its symbiotic nitrogen fixation ability. Through this association, cowpea can fix up to 88 kg N ha⁻¹ (Bationo *et al.*, 2002).

However, several constraints (abiotic and biotic) limit cowpea production. Drought, low soil fertility, limited access to improved varieties seeds and equipment (plough, cultivator, tractor) constitute some of the most important abiotic constraints to cowpea production in Burkina Faso (Tignegre, 2010; Batieno, 2014). Biotic constraints are also important threats hampering cowpea productivity. From farmers' and breeders' view, insect pests, parasitic weeds and diseases (viral, fungal and bacterial) are responsible for severe damages to the crop (Emechebe & Lagoke, 2002; Tignegre, 2010; Batieno, 2014).

Parasitic weeds of the family of *Schrophulariaceae* are widely known biotic constraints in grain legumes production. In this family, *Striga gesnerioides* and *Alectra vogelii* are both noxious witch weeds to several grain legume crops in the semi-arid and arid zones. Groundnut (*Arachis hypogaea*), soybean (*Glycine max*) and cowpea (*Vigna unguiculata*) are some of the most preferred hosts. *Striga* and *Alectra* parasitize their hosts in low soil fertility conditions leading to significant yield losses. Generally up to 75% of the damages due to these weeds occurs during the underground phase (Timko & Singh, 2008). In heavily infested fields, severe damage is registered Singh & Emechebe (1991). Thus, complete yield losses in cowpea production have often been reported (Karanja *et al.*, 2013; Teka, 2014). In these situations, the entire field can be abandoned (Emechebe *et al.*, 2004). Besides yield loss, the infestation of the host plant by *Striga* and *Alectra* results in a general decrease of the concentration of mineral elements in its grain (Alonge & Alabi, 2009).

In Burkina Faso, for several years, investigations on cowpea parasitic weeds were focused on *Striga gesnerioides*. Therefore, scientific information is available from the identification of sources of resistance to the use of molecular markers in the selection process including the inheritance pattern and the mechanism of resistance (Muleba *et al.*, 1997; Ouédraogo *et al.*, 2002; Tignegre, 2010; Tignegre *et al.*, 2013; Salifou *et al.*, 2016). In contrast, few studies have been carried out on the parasitism of *Alectra* on cowpea. In fact, up to now *Alectra vogelii* was considered as a minor threat in cowpea and the other legumes production in Burkina Faso. It was first reported by Subrahmanyam *et al.* (1989) but its economic importance has been neglected (Subrahmanyam *et al.*, 1989; Sankara, 1997). In addition, Singh *et al.* (2002) and Singh *et al.* (2003) reported that *Alectra vogelii* prevails more in the Northern Guinea savannah, the Eastern and Southern Africa while *Striga gesnerioides* is widespread in West and Central Africa. Therefore, focus was placed only on *Striga* control in West African countries. But in recent years, cowpea and groundnut fields are being heavily parasitized by *Alectra* in Burkina Faso in all the three agro-ecological zones. This can be explained by the wide-spreading ability of *Alectra*. Visser (1978) reported that a single plant of *A. vogelii* has a potential of producing between 400 000 and 600 000 viable seeds. The seeds can stay viable in the soil for 15 years. This seed bank in the soil obviously increases when susceptible varieties are cultivated in a field over years. The over exploitation of arable lands render them poor for efficient agriculture. Furthermore the damages caused by *A. vogelii* increase with poor nutrient status of soils (Kwaga *et al.*, 2010). Therefore, in poor heavily infested fields, drastic losses occur. Total yield losses due to *A. vogelii* have also been reported in Botswana, Kenya, Malawi, Nigeria, Tanzania and Zimbabwe (Kureh & Alabi, 2003; Omoigui *et al.*, 2012; Karanja *et al.*, 2013).

Alectra vogelii is undoubtedly an economically important parasitic weed in cowpea production. Therefore, it is necessary to investigate the implications of *Alectra* in cowpea production in Burkina Faso. Unlike *Striga*, *Alectra* is a leafy plant which looks like an ordinary weed. So it may not be known as a parasitic weed by most farmers and/or extension officers. This was the case in Malawi in 2013 when a study was carried out by Kabambe *et al.* (2013). This study pointed out that only 36% of the extension officers knew *Alectra* against 91% for *Striga asiatica*. This ignorance of the parasitic effect of *Alectra* may also be probably happening in Burkina Faso. Therefore, there is a need to determine how far farmers are familiar with the weed through Participatory Rural Appraisal (PRA). Beyond their awareness of this parasitic weed, it is also very important to assess farmers' preferred traits to be incorporated into a new variety conferring resistance to *Alectra vogelii*, otherwise it is a waste of time and resources if farmers reject the end product (Tignegre, 2010).

Having knowledge about a threat is a prerequisite for preventing or controlling it. Most of the control measures proposed (cultural practices, chemical control and biological control) for controlling parasitic weeds like *Alectra* failed because of either their efficiency, their expense or their technical requirements. Genetic resistance is an alternative for addressing these constraints. Combining genetic resistance to other control methods is the best way to control wide-spreading weeds like *Alectra*.

From artificially infested trials Atokple *et al.* (1993) and Singh *et al.* (1993) identified the land race B301, from Botswana, as source of resistance to *Alectra*. Kabambe *et al.* (2014) observed high resistance to *Alectra* conferred by the variety IT99K-494-6 in Malawi. However, these varieties, even though they are adapted to local climatic conditions in some countries, lack farmers'

preferred traits in other countries. In Burkina Faso for example large sized rough white cowpea grains are required by stakeholders (Tignegre, 2010; Batieno, 2014).

Identifying well adapted and farmer-preferred cowpea sources of resistance to *Alectra* from local germplasm collection will be beneficial for the cowpea value chain in Burkina Faso. The genetic material from this local germplasm has not been evaluated for its reaction to *Alectra vogelii* in Burkina Faso yet. Therefore, knowing the genetic composition of this material with regard to resistance to *Alectra vogelii*, the gene action controlling the resistance and the allelic relationship of the resistance genes will be of great contribution to cowpea breeding for resistance to *Alectra* infestation.

The overall goal of this study is to improve cowpea for resistance to *Alectra vogelii* in Burkina Faso.

The specific objectives are to:

- (i) assess farmers' awareness of the parasitic weed *Alectra vogelii* and identify their cowpea varietal preferences;
- (ii) identify sources of resistance to *Alectra vogelii* in cowpea germplasm from Burkina Faso;
- (iii) determine gene action controlling cowpea resistance to *Alectra vogelii*;
- (iv) determine the genetic inheritance of the resistance genes; and
- (v) determine the allelic relationship between genes conferring resistance to *Alectra vogelii* in cowpea.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 The cowpea crop

2.1.1 Taxonomy

Cowpea is a leguminous plant that belongs to the family of *Fabaceae*, genus *Vigna* and species, *V. unguiculata* (Maréchal *et al.*, 1978; Padulosi & Ng, 1997). The genus *Vigna* is composed of 150 to 170 species with most of them originating from Africa (Padulosi & Ng, 1997). Pasquet (1993, 1996a, 1996b, 1997) divided cowpea into 10 perennial sub-species and one annual sub-species, *V. unguiculata*. The annual sub-species comprises both cultivated forms (var. *unguiculata*) and annual wild relatives [var. *spontanea* (Schweinf.)]. Based on the rate of successful mating when crosses are made between the cultivated form and its wild relatives, the latter are separated into three groups as follows: spontaneous self-pollinating forms, cross pollinating forms and intermediate forms (Kouadio *et al.*, 2007).

2.1.2 Origin and domestication

Cowpea originated from Africa; precisely in Meridional or Equatorial Africa where the wild forms, from which it derives, are located (Vaillancourt *et al.*, 1993). Two centres where cowpea domestication is likely to have taken place have been proposed. Cowpea could have been domesticated about 4000 years ago by West Africans (Rawal, 1975; Padulosi & Ng, 1997). However, a West African centre of domestication of cowpea is not accepted by some authors who argued for an East African centre of domestication instead. Thus, since the 1980s Baudoin & Maréchal (1985) proposed East Africa as the centre of domestication of cowpea. They were supported by recent researchers such as Coulibaly *et al.* (2002) and Ba *et al.* (2004). India is proposed as secondary centre of domestication and selection of cowpea (Ehlers & Hall, 1997).

2.1.3 Biology of cowpea

Cowpea is a diploid plant with $2n = 2x = 22$ chromosomes (Pasquet, 1998; Botanga & Timko, 2006; Huynh *et al.*, 2013). Its genome size is about 680 cM with 11 linkage groups (Muchero *et al.*, 2009). Cowpea is an annual self-pollinating crop (Fery, 1985). It has got a symmetrical floral structure. Each flower contains a short stigma surrounded by 10 stamens which carry fertile anthers (Maréchal *et al.*, 1978). However, some perennial spontaneous forms with longer stigma are cross-pollinating (Lush, 1997). In general, with the cultivated forms, the flower opens at dawn (between 6:00 and 6:30 AM) and closes back by the end of the morning (between 11:30 and 12:00) (Ige *et al.*, 2011). While the dehiscence of the anthers occurs several hours before the flower opens, the stigma is receptive to pollen grains earlier to anthesis and remain receptive 12 hours later (Rachie *et al.*, 1994; Ige *et al.*, 2011). The cross-pollinating forms are characterized by bigger flowers which are brighter in colour. They are highly aromatic and are able to open consecutively for two days. Moreover, they present a particular design of anthers and the stigma (stigma longer than the stamens) which minimizes self-pollination (Lush, 1997). Furthermore, the cross-pollinating forms produce high number of pollen grains per anther (600 to 1,200) against 200 to 700 for self-pollinating forms (Pasquet, 1996a).

Genetic improvement of cowpea requires manual pollination. Rachie *et al.* (1994) reported that under natural conditions 10 to 20% of the crosses succeed. This rate can be increased when hybridization is made under low temperature and high relative humidity, cold nights enhancing fertilization (Rachie *et al.*, 1994). When crosses are made under these conditions, 50% (Rachie *et al.*, 1994) to 90% (Ehlers & Hall, 1997) of pod set can be achieved. These rates are reached only when crosses are made between cultivated forms. The results are quite different with crosses between cultivated forms and wild relatives. As a result of the extent of incompatibility from

crosses between cultivated and wild forms, that means the genetic barriers between them, a suggestion has been made for the existence of a secondary gene pool of cowpea (Pasquet & Baudoin, 1997; Pasquet, 1998, 2000; Kouadio *et al.*, 2007). However, these barriers can be broken for breeding purposes (Kouadio *et al.*, 2007).

2.1.4 Constraints to cowpea production

Cowpea production is drastically hampered by several abiotic, biotic and socio-economic constraints (Horn *et al.*, 2015). The crop is severely damaged by several insect pests, diseases and parasitic weeds at all its growth stages in the field; post-harvest damages are also important (AATF, 2003; Yakubu *et al.*, 2012; Oyewale & Bamaïyi, 2013). Some of the key constraints to cowpea production in the field are: low soil fertility, drought, insects (Aphids, thrips, pods sucking bugs, *Maruca*), fungal and viral diseases (*Cowpea Aphid-Born Mosaic Virus*: CABMV, brown blotch) and parasitic weeds (*Alectra vogelii* and *Striga gesnerioides*) (Singh & Allen, 1979; AATF, 2003; Tignegre, 2010; Yakubu *et al.*, 2012; Egbadzor *et al.*, 2013; Oyewale & Bamaïyi, 2013; Batieno, 2014; Horn *et al.*, 2015). Insect pests (bruchids) and fungal diseases are the main causes of losses in cowpea storage (AATF, 2003; Yakubu *et al.*, 2012). Constraints to cowpea production also include limited accessibility to seeds of improved varieties, inputs, market and limitation in processing (AATF, 2003; Tignegre, 2010; Egbadzor *et al.*, 2013). To summarize, the three categories of constraints are the following;

Socio-economic constraints:

- limited access to seeds of improved varieties,
- limited access to inputs and equipment,
- limitation in processing,
- limited access to markets.

Abiotic constraints:

- low soil fertility,
- drought,
- heat.

Biotic constraints:

- insects pests (aphids, thrips, pod sucking bugs, *Maruca*, bruchids),
- fungal, bacterial, and viral diseases (brown blotch, bacteria blight, CABMV),
- parasitic weeds (*Striga gesnerioides*, *Alectra vogelii*).

2.2 The parasitic weed *Alectra vogelii*

2.2.1 Taxonomy, biology and ecology

The yellow flowering weed, *Alectra vogelii* (Benth.) is a dicotyledonous plant that belongs to the order of *Scrophulariales*, family of *Scrophulariaceae*, genus *Alectra* (CABI, 2017). The genus *Alectra* comprises 13 species, among them eight (8) species occur in Africa (Morawetz & Wolfe, 2009). The weed parasitizes cultivated and spontaneous *Fabaceae*, *Compositae*, *Euphorbiaceae*, *Labiatae*, *Malvaceae* and *Pedaliaceae* families (Hoffmann *et al.*, 1997; Boussim, 2002). Cowpea (*Vigna unguicalata*), groundnut (*Arachis hypogaea*), soybean (*Glycine max*) are some preferred host species (Visser & Johnson, 1982; Riches *et al.*, 1992). *Alectra* is an erect herb of 10 to 45 cm tall, often as a single stem but sometimes branching from near the soil level (Boussim, 2002; Morawetz & Wolfe, 2009; CABI, 2017). It also has a regeneration potential when the main stem is cut by farming hoe. Both stems and leaves are conspicuously hairy. The leaves are simple with a wide range of leaf shapes from broadly ovate to reduced scales, which can be 1.5 to 3.5 cm long by 0.3 to 1.5 cm wide (Parker & Riches, 1993; Boussim, 2002; CABI, 2017). Both self-pollination

and cross pollination are operative in the reproduction system of *A. vogelii* but their relative rate is not determined (Parker & Riches, 1993). Its inflorescence has small sessile to shortly pedicellate (0.5 cm in length) flowers, which are pale to dark yellow in colour. The calyx and the corolla are each composed of five (5) lobes and five (5) petals respectively. In the centre of the flower are the stamens (Boussim, 2002; CABI, 2017). An *Orobranche* species generally produces an average seed number of 200 000 seeds per plant. However, *Alectra vogelii* can produce three times more seeds. An individual plant of *Alectra* has seed production potential of 600, 000 seeds (Visser, 1978; SP-IPM, 2003). Weed seeds are disseminated through wind, water and cattle dung. The latter one is the most important way of seeds dispersal of *Striga hermonthica* (Berner *et al.*, 1994).

Parker (2012) reported that *A. vogelii* is an obligate parasite and depends entirely on its host for its development and survival despite its normal-looking green foliage. However, Magani *et al.* (2008) and Morawetz & Wolfe (2009) argued that *Alectra* is a hemi-parasite and that two-third of its carbon requirement is obtained from the host after emergence. *Alectra vogelii* occurs in tropical, semi-arid and subtropical areas of Africa (Boussim, 2002; Mohamed *et al.*, 2006). Figure 2. 1 shows the geographical distribution of *Alectra* in the world (Mohamed *et al.*, 2006). Yellow bullets represent the areas where *Alectra* occurs.

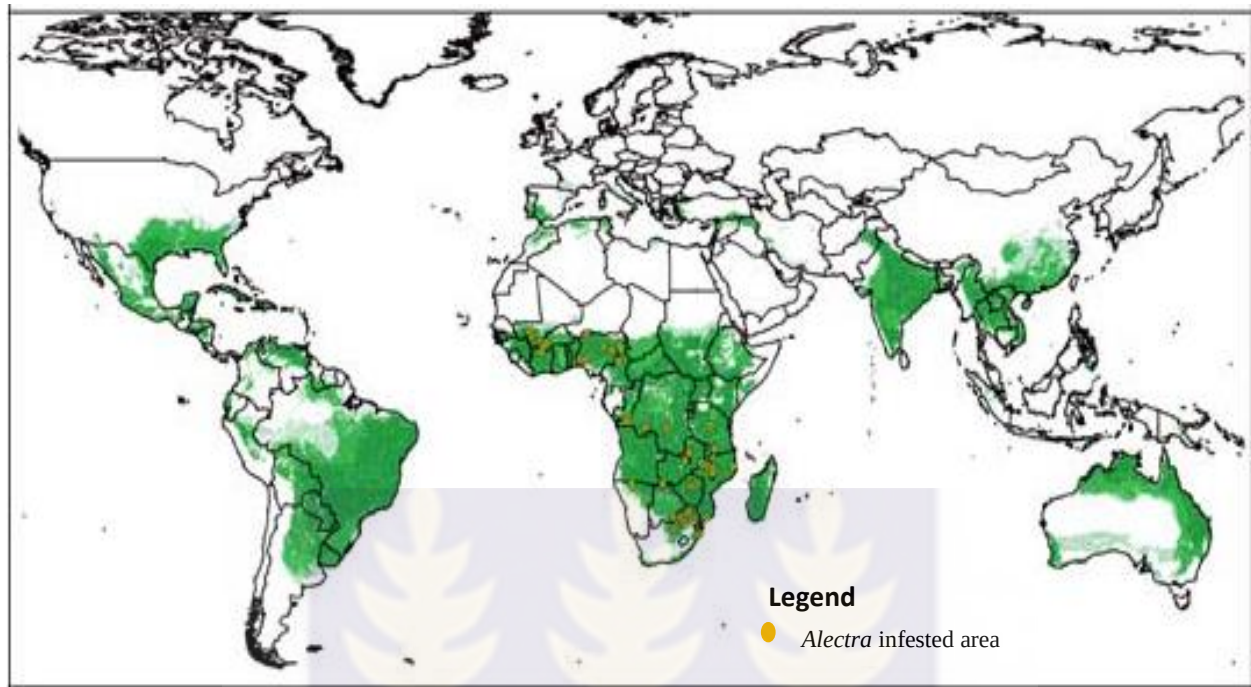


Figure 2.1: Geographical distribution of *Alectra vogelii* in the world (Mohamed *et al.*, 2006)

In Burkina Faso *Alectra vogelii* has been observed in several regions: East, Centre-East, Centre-North, North-West, West and South (Boussim, 2002) (Figure 2.2). It prefers climatic conditions similar to those suitable for *Striga* and can be both found in the same area (Mohamed *et al.*, 2006). *Alectra vogelii* has developed a more complex host specificity than *Striga gesnerioides*, each strain attacking a specific host-plant (Mohamed *et al.*, 2006). However, highly virulent strains attack across host-plants (Riches *et al.*, 1992). These authors have reported the prevalence of five strains of *A. vogelii* in Africa each strain occurring in different countries. Strain one occurs in Mali, Nigeria and Cameroon, strain two prevails in Botswana, strain three occurs in Kenya, strain four occurs in Malawi and strain five prevails in northern Transvaal (South Africa).

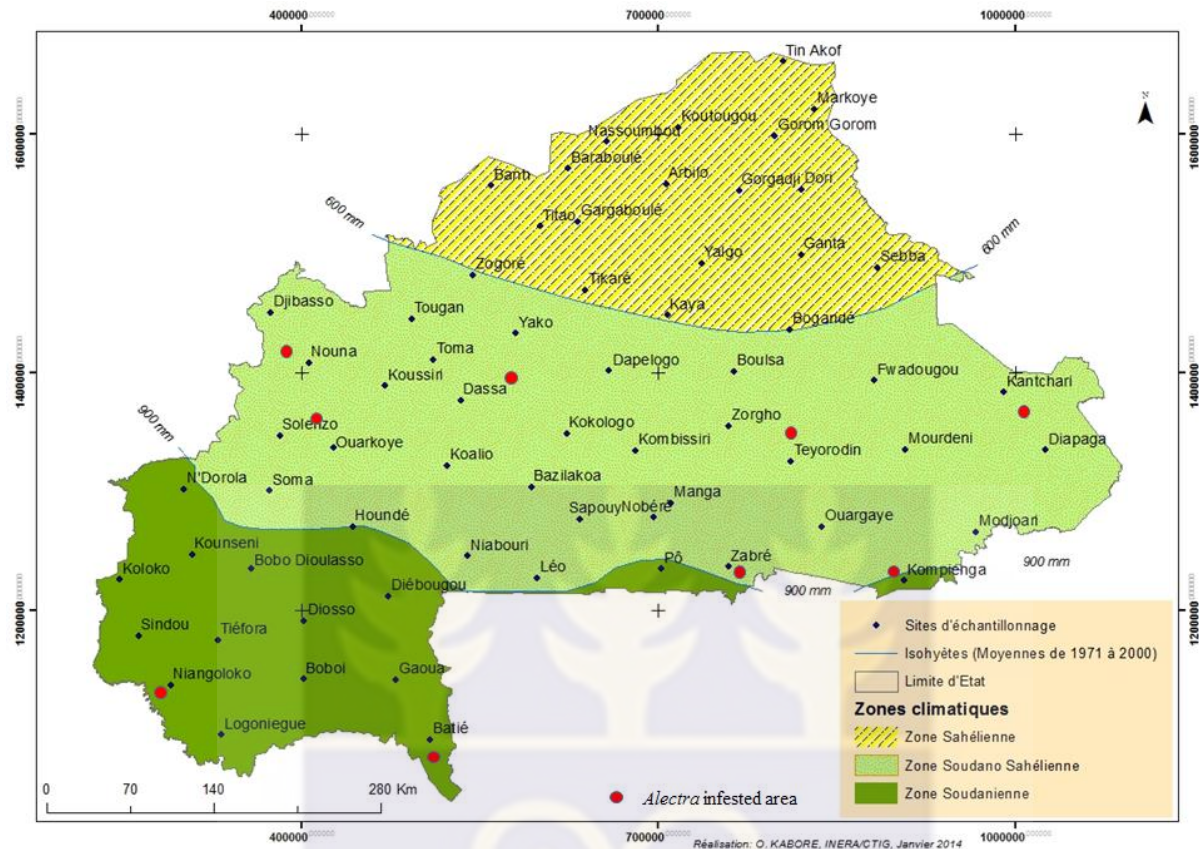


Figure 2.2: Geographical distribution of *A. vogelii* in Burkina Faso Boussim (2002)

2.2.2 Economic importance of *Alectra*

Alectra vogelii is a parasitic weed that depends entirely on its host during its underground stage. A cowpea plant expresses a set of chronological symptoms to *Alectra* infestation as the severity of the attack evolves. The general symptoms associated with *Alectra* infestation are leaf chlorosis, stunted growth, partial defoliation (Singh *et al.*, 1993) and plant death (Karanja *et al.*, 2013). In the underground level the effect of *Alectra* infestation leads to reduction in the nodulation potential the host crop (Alonge *et al.*, 2001a; Kureh & Alabi, 2003; Karanja *et al.*, 2013). Up to 57% of shoot biomass reduction can be observed with susceptible varieties of cowpea attacked by *Alectra* (Rugare *et al.*, 2013). Besides, an infection of a cowpea variety by *Alectra* can reduce by 98% the

number of pods per plant (Rugare *et al.*, 2013). Similarly the grain weight is reduced (Rugare *et al.*, 2013). As a result, a drastic yield loss can occur. Under heavy infestation 80% to 100% yield loss can be registered (Mbwaga *et al.*, 2011; Karanja *et al.*, 2013). Besides yield loss cowpea infestation by *Alectra* and *Striga* results in a decreased concentration of most mineral compounds (iron, magnesium, calcium) in cowpea seeds (Alonge *et al.*, 2001b; Alonge & Alabi, 2009).

2.3 Management strategies

Different methods have been proposed to prevent *Alectra* from damaging crops. The practices applied are: cultural, chemical, biological and genetic resistance approaches.

2.3.1 Cultural practices

The most frequent way of controlling parasitic weeds like *Alectra* and *Striga* by farmers are the usual cultural practices. Several years of hand weeding and proper crop rotation can reduce the seed bank in the soil but intensive communication with farmers is necessary for the achievement of these methods (Ransom, 2000). However, this method is efficient in only slightly infested fields (Ramaiah *et al.*, 1983). It is recommended to burn the uprooted plants otherwise they are capable of completing their life cycle (Ramaiah *et al.*, 1983; Dembélé *et al.*, 1994). So under heavy infestation, manual uprooting fails to control parasitic weeds (Berner *et al.*, 1994). Although this method is the most affordable to smallholder farmers, it fails to control *Alectra* from spreading.

Since *Alectra* mainly develops in poor soils, researchers realized that enriching the soil can reduce the severity of *Alectra* infestation. This can be achieved through proper soil fertilization. Magani & Lagoke (2009) reported that an application of high level of nitrogen (60 kg N ha⁻¹) reduces the number of *Alectra* shoots emerging per plot. A significant reduction of *Alectra* incidence on groundnut was achieved when nitrogen was applied at the rates of 25 and 50 kg ha⁻¹ (Kwaga,

2014). Unlike nitrogen, phosphorous does not have effect on *Alectra* meanwhile a rate of 40 kg P.ha⁻¹ was associated with more intensive damage of cowpea plants attacked by *Alectra* (Kwaga, 2014). This is explained by the induction of nodulation, by phosphorous, which become attachment points for *Alectra* radicles (Magani & Lagoke, 2009). Like mineral fertilizers, organic fertilizers can be used to reduce *Alectra* infestation. By applying 50 kg ha⁻¹ Kwaga (2014) obtained an increase in groundnut kernel yield but groundnut plants supported high infestation of *Alectra*. This is synonymous to high quantity of weed seeds production. Therefore, the use of this method to control *Alectra* is not judicious because it increases the stock of the soil seed bank.

In addition, trap crops can be used to reduce parasitic weeds effects on their hosts and their seed bank in the soil as well. Denwar & Ofori (2003) mentioned a potential genetic capacity in soybean genotypes as a trap crop in the control of *Striga hermonthica*. A suicidal germination of *Alectra* seeds was noticed by Yunusa *et al.* (2013) with *Celosia* (sp.) and *Amaranthus* (sp.) when they were planted before cowpea. Besides, it has been observed that *Parkia biglobosa* pulp possesses a good potential of controlling *Striga gesnerioides* when it is applied over a certain time (Zitta *et al.*, 2014).

2.3.2 Chemical control

Some chemicals have been successfully used to control *Alectra vogelii*. Magani & Lagoke (2008) obtained 90% reduction of both *Alectra* and *Striga* radicle attachment to cowpea roots when seeds were treated with 1.8 to 7.2 mg of imazaquin a.i/ml for five minutes. Imazaquin controls *Alectra* infestation through post attachment mechanism and therefore confers double advantages by protecting the host plant and reducing the parasite seeds bank level in the soil (Berner *et al.*, 1994). By cutting down the cycle of the parasite its reproduction is denied and this prevents a renewal of the seed stock. This means an optimal use of imazaquin every year for a long period of time (15

to 20 years) could eradicate *Alectra* from an area. This chemical can also be used in association with other herbicides. Magani & Lagoke (2008) reported that an efficient control of *Alectra* can be achieved by applying a combination of pre-emergence herbicide and post-emergence herbicide. However, they did not indicate the exact period for post-emergence herbicide application. Knowing that *Alectra* shoots do not emerge at the same time on all the field, the efficiency of the post-emergence herbicide may require several applications otherwise some plants could escape. Thus increasing the seed bank in the soil. Since seeds of parasitic weeds like *Alectra* and *Striga* do not germinate without germination stimulant, some chemicals have been tested for their ability to induce seed germination in absence of the host. Successful results have been obtained with *Alectra vogelii*, *Striga gesnerioides* and *Striga hermonthica* seeds (Visser & Johnson, 1982; Matusova *et al.*, 2005; Yoshida & Shirasu, 2009; Karaya *et al.*, 2012). These germination stimulants can be used to reduce considerably the witch weeds seed stock in the soil (Visser & Johnson, 1982).

2.3.3 Biological control

The predator-prey relationship between some living organisms have been studied and successfully used in many cases as a control method of some pests in crop production. Likewise host-parasite relationship has been used. So bacteria and fungi have been efficiently exploited in parasitic weeds control. For example it has been experienced that bacterium such as *Pseudomonas seringae* induces *Striga gesnerioides* seeds abortion when it is incorporated into the soil (Berner *et al.*, 1997). The efficiency of *Fusarium oxysporum* 34-FO inoculum has been proved in controlling *Striga hermonthica* (Yonli *et al.*, 2012). Few or no work has been undertaken on biological control of *Alectra*. Nevertheless, this method can be used in *Alectra* control if natural enemies are

available. It is an ecological method which efficiency can be improved when associated with other methods.

2.3.4 Genetic resistance

For most plant breeders, genetic resistance or true resistance is the most efficient and the most affordable method to control almost all the constraints in crop production. Nevertheless, genetic resistance needs to be supplemented with other methods, cultural practices mainly for optimal efficiency. Several cowpea genotypes conferring total or partial resistance to *Alectra vogelii* have been identified in previous studies. Singh *et al.* (1993) observed a full resistance to *Alectra* conferred by the landrace B301, from Botswana, in northern Nigeria. However, it supported few *Alectra* emergence in Botswana (Polniaszek *et al.*, 1991). Six improved varieties: IT90K-59, IT90K-82-2, IT93K-693-2, IT97K-205-8, IT97K-499-35 and IT87K-819-118, conferring resistance to both *Alectra* and *Striga* have been developed at IITA (Singh *et al.*, 2006). Magani *et al.* (2009) observed that the variety IT90K-59 also conferred high resistance to *Alectra* in Malawi. Besides, they identified one more variety (IT90K-76) which did not allow any emergence of *Alectra*. The genotypes that have expressed full resistance to *Alectra* can be considered as immune varieties to *Alectra* attack. Though IT82D-849 was resistant to *Striga gesnerioides* it was susceptible to *Alectra* (Atokple *et al.*, 1995). Based on these results it can be inferred that different factors are involved in the mechanisms of resistance of the genes controlling resistance to *Alectra* and *Striga*. Differences in the reaction of a given cowpea genotype to samples of both *Alectra* and *Striga* from different areas have been observed (Polniaszek *et al.*, 1991; Riches *et al.*, 1992; Lane *et al.*, 1996). Riches *et al.* (1992) have reported the occurrence of five different strains of *Alectra* in Africa. Polniaszek *et al.* (1991) and Riches *et al.* (1992) claimed that the strain from West Africa (Mali, Nigeria) was less virulent than the one from Botswana. *Alectra* samples from Burkina Faso

were not included in this study. Large variability in virulence of *S. gesnerioides* was reported in West Africa compared to *Alectra*. At least seven different races of *S. gesnerioides* exist in West Africa (Lane *et al.*, 1996; Botanga & Timko, 2006; Tignegre, 2010). Genetically different populations of *Striga hermonthica* were observed in Nigeria (Unachukwu *et al.*, 2017). The variability observed within these parasitic weeds make breeding for resistance a more complex task.

2.3.5 Integrated control measures

An integrated management system, which means an appropriate combination of two or more control measures is the most efficient approach for pest management in a breeding programme. Generally a combination of two methods works very well. Yonli *et al.* (2012) observed satisfactory results combining bio-control and cultural practices. A combination of organic matter and neem seed powder has been also successfully used (Dzomeku & Amegbor, 2013). The combination of genetic resistance and cultural practices could be the most applicable in parasitic weeds management. However, keeping the pressure on the parasite population over several years is required for the efficacy of this approach (Parker, 1991; Yonli *et al.*, 2012). For a technology to be adopted it must be the most affordable and profitable to smallholders. Then the combination of genetic resistance with proper soil fertilization and manual or hoe weeding could be the most appropriate to control *Alectra*. In fact, *Alectra* is prone to poor soils and its effect is reduced with optimum application of organic and inorganic fertilizer (Kwaga, 2010, 2014). Therefore, the use of this method, which in addition to reducing *Alectra* influence increases cowpea productivity, in combination with the genetic resistance potential of the cowpea variety being produced and farmers usual practices will be the most efficient and the most affordable to farmers.

2.4 Cowpea and *Alectra* interaction

2.4.1 Germination stimulants: Strigolactones

Plants secrete chemical compounds through their roots. These exudates serve both as nutrients for soil micro-organisms and signalling molecules in interactions between plants and their environment (Sugiyama & Yazaki, 2012). Several types of molecules including amino acids, sugars, organic acids, vitamins, nucleotides, various other secondary metabolites, etc. are exuded by plant roots. The nature of these exudates is affected by abiotic and biotic factors such as plant species, root age, microorganisms, temperature and light (Shukla *et al.*, 2011). A variety of secondary metabolites (flavonoids, strigolactone and other phenolic compounds) serve as chemical signals or mediators in different types of interactions between the plants and their environment (Matúšová & Bouwmeester, 2006; Shukla *et al.*, 2011). Very low concentrations of these exudates (pictogram to nanogram) are necessary to induce the communication signal (Akiyama & Hayashi, 2006; Gomez-roldan *et al.*, 2008).

Strigolactones are a group of sesquiterpenes that belong to the chemical class of isoprenoids like many other biological plants communication molecules (Akiyama & Hayashi, 2006; Matúšová & Bouwmeester, 2006). They are very important phytohormones exuded by legume plants roots and play diverse roles (positive and negative) in plants development. Their secretion is increased under low phosphorus level (Akiyama & Hayashi, 2006; Kapulnik & Koltai, 2014). These secretions induce the establishment of arbuscular mycorrhizal symbiosis (Akiyama & Hayashi, 2006; Gomez-roldan *et al.*, 2008; Sugiyama & Yazaki, 2012). Also strigolactones are known to be inhibitors in shoot branching (Gomez-roldan *et al.*, 2008). On the other hand, strigolactones are involved in negative functions (Kapulnik & Koltai, 2014). Strigolactones are known as germination stimulants of parasitic weeds (Akiyama & Hayashi, 2006; Matúšová & Bouwmeester,

2006; Gomez-roldan *et al.*, 2008; Sugiyama & Yazaki, 2012). Parasitic weeds germination stimulant function of strigolactones has probably evolved from their role as signal in symbiosis establishment (Gomez-roldan *et al.*, 2008; Sugiyama & Yazaki, 2012). Matúšová & Bouwmeester (2006) reported that these germination stimulants are very important compounds in the regulation of the parasitic weeds' life cycle to that of their hosts. Nine structurally different strigolactone molecules have been identified (Rani *et al.*, 2008). Three of them (alectrol, orobanchol and strigol) were isolated from roots exudates of cowpea and other related host crop (Müller *et al.* 1992; Yokota *et al.*, 1998). Four strigol analogues namely GR5, GR7, GR24 and GR28 have been reported to induce *Alectra* seeds germination. Among them GR7 was the most efficient (Visser & Johnson, 1982).

2.4.2 *Alectra vogelii* life cycle

The different steps of the life cycle of parasitic weeds are harmonized with the development stages of their host-crops by biochemical mediators (Matusova *et al.*, 2005; Matúšová & Bouwmeester, 2006). *Striga gesnerioides* and *Alectra vogelii* have similar life cycle but unlike *S. gesnerioides*, *A. vogelii* seeds do not require post maturity latency period for germination (CABI, 2017). Parasitic weeds seeds' germination require optimum temperature conditions (25°C- 35°C) otherwise they remain dormant (Okonkwo, 1975; Visser & Johnson, 1982; Visser *et al.*, 1990; Lane *et al.*, 1991; Riches *et al.*, 1992). An imbibition (conditioning) period of one to three weeks is necessary for seeds germination (Okonkwo, 1975; Lane & Bailey, 1992; Magani *et al.*, 2008). An optimum of 14 days has been reported for *Alectra vogelii* (Magani *et al.*, 2008). For off season and *in-vitro* experiments these requirements are fulfilled through water supply. *Alectra* seeds that are within 5 mm distance from a cowpea root will germinate when germination stimulants are exuded by the roots (Lane *et al.*, 1991; Karaya *et al.* 2012). Germination takes place two to five days after

exposure to the stimulus (Okonkwo, 1975; Visser & Johnson, 1982; Lane *et al.*, 1991; Karaya *et al.*, 2012). After germination *Alectra* radicle elongate and establishes contact with host roots. Two days later, it penetrates the root wall whereby it forms a *haustorium* (Lane *et al.*, 1991; Reiss & Bailey, 1998). A very small injury is caused to the host root wall during the penetration process (Lane & Bailey, 1992; Reiss & Bailey, 1998). The parasite establishes a fairly good connection with its host 12 days after germination (Visser *et al.*, 1990). If the radicle fails to establish contact with the host roots within four to ten days after germination it dies (Visser *et al.*, 1990; Lane *et al.*, 1991; Berner & Williams, 1998). Successful penetration is followed by intense metabolic activities in the penetration point leading to the development of lateral roots of the host plant and subsequently to haustorium formation (Visser *et al.*, 1990). The haustorium will further develop and establish links with the host' root vessels and deviate nutrients and water for the growth of the parasite. During the underground stage, *Alectra* is a holo-parasite and therefore entirely depends on its host (Okonkwo, 1975; Magani *et al.*, 2008). As a result, maximum damage (up to 75%) occurs at this stage (Timko & Singh, 2008). The parasite emerges and produces seeds before the host completes its cycle. *Alectra* plants can produce as much as 600 000 seeds. The seeds remain viable in the upper layers of the soil for several years and the cycle restarts when the conditions are favourable. The weed fails to complete its life cycle when a resistant variety is planted.

2.4.3 Mechanisms of resistance

Kureh *et al.* (2005) reported two main ways on soybean resistance to *Alectra* infestation: low germination stimulant production and host-parasite incompatibility. In the first mechanism the host plant secretes a small amount or does not secrete at all germination stimulant (*Alectrol*) necessary to induce *Alectra* seeds germination. This mechanism of resistance can be considered as a non-host resistance. In the second one, the host plant produces enough germination stimulant which induces

Alectra seeds germination but the attachment of its radicle to the plant roots and/or further development of the *haustorium* is denied. This type of resistance can be called true resistance. Like soybean, cowpea resistant genotypes to *Alectra* could express the same mechanisms of resistance. In the case of cowpea resistance to *Striga gesnerioides*, Tignegre (2010) has observed three ways whereby cowpea expresses resistance. The commonest mechanism is the development of mechanic barriers that prevent *Striga haustorium* from penetrating cowpea radicle. In fact cowpea resistant genotypes react to the contact of *Striga* radicle developing necrotic cells which blocks the formation of links between cowpea and *Striga* vessels (Tignegre, 2010). This is referred as hypersensitive reaction. A similar reaction is observed in sorghum resistance to *Striga hermonthica* (Maiti *et al.*, 1984). In addition to the two mechanisms observed in soybean resistance to *Alectra*, cowpea expresses a third mechanism which allows *Striga haustorium* to bind to the cowpea roots, however the attached *haustorium* is not capable to grow further (Tignegre, 2010). Some resistant genotypes express only one of the above stated mechanism, others can express the pre and post-attachment resistance at a time (Tignegre, 2010).

2.5 Inheritance and allelic relationships

Several genotypes conferring resistance to *Alectra vogelii* have been identified but only the inheritance pattern of the resistance in B301 and IT81D-994 to *Alectra* from Nigeria have been determined so far. The resistance to *Alectra vogelii* in B301 in Nigeria is conferred by two dominant genes named *Rav₁* and *Rav₂* (Atokple *et al.*, 1993, 1995; Singh *et al.*, 1993). A single dominant gene *Rav₃* confers the resistance to *Alectra* in the variety IT81D-994 (Atokple *et al.*, 1995; Kouakou *et al.*, 2009). As in cowpea resistance to *Alectra*, vertical resistance pattern is reported in cowpea resistance to *Striga gesnerioides*. The resistance is therefore conferred by one or two genes. For example one gene is responsible for the resistance to races 1 and 2 of *Striga*

gesnerioides (Atokple *et al.*, 1995; Touré *et al.*, 1997) whilst two tightly linked genes govern resistance to race 3 of *Striga* in B301 (Atokple *et al.*, 1995). It was also observed that a linkage relationship exists between genes conferring resistance to different races of *Striga* in some varieties. This relationship is observed with the genes *Rsg1* and *Rsg2*, *Rsg3* and *Rsg1* and 994-*Rsg* and *Rsg1* in B301, IT93K-693-2 and IT81D-994 respectively (Tignegre, 2010). It can be remarked that some of the cowpea varieties (B301 and IT81D-994) are resistant to both *Alectra* and *Striga*, however, the genes conferring resistance to them are inherited independently (Atokple *et al.*, 1993). Furthermore, a gene responsible for the stickiness of cowpea stems is probably associated with the gene of resistance to *Alectra* (Fite, 2010). In other words, there is a probable linkage or correlation between cowpea resistance to *Alectra vogelii* and the stickiness of cowpea stems (Fite, 2010). Little research has been done to confirm the inheritance patterns of the resistance to *Alectra*. Therefore, both phenotypic and genotypic studies have to be carried out to find out the actual inheritance and allelic relationships among genes for resistance to *Alectra vogelii* in cowpea.

2.6 Implications of the participatory rural appraisal (PRA) in plant breeding

In the past plant breeders have come out with final products to the end-users without their participation. In such cases efforts were devoted to develop new technologies for several constraints of production. But unfortunately most of them were rejected because they did not take into account stakeholders' needs and preferences which constitutes a waste of time and resources (Tignegre, 2010). Therefore, the PRA procedure has been used to fill the gap between breeders' objectives and the stakeholders' needs and preferences. In the PRA approach the stakeholders are the main actors in decision making (Chambers, 1994a, 1994b).

The involvement of stakeholders in the selection process increases adoption rates of products of breeding, thereby optimizing efforts deployed by breeders and leading to income generation. For

example in Ghana and Cameroon, cowpea consumers were willing to pay premium prices for their preferred grain types (Langyintuo *et al.*, 2004). In Burkina Faso a study implemented to evaluate the socioeconomic impacts of cowpea technologies, showed that the income generated by cowpea at Donsin (Central Burkina Faso) and Bik Baskoure (Eastern Burkina Faso) had increased from 0.0% (1990) to 14.1% (2001) and from 15.7% (1990) to 49.9% (2001) respectively (PRONAF, 2003). This significant increase was possible because farmers were the principal actors for implementing technological packages.



CHAPTER THREE

3.0 FARMERS' COWPEA VARIETAL PREFERENCES AND THEIR PERCEPTION OF *Alectra vogelii* Benth. IN *Alectra* PRONE AREAS IN BURKINA FASO

3.1 Introduction

The main parasitic weeds in cowpea production are *Striga gesnerioides* and *Alectra vogelii*. In Burkina Faso, average damages caused by *S. gesnerioides* is evaluated at 31.4% of yield losses (Muleba *et al.*, 1997), though this figure has evolved. However, yield losses related to *A. vogelii* in Burkina Faso has not been evaluated yet. In other countries like Kenya, Malawi, Nigeria and Tanzania more than 50% yield losses have been reported (Mbwaga *et al.*, 2009; Omoigui *et al.*, 2012; Karanja *et al.*, 2013; Mbega *et al.*, 2016).

A survey conducted in Malawi revealed that the noxiousness of *A. vogelii* was not well known by both agricultural extension agents and farmers (Kabambe *et al.*, 2013). The normal photosynthetic green foliage appearance of the weed (Parker, 2012) could contribute to ignorance of the farmers. This ignorance facilitates the dissemination of the weed, which is highly reproductive, within and across zones. An individual *Alectra* plant can produce up to 600 000 seeds that can remain viable in the soil for 15 to 20 years (Visser, 1978), making its eradication almost impossible. Nevertheless, control measures can be taken to reduce the effect of *Alectra* on cowpea if all the concerned actors are sensitized about this threat.

To bridge the gap between breeders' objectives and the stakeholders' needs and preferences, a new research approach including all the partners was necessary. One of the popular and effective alternative proposed to address this issue is the participatory breeding approach through Participatory Rural Appraisal (PRA) (Cavestro, 2003). The PRA consists of identifying with

stakeholders the principal constraints in their cropping system as well as their desired varietal characteristics. This collaborative research is a powerful way for technology adoption and dissemination. It allows a clear communication and understanding of stakeholders expectations and strengthens the learning partnerships between stakeholders, researchers and policymakers (McEntee, 2013). In fact, independently to scientists, farmers continuously experiment new technologies and innovate sometimes on their own. Therefore, involving them in a collaborative research program will greatly contribute to the development and the sustainability of agriculture (Leitgeb & Vogl, 2010).

Recent PRA studies implemented in Burkina Faso reported that low soil fertility, climate change, drought, *Striga gesnerioides*, inaccessibility to markets and lack of inputs were some the main constraints to cowpea production in Burkina Faso (Tignegre, 2010; Batieno, 2014). These authors also reported that big sized white coloured cowpea grain were largely accepted by farmers. However, the importance of some threats as well as farmers' preferences were specific to the targeted area. In addition, the importance of a threat can be neglected by farmers who ignore it. The previous studies did not cover farmers' preferred cowpea varietal growth habit and cycle. Therefore, it was important to determine farmers' preferences for these traits in combination with grain quality for the sake of further capturing their preferred varietal characteristics. It was also necessary to assess farmers' knowledge on the parasitic weed, *A. vogelii* in areas where it occurs.

The objectives of this study were to (i) determine the awareness of farmers on the parasitism of *Alectra vogelii* on cowpea and (ii) identify farmers' preferred varietal characteristics.

3.2 Materials and methods

3.2.1 Study sites

The Participatory Rural Appraisal (PRA) was conducted in two regions of the country: the West and the Central-east. These regions are located in the Sudanian and Sudan Sahelian climate respectively. The annual rainfall range is over 900 mm for the former and from 600 mm to 900 mm for the latter regions. Two districts (Koupela and Tenkodogo) in the centre-east region and one from the western region (Bobo-Dioulasso/Toussiana) were selected for this study. In each district, three villages where *Alectra* infested fields have been observed were targeted (Figure 3.1). Details of these sites are shown in **Error! Reference source not found..**

Table 3.1: Geographical description of the study sites

Region	Province	District	Village	Longitude (N)	Latitude (W)	Altitude (m)	Agro- ecology	Rainfall (mm)
Centre- east	Kouritenga	Koupela	Boantenga	12°12,8'	0°20	330	Sudan sahelian	600- 900
			Zano	11°42,5'	0°22,4'	325		
			Dabare	11°33,3'	0°20,59'	323		
	Boulgou	Tenkodogo	Laylay	11°34,3'	0°23,44'	328		
			Wempea I	10°52,9'	4°33,59'	339		
Haut Bassin	Houet	Bobo- Dioulasso (Toussiana)	Wempea II	10°51,52'	4°18,56'	339	Sudanian	>900
			Tapoko- deni	10°52,44'	4°32,44'	339		

3.2.2 Focus group discussion

Focus group discussions (FGD) were held with 15 to 30 farmers in November 2015 in the selected villages about the issues encountered in cowpea production in general and particularly about the parasitism of *Alectra vogelii* on cowpea as well as their expectations in terms of cowpea varietal improvement. Heads of farmers' local organizations and/or extension agents were involved the

organization of the FGD. One group discussion was organized for the three villages of the district of Koupela at the village Boangtenga. In the rest of the districts, it was held per village. A multi-disciplinary team, composed of a breeder, a social scientist and a weed scientist had a full day discussion with farmers in each village.

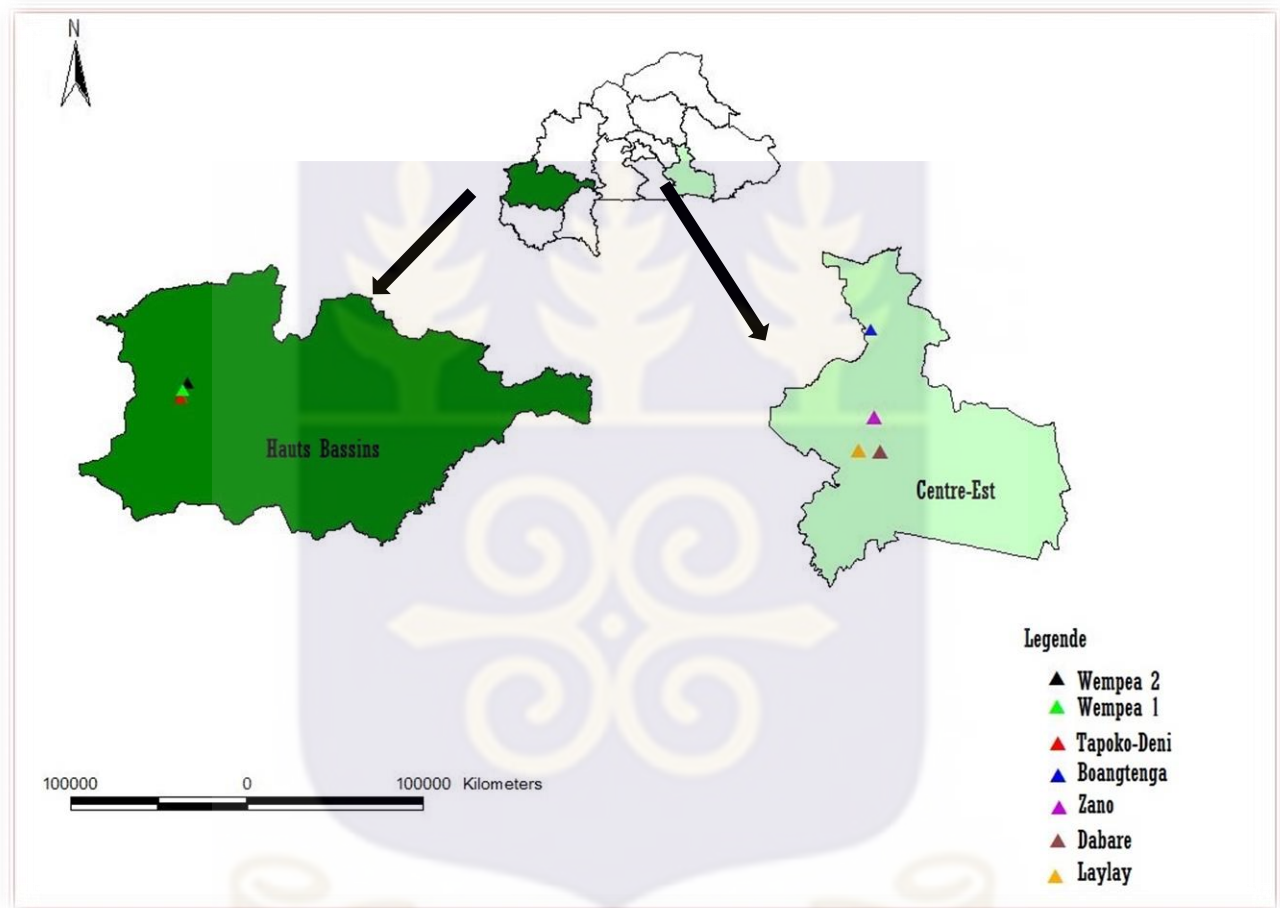


Figure 3.1: Map of Burkina Faso showing PRA sites

3.2.3 Farmers' participatory varietal selection

A participatory varietal selection was conducted in order to identify with farmers their preferred grain quality traits. Grains of seven cowpea varieties of different qualities (size, colour, texture) served as basis for selection (Table 3.2). One participatory varietal selection was conducted in each village. The participatory varietal selection was done separately for men and women since preferences can vary with regard to the gender of the farmer. Each group was therefore isolated from the other for this exercise starting with women groups in each village. Fruits of *Azadirachta indica* or *Arachis hypogaea* or small stones were used to help farmers quantify the varieties they preferred. Hundred fruits or stones were given to each group and after discussion (Figure 3.2) they were to put the maximum number of items on the variety of their choice. If a variety was not appreciated at all nothing was put on it. Ranking was done by calculating the percentage of items with regard to the variety. Varieties recording the highest allocated percentage were the most preferred. The criteria of choices were explained by the different groups.



Figure 3.2: Men ranking cowpea varieties at Toussiana based on their grain preferences.

Table 3.2: Grain characteristics of the varieties used for the participatory varietal selection

Variety	size	colour	hilum
Yiisyandé	big	white	black
TVU14676	big	black	black
Tiligré	big	white	cream
KVx61-1	medium	white	brown
IT82D-849	big	red	red
Gorom local	medium	brown	brown
Gourgou	big	white	white

3.2.4 Questionnaire administration

A questionnaire was randomly administered to 10 to 15 farmers per village. Gender ratio was considered as much as possible, in each village. Respondents were asked about their personal information, their crop production systems and problems they encountered in cowpea production as well as their varietal preferences. It was further necessary to understand how far farmers know the relation between the parasite and its host. For this purpose they were asked to identify *Alectra vogelii* host crops they knew. It was also important to know farmers' perceptions about the effects of *Alectra* on cowpea yield. To facilitate this estimation, farmers were told to assume that they harvest 100 bags of 100 kg if *Alectra* does not occur. They estimated the number of bags they lost due to the prevalence of *Alectra*.

3.2.5 Data analysis

Data collected were analysed with Sphinx Lexica version 4.5.0.28. Chi-square test was run to check for similarities and dissimilarities of responses. Computation was done for each district or as a combination of the three districts. Factorial analysis and principal component analysis were also used. Results are presented in tables and graphs.

3.3 Results

3.3.1 Farmers' awareness on *Alectra vogelii* as a parasitic weed to cowpea production

A total of 112 farmers were interviewed, among them 23.2% were women. The sample was distributed as follows: 33 farmers from Koupela, 32 farmers from Tenkodogo and 47 farmers from Toussiana (Table 3.3). Most of the respondents (72%) have seen *Alectra* before the survey but some of them did not recognise it as a parasite (Figure 3.3).

Table 3.3: Number of interviewed farmers per locality

Gender	Locality			Total
	Koupela	Tenkodogo	Toussiana	
Female	6 (23)	10 (38.5)	10 (38.5)	26 (100)
Male	27 (31.4)	22 (25.6)	37 (43)	86 (100)
Total	33	32	47	112

Percentage in brackets

The results of the study also showed that nearly 60 percent (59.8%) of the interviewed farmers knew *Alectra vogelii* as a parasitic weed. However, a large variability was observed in farmers' awareness across regions (Table 3.4). The results of the factorial analysis of farmers' awareness on *Alectra vogelii* showed that 66% of this variability was explained by the two first principal components (Axes 1 and 2). The locality of Toussiana was associated to farmers' awareness. The chi-square test for awareness between localities was highly significant ($P < 0.001$), in contrast it was not significant for gender ($P = 0.34$) (Table 3.4).

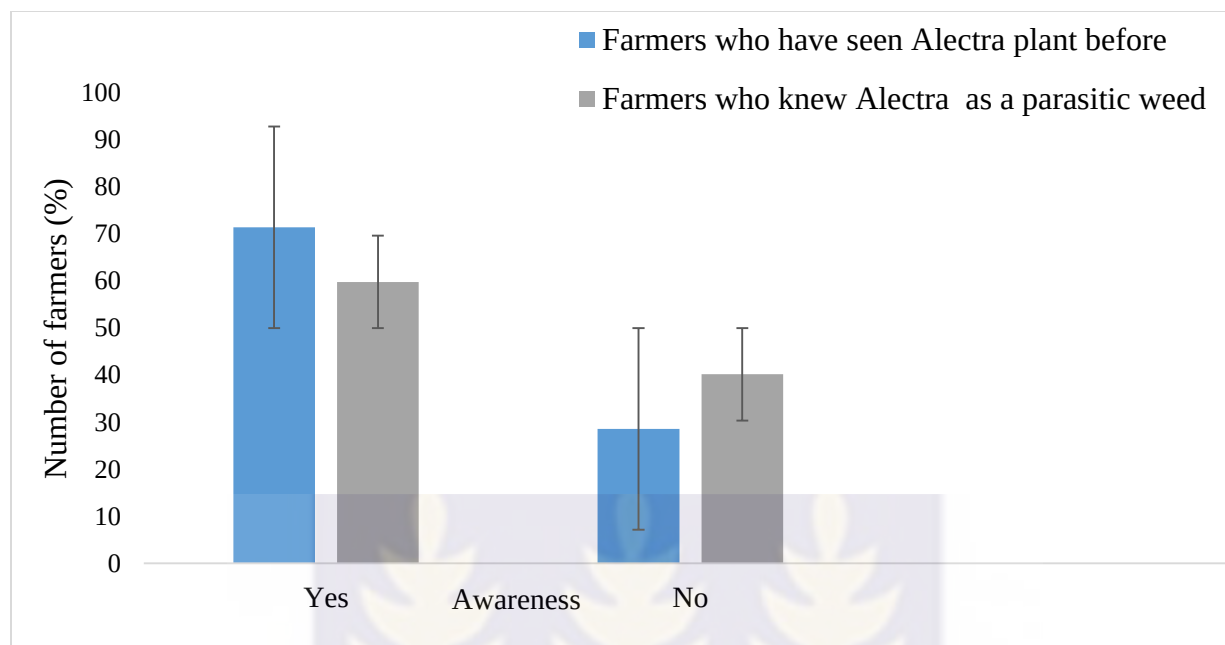


Figure 3.3: Proportion of farmers for their awareness on *Alectra vogelii* in the study areas

Table 3.4: Famers' awareness of *Alectra* as a parasitic weed

Awareness						
Variable	Yes		No		Total	p-value
	observed	expected	observed	expected		
Gender						
Male	53 (61.6)	51.45	33 (38.4)	34.55	86	0.34
Female	14 (53.8)	15.55	12 (46.2)	10.45	26	
Locality						
Koupela	11 (16.4)	19.74	22 (48.9)	13.26	33	<0.001
Tenkodogo	14 (20.9)	19.14	18 (40)	12.86	32	
Toussiana	42 (62.7)	28.12	5 (11.1)	18.88	47	

Percentage in brackets

The majority (89%) of the interviewed farmers from Toussiana knew *Alectra* as a parasitic weed. This locality accounted for 62.7% of the global farmers' knowledge about *Alectra*. On the other hand, 89.9% of the farmers who ignored its noxiousness were from Koupela and Tenkodogo (Table 3.4). No significant difference was observed between men and women awareness of *Alectra vogelii* (Table 3.4).

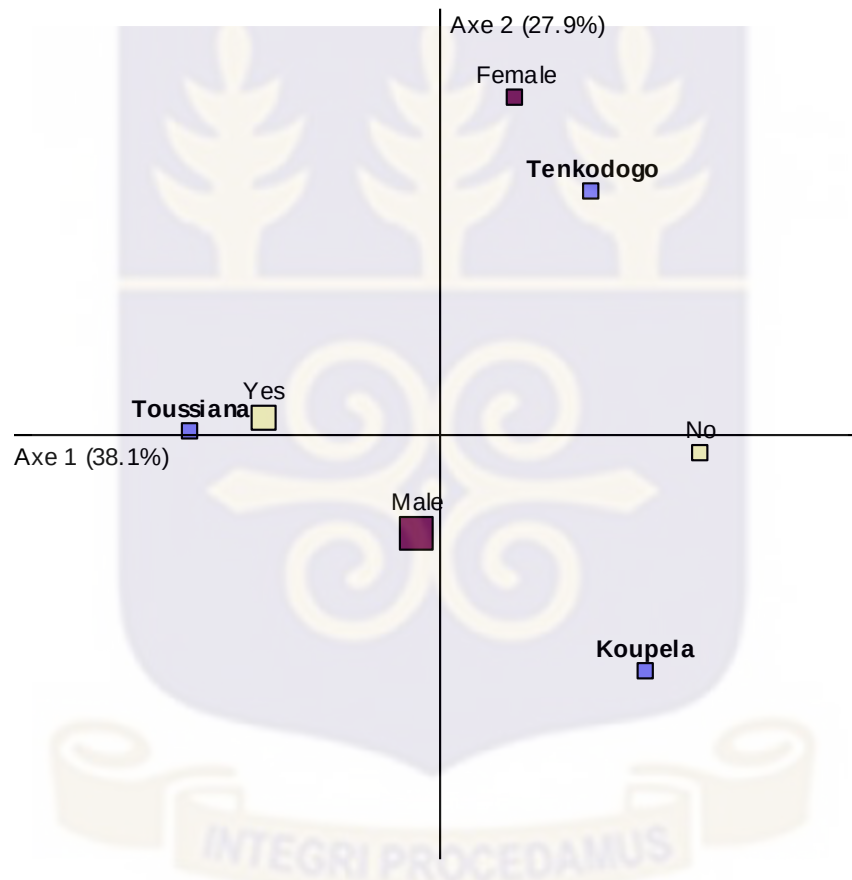


Figure 3.4: Factorial analysis of farmers' awareness on *Alectra vogelii* according to their locality and gender

3.3.2 Farmers' identification of *Alectra vogelii* host crops

The results of farmers' identification of *A. vogelii* host crops are presented in Table 3.5. The majority of the respondents (65.2%) identified cowpea as host crop of *Alectra* followed by

groundnut (48.2%). Three cereal crops: pearl millet, sorghum and rice were identified as host of *Alectra* by 16.1% of the respondents. These farmers thought that *Striga gesnerioides* and/or *Alectra vogelii* change into *Striga hermonthica* and vice versa depending on the crop grown (legume or cereal). They did ignore that *Alectra* and *Striga* are different species of parasitic weeds parasitizing crop plants from different classes. The remaining legume crops (soybean and Bambara groundnut) were not well known by farmers as host crops as expected because they were produced by few respondents.

Table 3.5: Farmers' perception of host crops of *Alectra vogelii*

Corp	Number
No response	31 (27.7)
Cowpea	73 (65.2)
Groundnut	54 (48.2)
Soybean	1 (0.9)
Bambara groundnut	3 (2.7)
Pearl millet	11 (9.8)
Sorghum	5 (4.5)
Rice	2 (1.8)
Total observation	112

Percentage of respondents in brackets

3.3.3 Farmers' identification of cowpea production constraints

Five biotic constraints to cowpea production were ranked by farmers in the three sites as presented in Table 3.6. At Koupela *Striga gesnerioides* was ranked as the most important constraint to cowpea production followed by insect pests, foliar diseases and stem diseases. *Alectra vogelii* was ranked the least important. Farmers at Tenkodogo did not recognize foliar and stem diseases as constraints to cowpea production. *Striga gesnerioides*, insects and *Alectra vogelii* in this order

were ranked as the main biotic constraints. However, at Toussiana *Alectra* was ranked first before insects and *Striga*. Over all, the most important biotic constraints in cowpea production identified in the three sites by farmers were *Striga gesnerioides*, insects and *Alectra vogelii* in this order. The prevalence of both *Striga gesnerioides* and *Alectra vogelii* was linked with low soil fertility which was also identified as a production constraint. Poor soil was thought to be a channel for *Alectra vogelii*. Farmers at Koupela mentioned that damages caused by *Striga* are more severe when drought occurs at the reproductive stage. Besides post-harvest problems were mentioned at Toussiana principally the high cost of the Purdue Improved Cowpea Storage (PICS) bags for safe storage. Inaccessibility to seeds of improved varieties and other inputs (fertilizers, pesticides) also came out as constraints in cowpea production.

Table 3.6: Farmers' ranking of the importance of biotic constraints of cowpea production in the study areas

Constraints	Locality						Total	Rank
	Koupela	Rank	Tenkodogo	Rank	Toussiana	Rank		
Foliar diseases	5	3	0		9	4	14	4
Stem diseases	3	4	0		2	5	5	5
Insects	19	2	23	2	27	2	69	1
<i>S. gesnerioides</i>	25	1	26	1	9	3	60	2
<i>Alectra vogelii</i>	1	5	4	3	34	1	39	3
Total	53		53		81		187	

Rank: 1= first, 2= second, 3= third, 4= fourth, 5= fifth.

3.3.4 Farmers' perception on the effects of *Alectra vogelii*

Yield loss due to *A. vogelii* was differently appreciated by farmers. The chi-square test was highly significant for the estimate of yield loss between farmers from the three locations (Table 3.7). The yield loss estimates were grouped into three classes as follows:

- Class one: yield loss less than 50%;
- Class two: 50% yield loss and
- Class three: more than 50% yield loss.

The proportions of farmers for their perception of cowpea yield reduction related to *Alectra* are presented in Table 3.7 and Table 3.8. Many farmers (45.5%) did not have an idea on the damages caused by *Alectra* on cowpea. Farmers' perceived yield losses ranged from 5% to 100% yield loss (Table 3.8). The study also showed that 44% of the farmers attributed at least 50% yield reduction due to *Alectra vogelii* (Table 3.8). At Toussiana 76.6% of the respondent were for that opinion (Table 3.7). The principal component analysis graph showed that Koupela and Tenkodogo were grouped at the opposite sides of Toussiana from the origin of the graph (Figure 3.5). The first axe accounted for the total weight of estimated yield loss.

Table 3.7: Association between yield loss and locality

		Yield loss					
Locality	Frequency	No idea	<50%	50%	>50%	Total	p-value
Koupela	Observed	26	2	3	2	33	<0.001
	Expected	15.03	3.24	5.6	9.13		
Tenkodogo	Observed	20	3	6	3	32	
	Expected	14.57	3.14	5.43	8.86		
Toussiana	Observed	5	6	10	26	47	
	Expected	14.57	3.14	5.43	8.86		
Total		51	11	19	31		

Table 3.8: Farmers' perception on cowpea yield losses due to *Alectra vogelii*

Yield loss	Number of respondent
No idea	51 (45.5) ^a
Less 50%	11 (10.5)
50%	19 (17)
More 50%	31 (27)

^a :Percentages in brackets

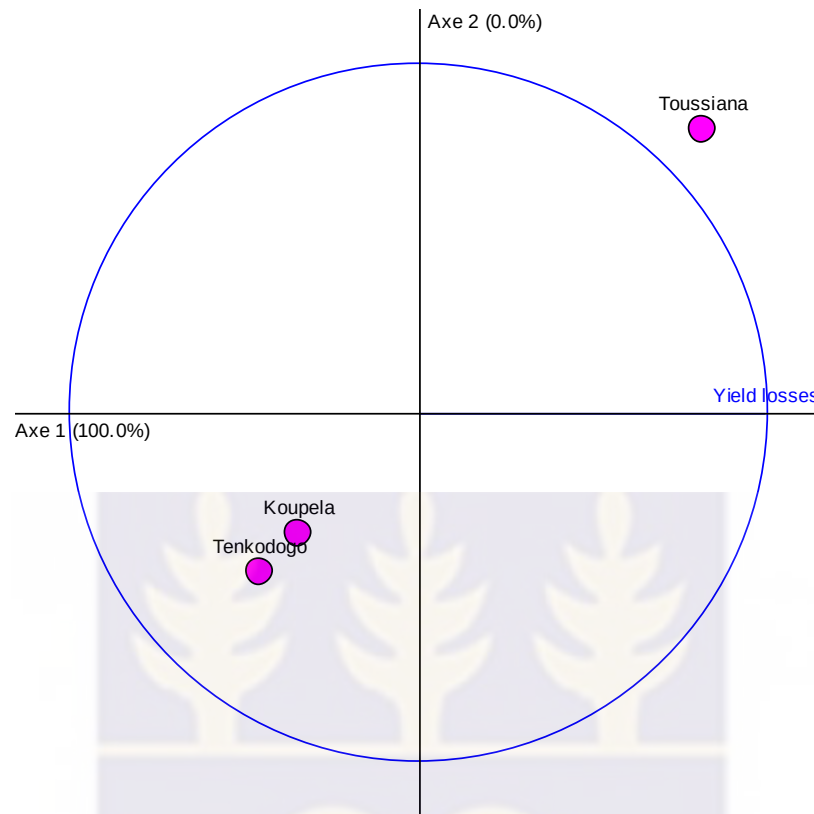


Figure 3.5: Principal component analysis showing the importance of estimated yield losses due to *Alectra vogelii*

3.3.5 Production system and control measures

Two main cropping systems were used by farmers: crop rotation (61%) and intercropping (36%) (Figure 3.6). The two systems were simultaneously used in some cases. Cereal-legumes or cereal-cereal (sorghum, pearl millet) rotations were used. A few of them were practicing pure culture. These practices are often used for restoring soil fertility and weeds management. Cultural practices have been farmers' main method for controlling *Striga* sp. and *A. vogelii*. Manual uprooting has been the widest practiced control measure. The application of organic matter was mentioned as a control method as well. However, farmers recognized the limitations of these methods and were therefore willing to experiment new technologies such as the use of resistant varieties.

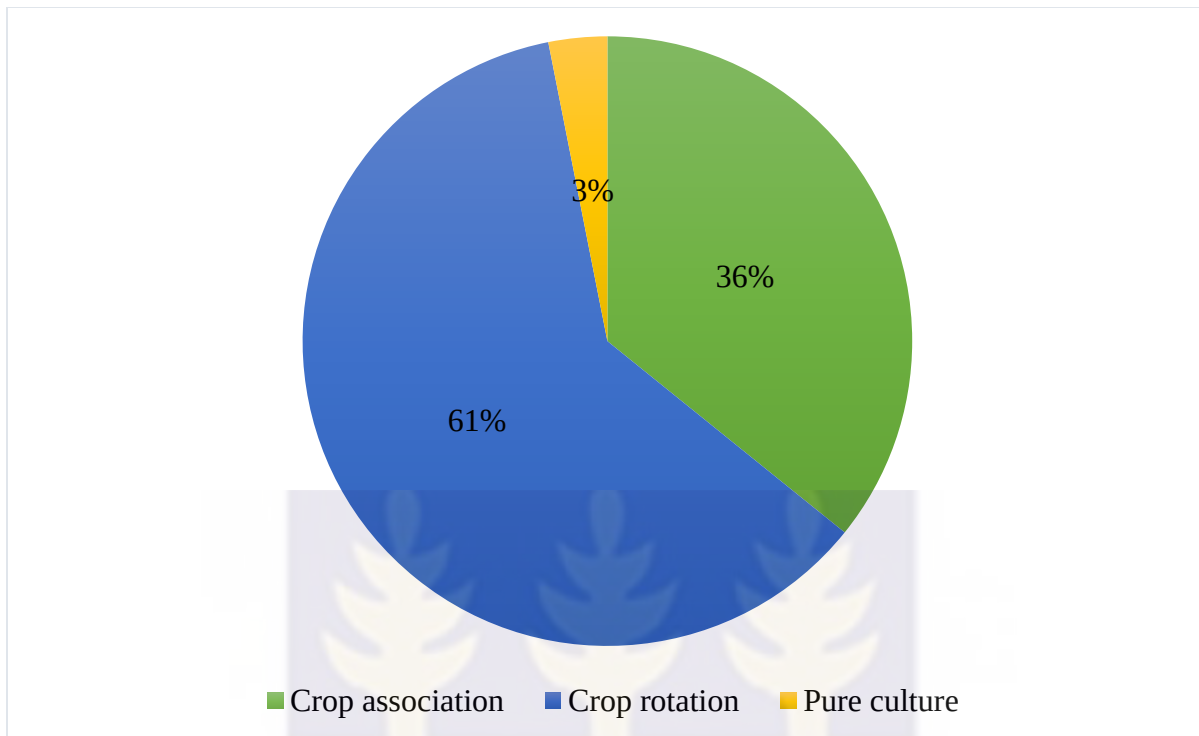


Figure 3.6: Cropping systems used by farmers

3.3.6 Farmers' varietal preferences

Farmers' preferred characteristics of cowpea varieties are presented in Table 3.9. It came out from this study that varieties with wrinkled grain texture (64.3%) large grain size (86.4%) and white grain colour (97.3%) were largely preferred by farmers across the three locations. Then for grain quality no difference was observed between farmers' preferences in the different locations. However, with regard to the growth habit and the cycle slight differences were observed even though prostrate (44.6%) and erect (44.6%) short cycle varieties (81.3%) were preferred. Prostrate varieties were more preferred at Toussiana whilst erect varieties were preferred at Koupela and Tenkodogo. In summary farmers' preferred cowpea varietal characteristics for all the locations were: prostrate and erect sort cycle varieties with rough big sized white grains.

Table 3.9: Farmers' preferred varietal characteristics and chi-square p-value

Trait	Varietal characteristic	Number of respondents			Total	p-value
		Koupela	Tenkodogo	Toussiana		
Growth habit	Prostrate	9	6	35	50 (44.6)	0.012
	Semi-erect	9	9	5	23 (20.5)	
	Erect	18	20	12	50 (44.6)	
Cycle	Short	30	27	34	91 (81.3)	0.042
	Medium	5	7	10	22 (19.6)	
	Long	0	0	6	6 (5.4)	
Grain colour	White	33	31	45	109 (97.3)	0.508
	Red	0	1	4	5 (4.5)	
	Black	0	0	0	0 (0)	
Grain size	Big size	31	28	38	97 (86.6)	0.313
	Medium size	5	6	9	20 (17.9)	
	Small size	0	0	3	3 (2.7)	
Grain texture	Wrinkled	25	22	25	72 (64.3)	0.134
	Smooth	8	10	22	40 (35.7)	

Percentages in brackets

Results from the participatory variety selection based on grain quality acceptability showed important differences between men and women farmers' choices at Koupela (Figure 3.7). The varieties Yiisyandé, KVx61-1 and Tiligré were the most preferred by men whilst Tiligré, Gourgou and KVx61-1 were the ones preferred by women. Criteria for the choice by men were mainly based on market demand for Yiisyandé and Tiligré, where big white grains with black or brown eyes were required. The other variety (KVx61-1) was selected because of its good taste, it was mainly used for family consumption. This variety was also chosen by women for the same reason as men. KVx61-1 is well appreciated and consumed by children but is poorly sold. On the other hand, big

grain size and their culinary ability and market acceptability were the criteria of women for selecting Tiligré and Gourgou.

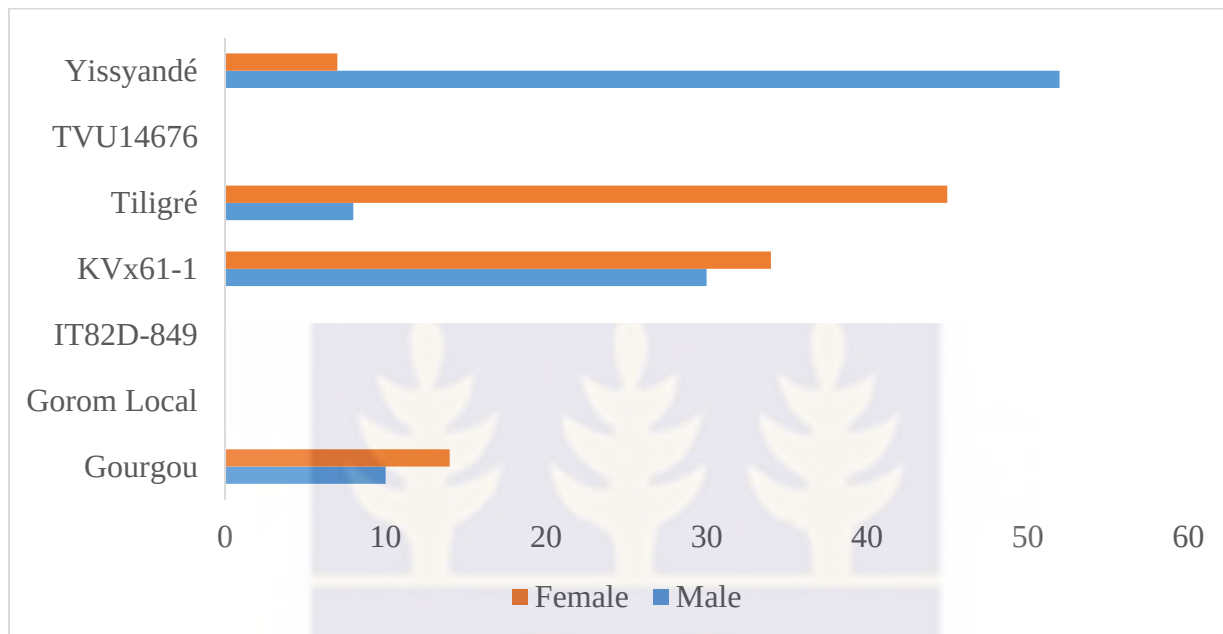


Figure 3.7: Cowpea varietal acceptability based on farmers' preferred grain quality at Koupela, 2015.

At Tenkodogo farmers' preferences were similar to those at Koupela but in this locality, men as well as women farmers, chose only the four varieties having white grains (Figure 3.8). In both groups the variety KVx61-1 was the least preferred. Tiligré, Gourgou and Yissyandé were the most accepted by men in this order even though there were no significant differences between them. Cowpea productivity and market acceptability were their criteria of choice. Unlike men, Tiligré was by far the most preferred by women compared to Yissyandé and Gourgou. Women made their choice with regard to cooking time, productivity and taste of the variety.

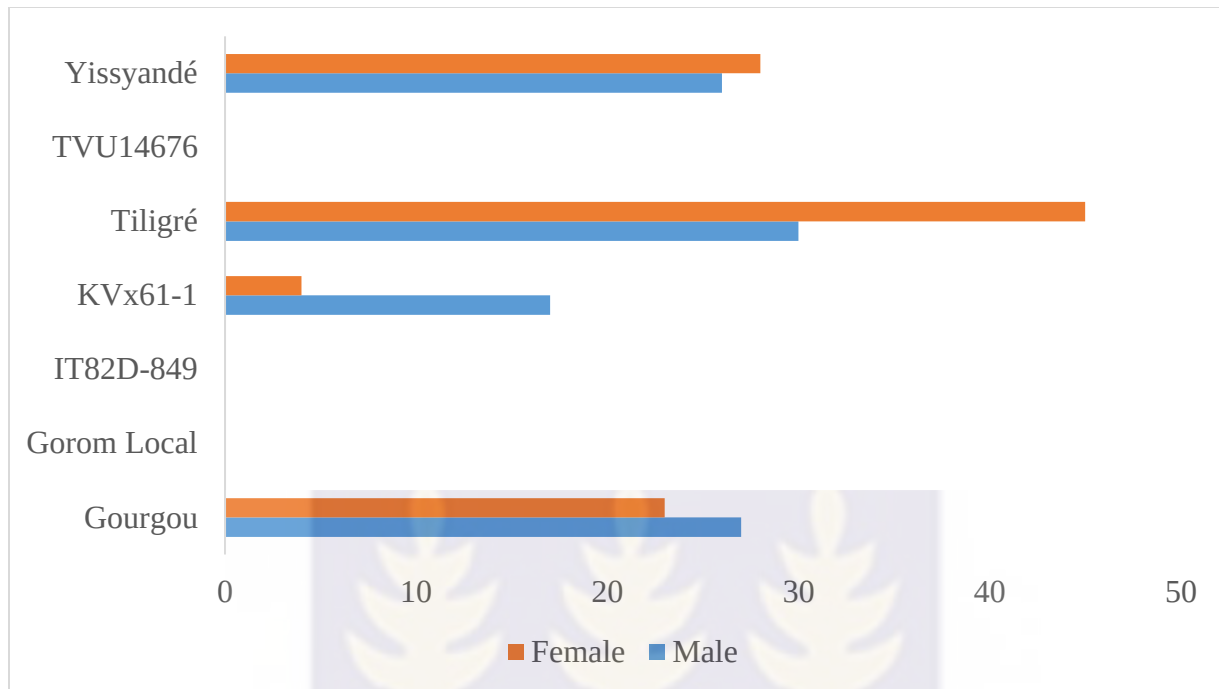


Figure 3.8: Cowpea varietal acceptability based on farmers' preferred grain quality at Tenkodogo, 2015.

At Toussiana Tiligré, KVx61-1 and Yissyandé were the preferred varieties of farmers (Figure 3.9). Tiligré and KVx61-1 were the most preferred by men whereas KVx61-1 and Yissyandé were women most preferred varieties. Tiligré was preferred by men because it is high yielding and is accepted by consumers. Besides this variety is adapted to intercropping with cereal crops. Both men and women justified their choice of the variety KVx61-1 by its good taste which is mainly preferred for family consumption. Women also mentioned that the variety is very easy to cook. Market acceptability was another criterion used to select varieties.

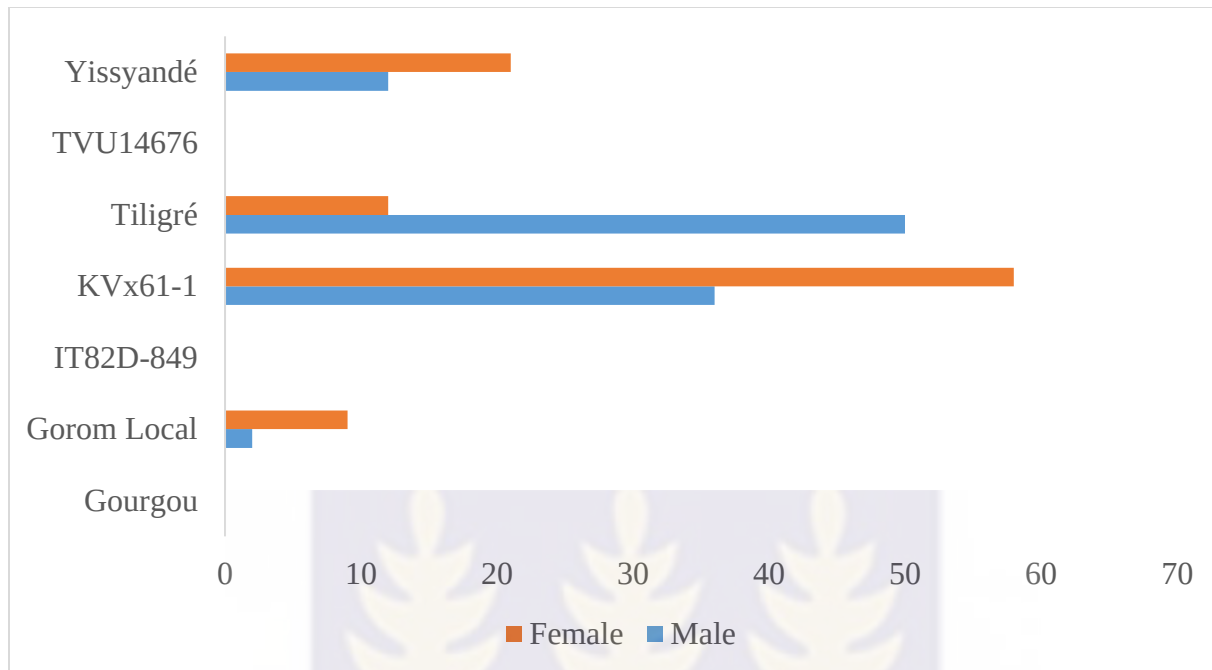


Figure 3.9: Cowpea varietal acceptability based on farmers' preferred grain quality at Toussiana, 2015.

3.4 Discussion

The results of this study showed a large variability in farmers' awareness on the parasitic effects of *Alectra vogelii*. Whilst the weed was well known by farmers from Toussiana in western Burkina Faso, its parasitic status was not known by the large majority of farmers from central east. In contrast its related species *Striga gesnerioides* was very familiar to the farmers from this region. Kabambe *et al.* (2013) obtained similar results in Malawi when a survey was addressed to extension officers. *Alectra vogelii* has green leaves like normal photosynthetic leaves but are lacking functional chlorophyll (Parker, 2012). As a result farmers do not pay particular attention to it until it becomes a serious problem. Their ignorance of the parasitic weed status of *Alectra* could have contributed to its dissemination. Actually farmers generally recognize a threat as such

from the importance of its damages. For example in western Burkina Faso where *Alectra* was first observed (Subrahmanyam *et al.*, 1989) (probably from where it was introduced into the country), it had unfortunately enough time to disseminate and increase the seed bank in the soil freely without any control measure. In addition, little research and communication were done to help farmers recognize it as a constraint. This is because the economic importance of *Alectra* was neglected by researchers. Therefore, it is undoubtedly the gradual severe effects of the weed that led most farmers to get familiar with it in this zone. The ignorance of the parasitic effects of *Alectra vogelii* by most farmers at Koupela and Tenkodogo could be related to its relatively low infection density in these areas.

Farmers identified very well the main host crops of *Alectra vogelii*. Cowpea (65.2%) and groundnut (48.2%) were recognized to be associated with the occurrence of *Alectra* in the field. These crops are the largest grain legume crops produced in Burkina Faso. Some farmers even think that the weed is brought by the identified crops. This opinion could be explained from their cultural practices. Legume-cereal rotation in *Alectra* infested field will obviously make farmers think that the legume crops bring *Alectra* because the weed only emerges when its hosts are grown. Cowpea and groundnut belong to the family of Legumes which have been identified as *Alectra vogelii* natural hosts (Boussim, 2002). Farmers' knowledge on the link between a parasite and its host derives from their power in field observations. This skill allows them to distinguish between various types of threats hampering their production. However, training is necessary to help them understand better some of the phenomenon. It was realized that some farmers thought that *Striga gesnerioides* changed into *Alectra vogelii* or *Striga hermonthica* and vice versa probably because of cereal-legume rotation and/or inter-cropping. They did not know that these weeds are different species of parasitic weeds with even host specificity. Collaborative research and other scientific

training should be intensified to strengthen farmers' knowledge about production constraints and the new technologies as well.

Previous studies in 2007 and 2012 aimed at identifying and ranking cowpea production constraints in general. In the present study only biotic constraints were addressed. *Striga gesnerioides* and insect pests were identified as the most important biotic threats to cowpea production. This is in agreement with the findings of Tignegre (2010) and Batieno (2014). However, these studies showed that abiotic constraints such as low soil fertility, drought and limited accessibility to seeds of improved varieties were mostly ranked before biotic constraints. The parasitic weed *Alectra vogelii* which was not mentioned during these studies was ranked third biotic constraint to cowpea production after *Striga gesnerioides* and insects. The findings of Boussim (2002) showed that *Alectra vogelii* did not prevail in the Centre-north and Sahel zones of Burkina Faso. The non-occurrence of *Alectra* in these regions which were covered by Tignegre (2010) and Batieno (2014) could explain why it was not reported. However, *Alectra* might have been recently introduced to these zones. Therefore, it is necessary to conduct further survey in these areas to check whether they are still free of *Alectra* or not.

Alectra vogelii is a noxious weed affecting cowpea production. The extent of damages depends on the degree of infestation of the field. The current study revealed that farmers from western Burkina Faso, regardless of gender, knew better about *Alectra vogelii* compared to the other studied localities. Similarly the highest yield loss was reported by farmers from this locality. The prevalence of *Alectra vogelii* in Burkina Faso was first reported in western Burkina Faso 30 years ago (Subrahmanyam *et al.*, 1989). But since then, rigorous measures were not implemented to control it. For 30 years long, whilst *Alectra* was neglected, its highly invasive potential allowed an exponential increase of the seed bank in the soil. As a result, *Alectra* is a serious constraint to grain

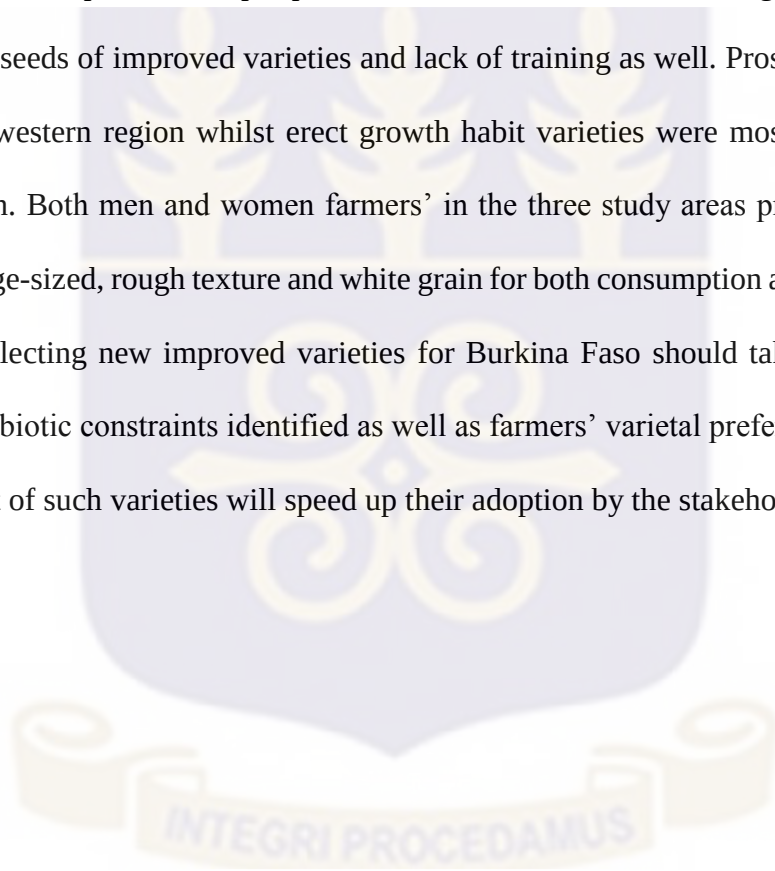
legumes production in the country nowadays. In heavily infested field, total yield loss were registered. Elsewhere in Africa, yield losses ranged from 30% to 100% (Mbwaga *et al.*, 2009; Omoigui *et al.*, 2012; Karanja *et al.*, 2013; Mbega *et al.*, 2016). The economic importance of *A. vogelii* revealed by this study calls for urgent measures to control it. However, it is important to notice that this weed like the other related parasitic weeds, is very difficult to manage. In addition, the occurrence and severity of *A. vogelii* is tightly related to poor soils. Therefore, only an appropriate integrated management strategy with genetic resistance as the principal component could allow to address this threat.

A successful use of genetic resistance in the control of *A. vogelii* will depend on farmers acceptance of the resistant varieties proposed. So the study also included farmers' varietal preferences as selection criteria. In all PRA sites, farmers selected varieties with large sized, rough texture and white seed coat grains (Tiligré, Yiisyandé and Gourgou). These criteria refer to productivity and market demand. Similar results were obtained in previous studies (Tignegre, 2010; Saidou *et al.*, 2011; Batieno, 2014; Ibrahim *et al.*, 2014; Horn *et al.*, 2015). Yield performance coupled with market demand are by far the most important criteria of farmers' choice (Tignegre, 2010; Gbaguidi *et al.*, 2013; Batieno, 2014). Besides these characteristics, farmers also selected varieties for culinary characteristics. For example farmers chose the variety KVx61-1 based on its good taste even though it is highly susceptible to *Alectra vogelii* and the grains poorly sold. This variety could be improved for *Alectra* resistance since it combines already farmers preferred traits and resistance to *Striga gesnerioides*. In the study areas brown and red coloured seed were entirely rejected by farmers. However, Tignegre (2010) found that farmers in the Sahel (Oudalan province) preferred brown coloured seeds. Therefore, a small variation is observed in farmers' choice for this trait within the country. Similar report was done by Langyintuo *et al.* (2003), though white grain testa

remains largely preferred by farmers in west and central Africa according to these authors. Cowpea growth habit and reproduction cycle were also important criteria of choice in the areas covered in this study. Unanimously, farmers chose short cycle varieties in all the three locations but prostrate and erect varieties were equally preferred by farmers from western region and centre-east region respectively. On one hand, rain decline with irregular rainfall within and across years has heavily weighted for farmers choosing short cycle varieties. Drought was mentioned by farmers as one of the most important constraints to cowpea production (Tignegre, 2010; Batieno, 2014) putting emphasis on terminal drought (Batieno, 2014). As such, short cycle varieties will be ideal for them to escape terminal drought. On the other hand, cultural practices (pure culture or intercropping) guided farmers' choice. Whilst farmers from western Burkina Faso (Toussiana) favoured prostrate varieties, erect ones were chosen in centre-east (Toussiana, Tenkodogo). In the latter region, farmers have progressively moved from intercropping to cowpea pure culture with the release of new varieties. In contrast at Toussiana local varieties are still widely used. Farmers mentioned the lack of improved cowpea varieties and technical packages as production constraints. Therefore, there is an urgent need to accompany farmers with training to increase their cowpea production. From the above analysis, it can be undoubtedly inferred that to meet farmers' preferred varietal characteristics breeding objectives in Burkina Faso should be focused on selecting varieties possessing large-sized and white-coloured grain with adaptation for both the local food consumption and market demand for all the covered zones. These selection criteria corroborate those suggested by Tignegre, (2010) and Batieno (2014). Such varieties should be able to withstand most biotic constraints (*Striga gesnerioides*, *Alectra vogelii*, and insects) and abiotic constraints (drought, heat).

3.5 Conclusion

This study showed that *Striga gesnerioides* insects and *Alectra vogelii* were the most important biotic constraints to cowpea production. *A. vogelii* was ranked third biotic constraint however, there was a variation in farmers' awareness about the parasitism of *Alectra* between regions. Farmers from western Burkina Faso had better knowledge about *Alectra*. No difference was observed between men and women knowledge of the weed. High yield losses (more than 50%) due to *A. vogelii* were reported. Cowpea production constraints included drought, low soil fertility, limited access to seeds of improved varieties and lack of training as well. Prostrate varieties were preferred in the western region whilst erect growth habit varieties were mostly accepted in the centre-east region. Both men and women farmers' in the three study areas preferred short cycle varieties with large-sized, rough texture and white grain for both consumption and market demand. Consequently, selecting new improved varieties for Burkina Faso should take into account the main biotic and abiotic constraints identified as well as farmers' varietal preferred characteristics. The development of such varieties will speed up their adoption by the stakeholders.



CHAPTER FOUR

4.0 IDENTIFICATION OF SOURCES OF RESISTANCE TO *Alectra vogelii* IN COWPEA GERMPLASM FROM BURKINA FASO

4.1 Introduction

Cowpea production is drastically limited by several abiotic and biotic constraints which are: drought, low soil fertility, limited access to seeds of improved varieties, insect pests, diseases and parasitic weeds (Emechebe & Lagoke, 2002; Tignegre, 2010; Batieno, 2014). Among the biotic constraints parasitic weeds are important in cowpea production. *Alectra vogelii* is a hemi-parasitic plant causing severe damages to cowpea and other grain legume crops such as groundnut, soybean and common bean. In heavily infested cowpea fields, total yield losses are often recorded (Singh & Emechebe, 1991; Kureh & Alabi, 2003; Omoigui *et al.*, 2012; Kabambe *et al.*, 2013; Karanja *et al.*, 2013). Besides yield loss, infestation by *Alectra* results in a general decrease of the concentration of mineral elements in cowpea grain (Alonge *et al.*, 2001b; Alonge & Alabi, 2009).

Alectra vogelii is a wide spreading weed making it a difficult constraint to manage. Most of the control measures proposed (cultural practices, chemical and biological controls) failed in containing this witchweed either because their inefficiency or for their high cost and technical skills required. Therefore, genetic resistance, the most efficient and affordable method, has been explored. As a result several genotypes has been identified conferring resistance to *Alectra* in different countries. Atokple *et al.* (1993) and Singh *et al.* (1993) reported that the land race B301, from Botswana, is resistant to *Alectra* in northern Nigeria. But, this landrace was infected with few *Alectra* shoots in Botswana (Polniaszek *et al.*, 1991). Six improved varieties: IT90K-59, IT90K-82-2, IT93K-693-2, IT97K-205-8, IT97K-499-35 and IT87K-819-118, conferring resistance to both *Alectra* and *Striga* have been developed at IITA (Singh *et al.*, 2006). Kabambe *et al.*, 2014)

observed high resistance to *Alectra* conferred by the variety IT99K-494-6 in Malawi. However, these varieties do not possess farmers' preferred characteristics in Burkina Faso. In addition, differential reaction of cowpea genotypes to *Alectra* ecotypes has been reported Polniaszek *et al.* (1991); suggesting the existence of different races of the weed. Moreover, in Burkina Faso no study has been done on the genetic resistance of cowpea to the ecotypes of *Alectra* prevailing in the different agro ecologies. Therefore, there is a necessity to assess the cowpea genotypes for their reaction to these ecotypes of *Alectra vogelii*. Field screening for identification of sources of resistance has been successful even though it is difficult for breeders to entirely control the experimental factors in field conditions (Hausmann *et al.*, 2000). On the other hand, in pot screening, the breeder controls the conditions principally *Alectra* inoculation. This study aimed at identifying *Alectra*-resistant cowpea genotypes. The specific objectives were: (i) to identify *Alectra*-resistant genotypes under artificial and natural infestation using three ecotypes of *Alectra* prevailing in Burkina Faso and (ii) to determine whether the three ecotypes of *Alectra* are different ecotypes.

4.2 Materials and methods

4.2.1 Cowpea germplasm and *Alectra vogelii* seeds

The cowpea genetic material used in the study comprised of 120 genotypes from the cowpea germplasm of the Institut de l'Environnement et de Recherches Agricoles (INERA) research station at Kamboinsé in Burkina Faso. The genotypes B301 a landrace from Botswana and TVx3236 were used as resistant and susceptible checks respectively. Three wild relatives of cowpea were also included (Appendix 1). A set of twenty five genotypes were selected, on the

basis of farmers' preferences and their reaction to *A. vogelii*, from the screen house screening and taken to the field for genotypes by environment study (Table 4.1).

Alectra vogelii seeds were collected from Koupela (12°12 N; 0°19 W) Tenkodogo (11°42 N; 0°22W), and Toussiana (10°52 N; 4°33 W) at the end of the 2014 rainy season. The seeds were dried under shade and later sieved with a suitable (250-300 µm) meshed sieve.



Table 4.1: Origin and grain colour of the 25 cowpea genotypes selected for field screening

Variety	Origin	Grain colour	<i>Alectra</i> -resistance
B301	Botswana	Brown	HR
Djouroum local	Burkina Faso	White	MR
Gorom local	Burkina Faso	Brown	HS
Gourgou	Burkina Faso	White	MR
HTR	Niger	White	MR
IT81D-994	IITA/Nigeria	White	MR
IT82D-849	IITA/Nigeria	Red	HS
IT86D10-10	IITA/Nigeria	Brown	HR
IT93K-693-2	IITA/Nigeria	Brown	HR
IT98K-205-8	IITA/Nigeria	White	HR
IT99K-573-2-1	IITA/Nigeria	White	HR
Komcalle	Burkina Faso	White	HR
Komcalle P-5	Burkina Faso	White	MR
KVX 165-14-1	Burkina Faso	Brown	HR
KVX30-309-6G	Burkina Faso	White	S
KVX414-22-2	Burkina Faso	White	HR
KVX61-1	Burkina Faso	White	HS
KVX780-1	Burkina Faso	White	MR
KVX780-3	Burkina Faso	White	MR
KVX780-4	Burkina Faso	White	MR
KVX780-6	Burkina Faso	White	MR
KVX780-9	Burkina Faso	White	MR
Moussa local	Burkina Faso	White	HS
Nafi	Burkina Faso	White	MR
Tiligre	Burkina Faso	White	MR

HR: highly resistant, MR: moderately resistant, S: susceptible, HS: highly susceptible

4.2.2 Pot screening

The experiment was conducted under screen house at Kamboinsé research station (12° 27'N, 1° 32' W) in 2015 (March 2015 to June 2015). The trial was laid out as a randomized complete block design (RCBD) with three replications. In each replication plastic pots of 10 litres (L) were the experimental units. A mixture of soil made of three volumes of sand for one volume of clay (3:1) in order to provide a suitable substrate for the development of both cowpea and *Alectra* was used. The mixture was first sterilized, at 100°C for 8 hours to eliminate any other sources of weed seeds including those of *Alectra* that could be in the soil, and dried under screen house. Thereafter, approximately 12 kg of the dried soil was filled into 1080 pots. Later the pots were infested with about 1,000 *Alectra vogelii* seeds each according to the recommendations of Musselman & Ayensu (1983) and Magani *et al.* (2008). *Alectra* seeds were thoroughly mixed with sieved sterile soil before infestation. In each pot two layers of weed seeds were applied and covered with the sterile soil. Infested pots were watered for two weeks to precondition *Alectra* seeds in order to ensure optimum germination by breaking their dormancy. This period of time was reported to be optimal for preconditioning *Alectra* seeds (Magani *et al.*, 2008). Thereafter, three cowpea seeds were sown per pot and thinned to one plant two weeks after sowing. The plants were watered when there was the need. Five grams (5 g) of NPK fertilizer (14-23-14) was applied a day before planting cowpea. This dose was estimated based on the recommendation of fertilizer use in cowpea production in Burkina Faso. Two insecticide sprays were done as recommended. Three sets of the trial were laid out, each infested with one of the ecotypes of *A. vogelii*.

4.2.3 Field experiment

Field experiments were conducted in the three locations where *Alectra vogelii* seeds were collected namely Koupela (12° 12'N, 0° 20'W), Tenkodogo (11° 42'N, 0° 22'W), and Toussiana (10° 52'N, 4° 33'W) during the 2017 rainy season. The experiments were laid out in a 5x5 square lattice design replicated three times for each of the three sites. The experimental units were composed of two rows of 4 m long with a 0.8 m x 0.4 m spacing between rows and within rows respectively, 1.8 m spacing was left between plots. Two cowpea seeds were planted per hole. NPK (14-23-14) fertilizer was applied before cowpea planting at a dose of 100 kg ha⁻¹ as recommended in cowpea production in Burkina Faso. Trials were kept free of other weeds through hand-weeding. Two insecticides sprays were applied at flowering and pod setting.

4.2.4 Data collection

Days to cowpea first flowering (DTF), days to cowpea maturity (MAT) and days to *Alectra* shoots emergence (DAEMG) (number of days from cowpea planting) were daily recorded from the fourth (4) to the thirteenth (13) week after planting. Severity of *Alectra* attack was recorded 60 (SEV60), 70 (SEV70) and 80 (SEV80) days after planting (DAP) using a 1-5 scale (Singh & Emechebe, 1997). The classes of *Alectra* severity were:

- 1: highly resistant, no emergence of *Alectra* shoots;
- 2: resistant, one to three shoots of *Alectra* emerged above ground which can die few days later;
- 3: moderately resistant, presence of some fertile shoots of *Alectra*;
- 4: susceptible, presence of many shoots of *Alectra* with moderate damages (leaf discoloration and browning) and

5: highly susceptible, severe damages with sometimes death of the cowpea plant.

Cowpea 100 seeds weight (HSW) and *Alectra* dry biomass (ADB) were also weighed.

For the field experiments data collected were cowpea plant stand, number of holes with *Alectra* shoots emergence: *Alectra* shoots count (ASC), cowpea pod yield (PY) and cowpea grain yield (GY) per plot.

4.2.5 Data analysis

Normal distribution of the data was checked before the analysis of variance (ANOVA).

Pot screening data were subjected to analysis of variance (ANOVA) following the general linear model in SAS (SAS 9.4).

The combined analysis of reaction of the ecotypes of *Alectra vogelii* was performed with R statistical analysis package (R core Team, 2015). When the analysis of variances was significant, means separation was done using Bonferroni adjustment mean separation test.

Genotype by environment (GXE) interaction was run according to the general linear model in SAS version 9.4. The genotype and genotype by environment interaction (GGE) was run in the GenStat edition 12 to identify genotypes with grain yield stability.

4.3 Results

4.3.1 Pot screening

4.3.1.1 *Alectra* ecotype from Koupela

There were significant differences for all the studied parameters. Ten (10) top resistant and five (5) bottom susceptible genotypes ranked according to *Alectra* severity score of 80 DAP are presented in Table 4.2.

Days to first flowering (DTF) ranged from 37 (Bambey 21) to 64 (Goinkoro 2) days after planting (DAP) with a mean of 45 DAP. Days to maturity (MAT) varied from 54 (IT82D-849) to 74 (NS-1) days after planting, the mean was 63 DAP. Some genotypes did not flower at all, similarly some flowered but failed to set pods.

Mean weight for cowpea 100 seed (HSW) was 18.18 g. The HSW varied from 2.18 g (B301) to 28 g (Pobe local).

Alectra vogelii shoots emerged between 41 days (KVx421-2J) and 67 days (TVU14676) after planting. The average number of days to *Alectra* shoot emergence was 48 days from cowpea sowing date.

Alectra vogelii severity (SEV) scores were recorded 60, 70 and 80 days after planting (DAP). The severity score varied from 1 (highly resistant varieties) to 5 (highly susceptible varieties) for the severity score observed on the 80th DAP. The highest severity scores were 3 and 4 for severity recorded 60 and 70 DAP respectively. The average severity value for SEV80 was 3.29.

Dry biomass of *Alectra* (ADB) ranged between 0 g for the highly resistant varieties to 12.53 g (Woango-1). The mean value of ADB was 4.63 g.

Table 4.2: Cowpea reaction to *Alectra vogelii* ecotype from Koupela

Genotypes	DAEMG	DTF	MAT	ADB	HSW	SEV60	SEV70	SEV80
Top resistant								
B301	-	52.33	62.54	0	2.18	1	1	1
Komcalle	-	40.67	62.38	0	19.93	1	1	1
HTR	-	44.67	68.99	0	16.18	1	1	1
KVX414-22-2	-	47.33	63.94	0	18.27	1	1	1
IT86D10-10	-	38	54.32	0	17.7	1	1	1
IT93K-693-2	-	45	67.73	0	15.98	1	1	1
KVX780-1	-	40.33	65.32	0	23.1	1	1	1
N°2300	-			0		1	1	1
IT98K-205-8	-	40	65.52	0	16.44	1	1	1
NS1	-	62.67	74.42	0		1	1	1
bottom susceptible								
SARC1-91-1	43.66	43	61.75	8.44	16.14	3.35	4.33	5
Sanzi	43.34	49	63.73	9.3	10.73	4.01	5	5
KVX745-11P	48.33	0	58.67	8.35	0	3.01	4.33	5
IT82D-849	43.34	40	53.96	10.26	17.15	3.33	4.33	5
Woango-1	42.66	61	0	12.53	0	4.01	4.33	5
Mean	48.52	45.21	62.86	4.63	18.18	2.50	3.10	3.29
CV (%)	6.57	6.48	4.45	25.44	11.93	14.97	10.22	8.89
P-value	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001

CV: coefficient of variation, DAEMG: days to *Alectra* shoots emergence, DTF: days to first flowering, MAT: days to maturity, ADB: *Alectra* dry biomass, HSW: 100 seeds weight, SEV60: severity of *Alectra* 60 days after planting, SEV70: severity of *Alectra* 70 days after planting, SEV: severity of *Alectra* 80 days after planting

4.3.1.2 *Alectra* ecotype from Tenkodogo

Table 4.3 presents the ten top resistant and five bottom susceptible genotypes. Varieties were sorted by *Alectra* severity score. There were significant different mean squares for all the studied parameters ($P < 0.001$).

Days to flowering (DTF) varied from 35 (IT93K-1381) to 72 (KVx295-2-124-99) DAP. Days to maturity ranged (MAT) from 55 (SARC1-57-2) to 76 (N°2300) DAP. The average days to flowering and maturing were 45 and 62 DAP respectively.

Cowpea hundred seed weight (HSW) varied from 2.44 g (NS-1) to 27.42 g (KVx771-10x693-2GB). The Mean for this parameter (HSW) was 17.74 g.

Alectra vogelii shoots emerged between 42 days (Mx499-BC3F3-48P93) and 79 days (TVU14676) after planting. The average number of days to *Alectra* shoot emergence was 50 days from cowpea sowing date.

The severity score for 80 days after planting varied from 1 (highly resistant varieties) to 5 (highly susceptible varieties). The highest severity scores were 3 and 4 for severity recorded 60 and 70 days after planting respectively. The mean value for SEV80 was 3.15.

Alectra dry biomass (ADB) varied from 0 g for the highly resistant varieties to 10 g (Komsare). The mean value of DAB was 3.67 g.

Table 4.3: Cowpea reaction to *Alectra vogelii* ecotype from Tenkodogo

Genotypes	DAEMG	DTF	MAT	ADB	HSW	SEV60	SEV70	SEV80
Top resistant								
B301	-	47.15	63.65	0	7.21	1	1	1
Komcalle	-	43.46	57.81	0	19.65	1	1	1
KN-1	-	59.12	0	0	0	1	1	1
IT99K-573-2-1	-	41.35	55.93	0	20.4	1	1	1
KVX414-22-2	-	42.15	62.48	0	19.02	1	1	1
IT86D10-10	-	39.43	62.97	0	15.78	1	1	1
IT81D-994	-	43.16	61.05	0	20.01	1	1	1
KVX780-1	-	46.16	63.38	0	20.86	1	1	1
N°2300	-	59.74	75.64	0	3.62	1	1	1
IT98K-205-8	-	40.57	57.09	0	17.47	1	1	1
Bottom susceptible								
58-57	44.26			9.63		3	4.67	4.67
IT82D-849	43.66	42.86	58.88	7.3	19.19	3	4	4.67
Vita-5	42.79	49.68	66.98	7.73	15.89	3	4	5
Sanzi	42.95	42.03	57.66	7.17	7.28	3	4	5
Woango-1	46.68	55.25	72.2	5.43	18.05	3	4	5
Mean	49.54	45.18	62.22	3.67	17.74	2.24	2.96	3.15
CV (%)	4.34	8.69	2.84	21.34	12.16	10.56	7.19	9.92
P-value	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001

CV: coefficient of variation, DAEMG: days to *Alectra* shoots emergence, DTF: days to first flowering, MAT: days to maturity, ADB: *Alectra* dry biomass, HSW: 100 seeds weight, SEV60: severity of *Alectra* 60 days after planting, SEV70: severity of *Alectra* 70 days after planting, SEV: severity of *Alectra* 80 days after planting.

4.3.1.3 *Alectra* ecotype from Toussiana

Top ten resistant and 5 bottom susceptible genotypes are presented in Table 4.4. There were significant differences for all the parameters ($p < 0.001$).

Days to first flowering (DTF) ranged from 35 (KVX771-10x693-2 BulkF8-P2) to 73 (KVx295-2-124-99) DAP. The maturity (MAT) ranged from 51 (SR3) to 75 (Youngou local) DAP. The means were 44 days and 63 days for DTF and MAT respectively.

The lowest and highest cowpea hundred seed weight (HSW) were 3.62 g (NS-1) and 26 g (KVx780-1) respectively. The average HSW was 18.98g.

Alectra vogelii shoots emergence varied from 41 days (CB27) and 64 days (CR06-07) after planting with a mean of 49 days from cowpea sowing date.

The severity score varied from 1 (highly resistant varieties) to 5 (highly susceptible varieties) for 80 days after planting. The highest severity scores were 3 and 4 for Severity recorded 60 and 70 days after planting respectively. The mean severity was 3.28 for SEV80.

The average weight of *Alectra* dry biomass (ADB) was 3.71 g. The highest value recorded for ADB was 9.74 g (Dimbo local).

4.3.1.4 Differential reaction of *Alectra vogelii* ecotypes

Table 4.5 summaries the results of the combined analysis of variance (ANOVA). There were significant differences ($p < 0.05$) in cowpea genotype and ecotype of *Alectra* effects for all the traits except HSW where the effect of ecotype of *Alectra* was not significant. Significant genotype by ecotype interaction was observed for all the studied parameters. Most of the resistant varieties identified conferred resistance to the three ecotypes of *Alectra*. However, some of them showed differential response between ecotypes.

Table 4.4: Cowpea reaction to *Alectra vogelii* ecotype from Toussiana

Genotype	DAEMG	DTF	MAT	ADB	HSW	SEV60	SEV70	SEV80
Top resistant								
B301	-	49	71.48	0	8.31	1	1	1
Komcalle	-	43.33	68	0	18.96	1	1	1
KN-1	-	48.23		0		1	1	1
IT99K-573-2-1	-	42	65	0	21.35	1	1	1
KVX414-22-2	-	41.67	66.03	0	18.05	1	1	1
IT86D10-10	-	37.33	62.67	0	18.01	1	1	1
N°2300	-			0		1	1	1
IT98K-205-8	-	40.67	58	0	17.98	1	1	1
IT81D-994	-	44.33	66.33	0	20.02	1	1	1
Komcalle P-5	-	41	57.67	0	18.83	1	1	1
Bottom susceptible								
Vita-5	44	46	66.03	7.94	16.46	3	4	5
KVX771-B	46	41.67	60.49	5.71	23.4	3	4	5
Vita-4	47.33	59.39		7.92		3	4.67	5
Sanzi	45.33	47.67	66.99	8.83	8.66	2.67	3.33	5
Woango-1	44.67	58		6.35	17.49	3	4	5
Mean	49.45	44.28	63.17	17.98	3.71	2.27	3.01	3.28
CV (%)	7.27	8.17	6.69	10.54	30.37	14.23	9.83	10.18
P-value	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001

CV: coefficient of variation, DAEMG: days to *Alectra* shoots emergence, DTF: days to first flowering, MAT: days to maturity, ADB: *Alectra* dry biomass, HSW: 100 seeds weight, SEV60: severity of *Alectra* 60 days after planting, SEV70: severity of *Alectra* 70 days after planting, SEV: severity of *Alectra* 80 days after planting.

Table 4.5: Mean squares of combined analysis for differential reaction of ecotypes of *Alectra* for resistance parameters

Source	df	DTF	DAEMG	MAT	HSW	SEV60	SEV70	SEV80	ADB
Rep	2	8.16 ^{ns}	1.75 ^{ns}	0.51 ^{ns}	2.16 ^{ns}	0.08 ^{ns}	0.12 ^{ns}	0.03 ^{ns}	0.79 ^{ns}
G	119	262.67**	185.64**	92.06**	87.06**	4.67**	9.04**	11.87**	54.21**
Ec	2	132.49**	202.07**	48.68*	0.52 ^{ns}	7.41**	2.84**	2.06*	112.86**
GxEc	238	27.7**	19.74**	20.61**	1.36*	0.32**	0.37**	0.35**	3.13**
Error	634	11.94	9.22	9.68	4.32	0.1	0.08	0.09	1.13

G: genotype, Ec: ecotype, GxEc: genotype by ecotype interaction, DTF: days to first flowering, DAEMG: days to *Alectra* shoots emergence, MAT: days to maturity, HSW: 100 seed weight, SEV60: Severity of *Alectra* 60 days after planting; SEV70: Severity of *Alectra* 70 days after planting, SEV80: Severity of *Alectra* 80 days after planting, ADB: *Alectra* dry biomass, **: significant (0.01); * significant (0.05), ns: not significant (0.05).

4.3.2 Field screening

4.3.2.1 Genotype by environment interaction

The results of single sites analysis are presented in Table 4.6, Table 4.7, Table 4.8 and Table 4.9. There were significant differences ($P < 0.01$) for all the parameters except number of plant stand for all the site and grain yield (GY) for the site of Tenkodogo. The average *Alectra* shoots counts (ASC) and *Alectra* severity (SEV) were higher at Toussiana site than Koupela and Tenkodogo sites (Table 4.7). However, the opposite order was observed for pods yield (PY) and grain yield (GY). Under heavily infested field conditions, clearly contrasting reaction of susceptible and resistant genotypes was observed (highlights in Table 4.7, 4.8 and 4.9).

Table 4.6: Means of number of plant stand at harvesting for different study sites

Variety	Locality		
	Koupela	Tenkodogo	Toussiana
B301	23.18	18.67	25.38
Djouroum local	17.93	23	26.53
Gorom local	20.97	23.33	27.62
Gourgou	18.44	21.33	27.59
HTR	22.82	20	24.06
IT81D-994	17.66	21.33	24.31
IT82D-849	22.39	23	30.27
IT86D10-10	19.35	21.33	27.22
IT93K-693-2	18.99	21.67	27.52
IT98K-205-8	18.61	21.33	25.56
IT99K-573-2-1	18.66	21.67	26.11
Komcalle	20.95	23	29.29
Komcalle P-5	18.63	23	27.78
KVX 165-14-1	22.2	22.33	28.97
KVX30-309-6G	22.22	23.33	26.45
KVX414-22-2	20.5	25	32.9
KVX61-1	24.1	22.67	31.07
KVX780-1	19.75	23.33	26.02
KVX780-3	22.49	22.33	27.71
KVX780-4	19.81	22	27.47
KVX780-6	20.66	19.33	26.61
KVX780-9	21.37	22.33	28.45
Moussa local	21.25	23.33	24.98
Nafi	17.34	21.33	24.33
Tiligre	21.37	22	27.13
Mean	22.75	22.08	27.25
SE	0.37	0.27	0.61
P-value	0.33	0.61	0.98

SE: Standard error

Table 4.7: Means of *Alectra* infection parameters for the three locations

Variety	<i>Alectra</i> shoots count			Severity of <i>Alectra</i>		
	Kp	Tenk	Tss	Kp	Tenk	Tss
B301	0	0	0	1	1	1
Djouroum local	1.77	1.91	3.6	1.65	1.68	2.34
Gorom local	6.49	2.96	17.87	3.35	2.28	4.67
Gourgou	2.47	1	8.32	1.97	1.65	3.02
HTR	1.81	3.42	4.35	1.36	1.86	2.99
IT81D-994	3.02	0	0	2	1	1
IT82D-849	9.97	5.48	22.57	3.67	2.9	4.65
IT86D10-10	0	0	0	1	1	1
IT93K-693-2	0	0	0	1	1	1
IT98K-205-8	0	0	0	1	1	1
IT99K-573-2-1	0	0	0	1	1	1
Komcalle	0	0	0	1	1	1
Komcalle P-5	3.43	0	0	2.02	1	1
KVX 165-14-1	0	0	0	1	1	1
KVX30-309-6G	6.23	2.04	6.91	2.62	1.72	3.68
KVX414-22-2	0	0	0	1	1	1
KVX61-1	9.4	4.16	15.92	3.64	2.32	4.66
KVX780-1	0	0	5.62	1	1	2.66
KVX780-3	2	1.12	2.66	1.36	1.45	2.34
KVX780-4	3.77	1	3.05	2.31	1.3	2.34
KVX780-6	2.64	2.77	3.33	1.66	1.78	1.98
KVX780-9	1.28	1.9	3.48	1.72	1.95	1.99
Moussa local	9.91	5.91	14.7	3.63	2.11	4.32
Nafi	1.36	2.36	6.54	1.64	2.02	2.98
Tiligre	3.98	0	5.77	2.38	1	2.35
Mean	2.84	1.48	5.01	1.85	1.49	2.29
SE	0.42	0.29	0.78	0.12	0.09	0.16
P-value	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01

Kp: Koupela, Tenk: Tenkodogo, Tss: Toussiana, SE: Standard error

Table 4.8: Means of pod yield (PY) of 25 genotypes in the three study sites

Variety	Locality		
	Koupela	Tenkodogo	Toussiana
B301	2091.63	1513.94	1883.03
Djouroum local	1407.5	1990.69	2797.53
Gorom local	1565.16	2270.69	468.5
Gourgou	1597.03	1861.66	1452.16
HTR	1943.25	1593.78	889.97
IT81D-994	937.38	2157.47	1124.66
IT82D-849	973.56	1572.44	632.84
IT86D10-10	1565.5	1643.44	2089.66
IT93K-693-2	460.19	1663.78	377.47
IT98K-205-8	898.81	1857.81	1564.75
IT99K-573-2-1	937.56	1847.25	1212.84
Komcalle	1793.47	1316.56	1772.19
Komcalle P-5	1111.31	1366.5	1039.09
KVX 165-14-1	1479.03	1627.84	2344.47
KVX30-309-6G	1821.28	1655.25	873.44
KVX414-22-2	1342.59	1711.28	1492.5
KVX61-1	2190.78	1460.53	578.75
KVX780-1	1862.09	1923.09	1948.5
KVX780-3	2229.41	1891.81	1253.06
KVX780-4	1707.09	2143.91	1365.41
KVX780-6	1798.13	1544.19	2023.16
KVX780-9	1736.16	914.5	1815.13
Moussa local	1462.63	2103.5	1567
Nafi	1346.63	1186.5	1781.44
Tiligre	2211.13	1483.72	1615.38
Mean	1538.75	1692.19	1438.44
SE	22.07	22.24	27.94
P-value	<0.01	0.47	<0.01

SE: Standard error

Table 4.9: Means of grain yield (kg ha⁻¹) of 25 genotypes in the three study sites

Variety	Locality			Yield mean
	Koupela	Tenkodogo	Toussiana	
B301	1336.69	1118.4	1200.52	1212.17
Djouroum local	985.03	1468.79	1678.82	1378.95
Gorom local	778.2	1631.04	276.08	898.98
Gourgou	1118.53	1364.21	882.25	1128.41
HTR	1524.92	1139.6	342.42	1007.46
IT81D-994	613.93	1605.38	483	898.77
IT82D-849	536.01	1120.85	238.58	627.65
IT86D10-10	976.72	1251.24	1034.43	1084.44
IT93K-693-2	351.02	1137.3	113.38	535.87
IT98K-205-8	608.02	1371.37	979.92	985.01
IT99K-573-2-1	676.45	1342.55	408.53	810.03
Komcalle	1472.67	989.95	1273.8	1241.44
Komcalle P-5	885.47	1004.31	789.7	890.85
KVX 165-14-1	1108.97	1143	1496.76	1246.4
KVX30-309-6G	1023.06	1249.53	318.98	867.18
KVX414-22-2	891.15	1267.16	960.66	1044.37
KVX61-1	853.16	1026.8	51.57	902.57
KVX780-1	1380.63	1358.65	1037.36	1264.82
KVX780-3	1637.29	1393.03	795.07	1273.18
KVX780-4	1224.65	1579.88	870.06	1219.39
KVX780-6	1188.75	1064.44	1278.65	1167.8
KVX780-9	1254.22	686.98	1294.05	1080.62
Moussa local	932.38	1494.18	807.22	1079.45
Nafi	1016.68	815.43	1273.9	1036.83
Tiligre	1507.08	999.36	951.58	1155.11
Mean	1066	1225	833.5	1041.51
SE	48.02	52.12	59.57	
P-value	<0.01	0.48	<0.01	<0.01

SE: Standard error

The results of genotype by environment interaction analysis (GxE) are presented in (Table 4.10). The GxE mean squares were significant for SEV ($P < 0.05$), for the other parameters was highly significant ($P < 0.01$). Similarly, highly significant differences ($P < 0.01$) were observed between the genotypes for all the parameters across the three locations. The analysis was also significant for the studied parameters within the locations at 99% confidence interval level. The mean yield performance across the three environment was $1041.51 \text{ kg ha}^{-1}$.

Table 4.10: Mean squares values and significance for ASC, SEV, PY and GY

Source	df	ASC	SEV	PY	GY
Rep	2	11.6 ^{ns}	0.173 ^{ns}	235968.41 ^{**}	942229.54 ^{**}
Block	4	3.41 ^{ns}	0.096 ^{ns}	123873.24 ^{**}	386709.37 [*]
Genotype	24	115.17 ^{**}	6.65 ^{**}	78509.86 ^{**}	410758.85 ^{**}
Location	2	238.22 ^{**}	12.04 ^{**}	135350.81 ^{**}	2873975.2 ^{**}
Location*Genotype	48	19.29 ^{**}	0.74 [*]	61985.76 ^{**}	338973.71 ^{**}

df: degree of freedom, ASC: Alectra shoot count, SEV: severity, PY: pods yield, **: significant ($P < 0.01$), *: significant ($P < 0.05$) ns: not significant

4.3.2.2 Grain yield stability

The “Which won where” of the genotype and genotype by environment interactions (GGE) biplot showed the presence of important genotype by environment interaction. The first two principal components (PC) axes of the GGE biplot explained 84.99% of the total variation of cowpea grain yield with PC1 and PC2 accounting for 64.40% and 20.59% respectively (Figure 4.1).

The polygon view of the “Which won where” pattern was composed of nine sectors based on the grain yield performance of the genotypes (Figure 4.1). Each of the locations (Koupela, Tenkodogo and Toussiana) fell into different sectors, they all constituted different environments based on the

yield performance of the genotypes. Toussiana and Koupela accounted for the largest variability. Genotypes situated on the vertices of a sector represent the best performer at sites associated with this sector. Therefore Djouroum local (2), HTR (5) and IT93K-693-2 (9) were the winning genotypes at Toussiana, Koupela and Tenkodogo respectively. The codes attributed to each genotype are presented in Table 4.11.

Table 4.11: Genotypes and the associated numbers

Genotype	code	Genotype	code	Genotype	code	Genotype	code
B301	1	IT86D10-10	8	KVX30-309-6G	15	KVX780-9	22
Djouroum local	2	IT93K-693-2	9	KVX414-22-2	16	Moussa local	23
Gorom local	3	IT98K-205-8	10	KVX61-1	17	Nafi	24
Gourgou	4	IT99K-573-2-1	11	KVX780-1	18	Tiligre	25
HTR	5	Komcalle	12	KVX780-3	19		
IT81D-994	6	Komcalle P-5	13	KVX780-4	20		
IT82D-849	7	KVX 165-14-1	14	KVX780-6	21		

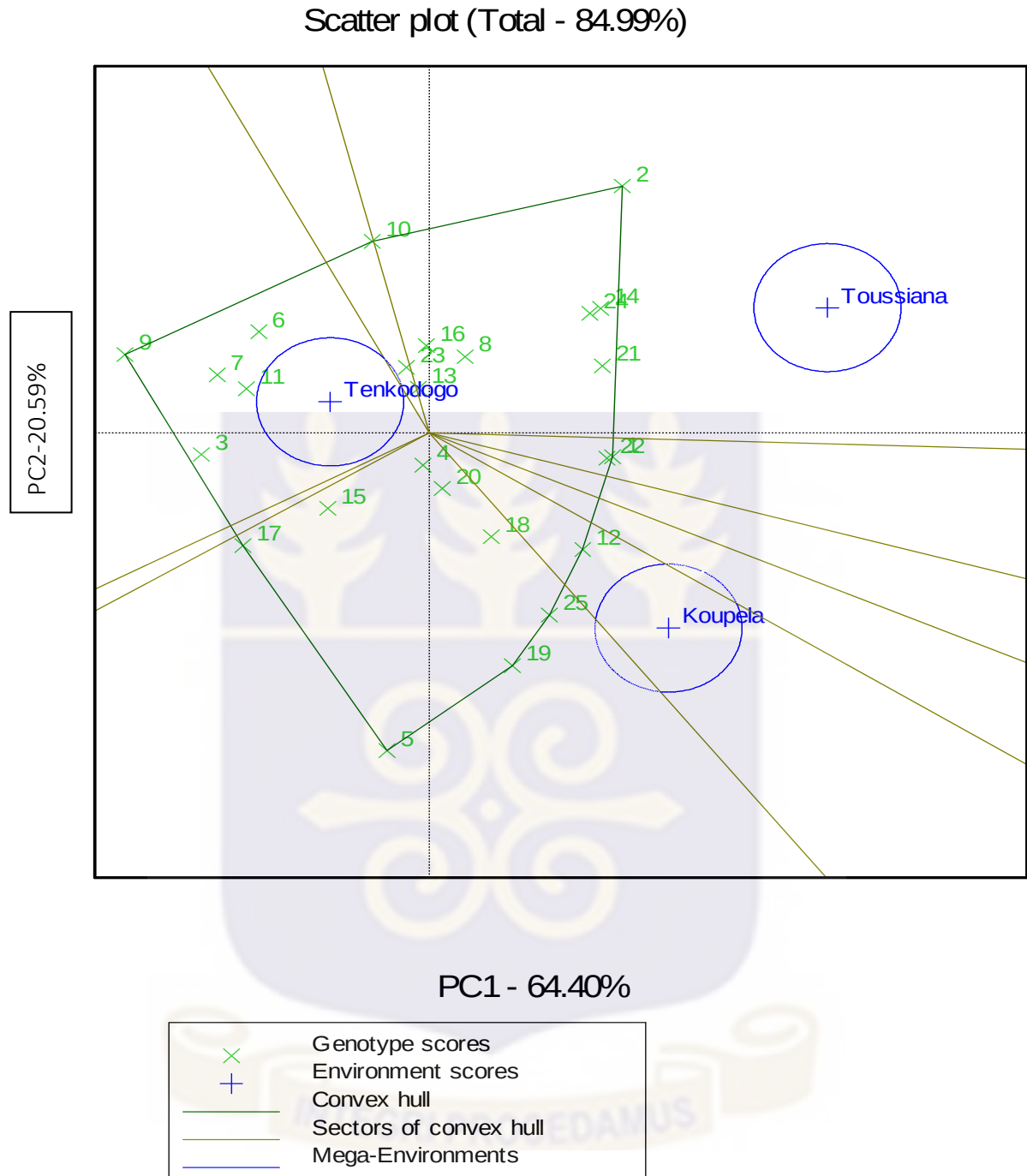


Figure 4.1: “Which won where” plot for grain yield performance

The average environment coordinate (AEC) view based on genotype-focused singular value partitioning (SVP) shows the mean performance and yield stability of the genotypes. The varieties B301 (1), Djouroum local (2), Komcalle (12), KVx165-14-1 (14), KVx780-6 (21), KVx780-9 (22), Nafi (24) and Tiligre (25) were the highest yield performing genotypes; in contrast the genotype IT93K-693-2 (9) was the lowest yielding (Figure 4.2). Among the high yielding genotypes B301 (1), Komcalle (12), KVx780-6 (21) and KVx780-9 (22) were the most stable across the environments and seemed to be the ideal genotypes since they are close to the concentric circle (Figure 4.3).



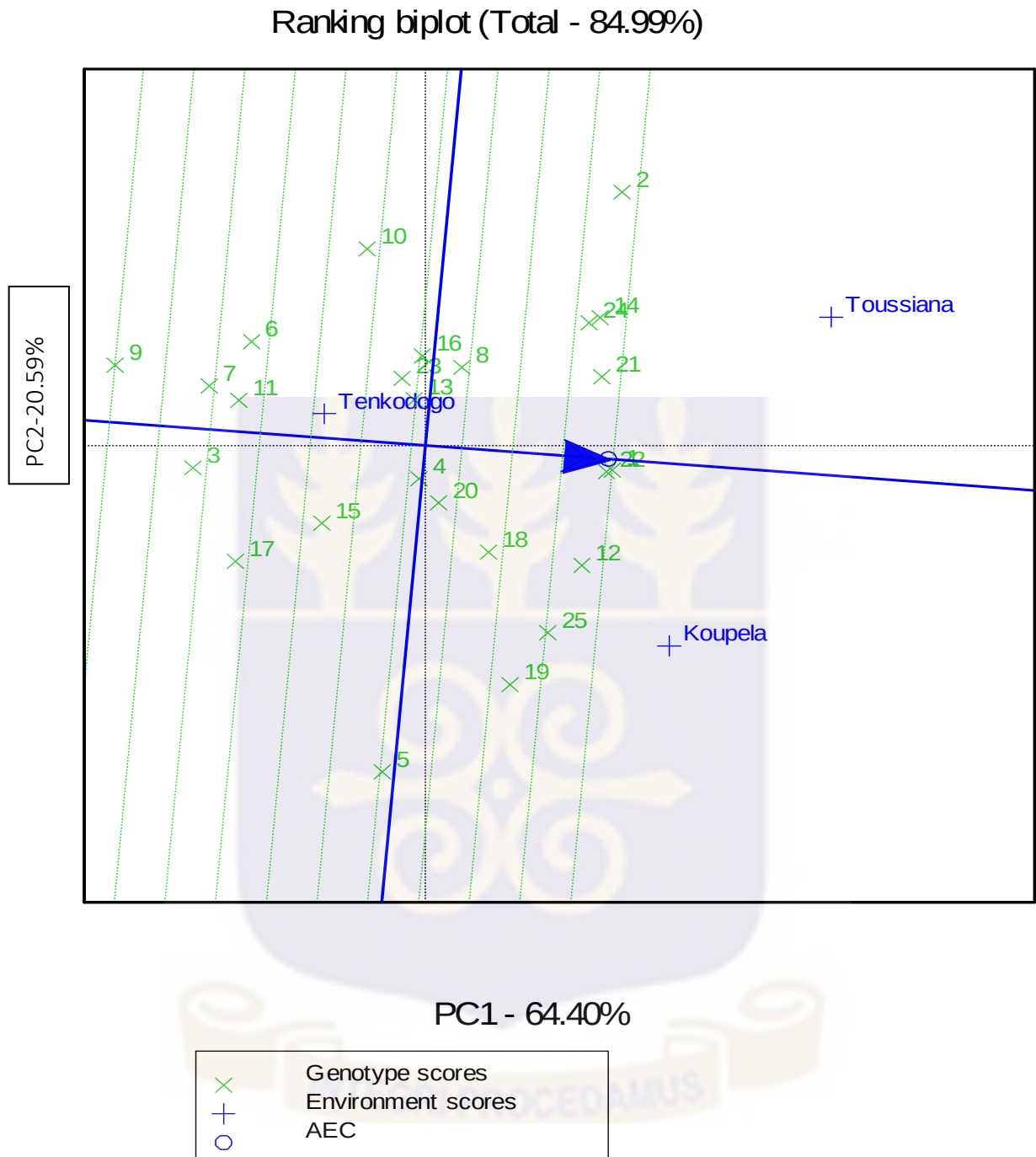


Figure 4.2: Biplot showing the rank of GGE for grain yield performance

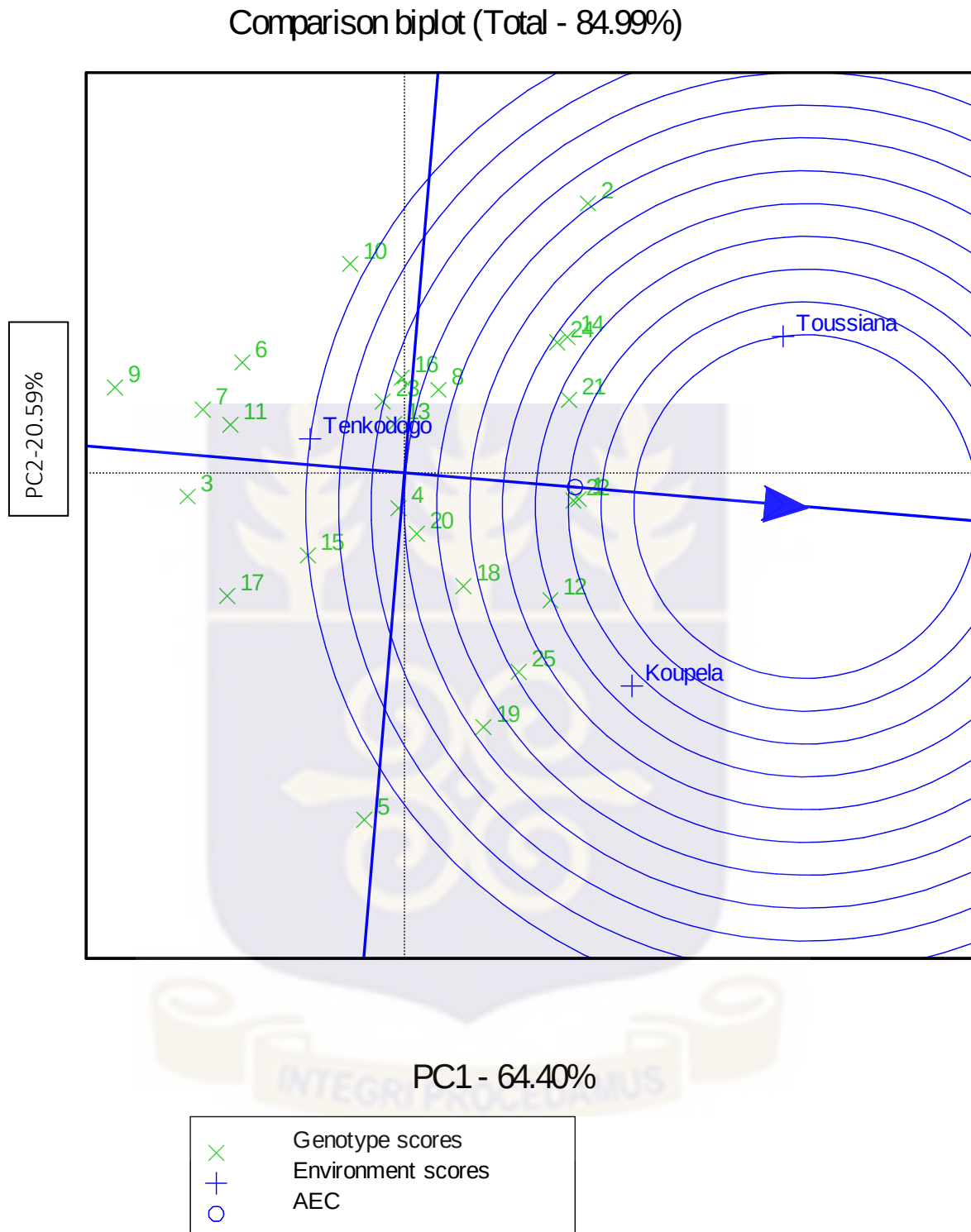


Figure 4.3: Biplot showing the rank of GGE for grain yield stability

4.3.2.3 Correlations between the traits

Significant positive correlation coefficient was detected between *Alectra* shoots count (ASC) and its severity (SEV). Grain yield (GY) was significantly and positively correlated to pod yield (PY). In contrast, both GY and PY were significantly ($P < 0.01$) but negatively correlated to ASC and SEV (Table 4.12).

Table 4.12: Correlations matrix between parameters

	ASC	SEV	PY	GY
ASC	-			
SEV	0.903**	-		
PY	-0.193**	-0.181**	-	
Yield	-0.265**	-0.242**	0.895**	-

** : significant at $P < 0.01$, ASC: *Alectra* shoots count, SEV: severity, PY: pod yield, GY: grain yield

4.4 Discussion

4.4.1 Pot screening

Alectra vogelii shoots emerged in general about forty nine (49) days after planting (DAP) though for highly susceptible genotypes, first shoots emergence was observed 34 DAP while late emergence was observed for some genotypes. This trend of shoot emergence was also observed in Nigeria (Magani & Lagoke, 2009; Magani *et al.*, 2008, 2009). Rugare *et al.* (2013) observed first shoot emergence 55 days after planting (DAP) in Zimbabwe. Shoot emergence in their study was delayed compared to that of the current one. The difference between days to shoot emergence observed can be either related to the cowpea genotype, or to the virulence of *Alectra* or both. In

fact, *Alectra* seeds germination and emergence take place subsequent to exudation of germination stimulants by the cowpea roots. These exudates synchronize the lifecycle of the weed with that of its host (Matúšová & Bouwmeester, 2006). Thus, an early production of these chemicals will result in early *Alectra* shoots emergence. In addition, the nature and the quantity of these exudates are important factors determining host plant resistance. A low amount of germination stimulant or the absence of its production constitutes a mechanism of resistance (Kureh *et al.*, 2005).

Alectra vogelii causes damages to its hosts even if its emergence is delayed. First shoot emergence of *Alectra* on soybean and groundnut genotypes was recorded 109 DAP in Malawi; nevertheless, substantial yield reduction was recorded (Kabambe *et al.*, 2008). Prior to emergence, the underground host-parasite interaction results into important damages to the host plant, *Alectra* being entirely holoparasitic at this stage (Magani *et al.*, 2008) and this stage often accounts for up to 75% of the total damage (Timko & Singh, 2008). In general damage is more severe with early emergence as the severity of the attack is more pronounced. The degree of severity of the attack determines the level of resistance of the genotype.

In the current study cowpea genotypes showed differential responses to *Alectra vogelii* ecotypes. They were classified into three categories (resistant, moderately resistant or tolerant and susceptible) based on the scores of severity of *A. vogelii* effects. Genotypes that expressed a severity score of two (2) or less were considered as resistant. When the score of severity was 4 or higher, the genotype was classified as susceptible. The moderately resistant lines were intermediate to the above categories. Resistant genotypes that were free of *Alectra* infection were referred as highly resistant. Host plant resistance to pathogens can be referred as true resistance, which is inherent to the genotype and fake resistance related to an escape factor. It is defined as a multicomponent event resulting from different escape factors or resistance mechanisms operating

at different levels of the host-pathogen interaction process (Rubiales *et al.*, 2006). The resistance resulting from the host plant reaction to the parasite attack is referred as true resistance (Aalders & Pieters, 1987). The true resistance is of more interest to plant breeders.

The sources of resistance identified were composed of both cultivated and wild relatives of cowpea genotypes. All the three cowpea wild relatives included in the current study were resistant to all the ecotypes of *Alectra vogelii*. In contrast, none of the landraces conferred resistance to *Alectra vogelii*. The best landraces (Djouroum local and Pouytenga-9) were moderately resistant across the three ecotypes. Some cowpea wild relatives also conferred resistance to *Striga gesnerioides* (Tignegre, 2010). The cowpea wild relatives constitute a reservoir of source of resistance to parasitic weeds and therefore could be alternative donor parents when cultivated varieties fail to provide resistance.

Overall, 25 and 23 genotypes were found conferring resistant to *Alectra* ecotypes from Tenkodogo and both Toussiana and Koupela respectively. Among them, 20 were resistant to all the three ecotypes. However, genotypes TVU14676, CR06-07, KN-1 supported few *Alectra* shoots for ecotype from Koupela but were free of *Alectra* for one or both of the other ecotypes. In addition the varieties IT81D-994 and Komcalle-P5 that expressed moderate resistance to the ecotype from Koupela were highly resistant to the two other ecotypes.

The other genotypes conferring resistance to the three ecotypes were:

B301, IT98K-205-8, KVx414-22-2, IT86D10-10, IT93K-503-1, IT93K-693-2, IT95K-627-4, IT99K-573-2-1, Komcalle, K VX 165-14-1, (KVX775-33-2 x693-2) BC4F8-P7, (KVX775-33-2x693-2) BC4 F8-P14, Moussax205-8 F8-P1, N°2300, NS Farakoba, NS1, KN-1 and TVU14676. Genotypes B301, IT98K-205-8, IT93K-693-2, IT99K-573-2-1 and IT93K-503-1 were reported to be resistant to *Alectra vogelii* in Nigeria, Botswana, Malawi and Tanzania (Atokple *et al.*, 1993,

1995; Singh *et al.*, 1993; Singh, 2002; Magani *et al.*, 2008; Mbwaga *et al.*, 2009; Fite, 2010; Omoigui *et al.*, 2012; Itta *et al.*, 2014; Kutama *et al.*, 2014;). These findings are in agreement with the outcome of the current study. Some of the new sources of resistant varieties to *Alectra vogelii* identified in this investigation are: KVx414-22-2, Komcalle, Komcalle P-5, K VX165-14-1, IT86D-10-10, IT95K-627-4, N°2300, NS Farako-ba, NS1, KN-1 and TVU14676.

K VX414-22-2 is a large seed sized variety conferring resistance to all the ecotypes of *Alectra* but it is *Striga* susceptible. Therefore, it cannot be produced in *Striga* prone areas. Komcalle and Komcalle P-5 are newly released and farmers' adopted cowpea varieties. Komcalle P-5 is *Striga* tolerant but it showed less resistance to *Alectra* ecotype from Koupela compared to Komcalle. IT98K-205-8 and IT99K-573-2-1 are short duration farmers' accepted varieties that are resistant to both *Alectra* and *Striga*. The other new released varieties and largely adopted by farmers (Tiligre and Nafi) were also *Alectra* tolerant.

Differential reaction of the varieties IT81-994 and Komcalle P-5 to *Alectra* ecotypes was observed in both pots and field screening. Magani *et al.* (2009) described the variety IT81D-994 as highly resistant to *A. vogelii* at Samaru (Nigeria) though it supported few *Alectra* shoots. In IITA/Kano (Nigeria) a moderately resistant status was reported for the same line (IT81-994) (Atokple *et al.*, 1995; Kouakou *et al.*, 2009) as it was the case with *Alectra* ecotype from Koupela in the current study. The two differential reactions of this variety reported in the present study are consistent with the findings of the authors cited above. However, a third differential reaction of the same variety to *A. vogelii* was reported by Omoigui *et al.* (2012). These authors observed susceptible response of IT81D-994 to *A. vogelii* in the northern Guinea savanna of northeast Nigeria. Polniaszek *et al.* (1991) also found that this variety was susceptible to *A. vogelii* sample from Mali.

These differential responses of the same cowpea genotype (IT81D-994) to *Alectra vogelii* in different areas could suggest the existence of different strains or races of the weed in Burkina Faso as well as in Nigeria. This hypothesis could be further supported with the differential reaction of the genotype Komcalle P-5 to the ecotypes used in the present study. The occurrence of five different strains of *A. vogelii* in Africa has been reported (Riches *et al.*, 1992). Polniaszek *et al.* (1991) claimed that strains of *A. vogelii* in Southern Africa are more virulent compared to the West African strains. However, differences between ecotypes within each region and country should be further investigated and stated for breeding purpose. Further details of the geographical distribution map of *A. vogelii* strains could greatly contribute at determining breeding objectives for cowpea resistance to *A. vogelii* in each country. Lane *et al.* (1996) have mapped the 5 races of *Striga gesnerioides* prevailing in West Africa. This map has evolved with the identification of new races in Benin (Botanga & Timko, 2006) and Burkina Faso (Tignegre, 2010). Three different races of *S. gesnerioides* namely race 1, race 5 and race KP prevail in Burkina Faso (Tignegre, 2010). Cowpea improvement for *Alectra* resistance should take into account *Striga* resistance in *Alectra* and *Striga* prone areas like Burkina Faso. Such breeding objectives have been implemented in Nigeria. But most cowpea resistant genotypes to *Alectra* are susceptible to *Striga* and vice versa. Therefore, breeding for combined resistance to both parasitic weeds is a more difficult task. Nevertheless, good progress can be achieved with the few genotypes conferring combined resistance to both *Alectra* and *Striga*.

4.4.2 Field screening

Results from the field evaluation showed significant GxE effects for the traits studied. The *Alectra* shoots count (ASC) and the severity of *Alectra* (SEV) at Toussiana site were greater than at Koupela and Tenkodogo sites. Inversely pod yield (PY) and grain yield (GY) were lower at

Toussiana site. In the experimental site of Toussiana, very high *Alectra* infection pressure was observed, particularly on the susceptible check (IT82D-849). In contrast, the resistant check and all the genotypes that were identified as resistant from the pot screening did not support *Alectra* shoots. The susceptible genotypes supported lower *Alectra* infection pressure at Koupela site compared to Toussiana suggesting a higher *Alectra* infestation pressure in the latter site. Cowpea genotypes consistently responded to *A. vogelii* infection in both pot screening and field screening for the two sites. However, at Tenkodogo experimental site, some of the moderately resistant genotypes identified in pot screening did not support *Alectra* shoots emergence. This can be related to ununiformed and low degree of infestation of the experimental site. However, this was not studied.

The average pods yield (PY) and grain yield (GY) performance was higher at Tenkodogo compared to the two others sites. The lowest PY and GY registered at Toussiana is explained by the high level of infestation observed at Toussiana. Negative and highly significant correlations were detected between the grain yield and *Alectra* infection parameters. This meant that *Alectra* infection results in yield reduction. The importance of yield loss depends on the degree of infestation. For the susceptible check (IT82D-849) yield losses of 78.72% and 52.18% were registered respectively at Toussiana and Koupela sites as compared to Tenkodogo site. These findings are consistent with the yield loss estimates of farmers through the PRA study. In addition significant reduction in cowpea yield parameters (grain weight and pod number) due to *Alectra* infestation was reported by Kabambe *et al.* (2008).

In order to identify resistant cowpea genotype combining yield performance and stability, multi-location trials were conducted. Multi-environment trials (MET) are conducted with the aim of identifying stable and high yielding genotypes (Flores *et al.*, 1998; Yan *et al.*, 2000; Yan & Rajcan,

2002). The widely used method to analyse MET data are the joint regression analysis method of Eberhart & Russell (1966), Additive main effect and multiplicative interaction (AMMI) of Gauch (1992) and the GGE biplot method of Yan (2001, 2002). According to Flores *et al.* (1998) and Yan *et al.* (2007) the GGE biplot method is more effective than joint regression analysis and AMMI. In this study genotype by environment interaction of 25 genotypes for their yield performance was investigated in three environments through GGE biplot method. highest yielding genotypes: B301 (1), Djouroum local (2), Komcalle (12), KVx165-14-1 (14), KVx780-6 (21), KVx780-9 (22), Nafi (24) and Tiligre (25) were detected, among them four (B301, Komcalle, KVx780-6 and KVx780-9) were the most stable. The remaining four genotypes did not appear on the biplot towards the arrow of the AEC x-axis implying that there were crossover in the GxE interactions resulting in rank change among genotypes in the three locations (Yan *et al.*, 2000; Yan & Rajcan, 2002; Yan & Tinker, 2006; Alwala *et al.*, 2010).

The genotypes exhibiting high yield performance and stability are referred as ideal genotypes. In this regard, the landrace B301 combining *Alectra* and *Striga* resistance and yield stability was the ideal genotype but it does not possess farmers' preferred traits. Nafi, Tiligre, KVx780-6 and KVx780-9 exhibited good level of tolerance to *Alectra*. They can be grown in *Alectra* prone areas without substantial yield loss, though their production in *Alectra* infected areas could contribute to increase in *Alectra* seed bank. Therefore, only the variety Komcalle could be referred to as ideal variety for *Alectra* resistance since it combines farmers' preferred characteristics, high yield performance and stability across the environments and *Alectra* resistance. Therefore, this variety could be recommended for all the three locations. Two other farmers' adopted varieties (IT98K-205-8 and IT99K-573-2-1) and resistant to both *Alectra* and *Striga* could be also recommended

even though they were less stable. The landrace Djouroum local could be the ideal recurrent parent for breeding cowpea for resistance to *A. vogelii*.

4.5 Conclusion

The present study aimed at identifying cowpea genotypes that confer resistance to *Alectra vogelii* in Burkina Faso. At the end of this investigation, 25 cowpea genotypes with high resistance to *Alectra* ecotypes have been identified, among them 20 genotypes conferred resistance to all the three ecotypes. Two cowpea genotypes IT81D-994 and Komcalle-P5 showed differential reactions to the ecotypes of *Alectra vogelii* used, suggesting the occurrence of different ecotypes of the weed in Burkina Faso.

The field screening revealed an important genotype by environment interactions. *Alectra vogelii* infection was a key factor in the GxE interactions. Cowpea grain yield was negatively and significantly correlated to *Alectra* infection parameters inferring the importance of yield loss due to *Alectra* effects.

The varieties Nafi, Tiligre, KVx780-6 and KVx780-9 were *Alectra* tolerant and expressed their high yielding potential. The variety Komcalle was one of the most stable genotype across the three location and possessing resistance to *Alectra* and farmers' preferred traits. Two other farmers' adopted varieties IT98K-205-8 and IT99K-573-2-1 were also identified as *Alectra* resistance sources. They could also be recommended to farmers in *Alectra* prevailing areas. The other resistant genotypes could be used in a breeding programme.

CHAPTER FIVE

5.0 GENE ACTION STUDIES FOR *Alectra vogelii* RESISTANCE IN COWPEA

5.1 Introduction

Cowpea (*Vigna unguiculata*) is an important grain legume crop in Sub-Saharan Africa. The United Nations' 68th General Assembly declared the year 2016 as the international year of pulses. The closing session of this international year of pulses was hosted by Burkina Faso which is the third largest cowpea producer in West Africa (FAOSTAT, 2016). In the country cowpea occupies a key position in the agricultural system. It is the leading grain legume crop and the fourth most important staple crop produced. However, cowpea production encounters several abiotic and biotic constraints resulting in lower yields gain. *Alectra vogelii* is a hemiparasitic weed responsible for several negative effects on cowpea production. Remarkable (50%-100%) yield losses are not uncommon in *Alectra* infested fields (Karanja *et al.*, 2013). In addition, *Alectra* infestation affects the mineral composition of cowpea grain (Alonge *et al.*, 2001b).

Control measures, from cultural practices to genetic resistance, have been proposed. From these methods, genetic resistance is the most efficient and most affordable from both breeders and farmers view. However, the cowpea lines identified as sources of resistance to *Alectra vogelii* do not have most of farmers' preferred traits. Therefore, the creation of genetic variability which is the basis for plant improvement is necessary.

The genetic variability required can be created through hybridization. For the sake of creating useful genetic variability, a judicious choice of parents to be crossed and the breeding approach is crucial.

A breeding programme for cowpea resistance to *Alectra vogelii* does not exist in Burkina Faso yet. So there is an urgent need to determine the appropriate breeding strategy to settle down a sustainable breeding programme and provide high valuable information to breeders in making decision for the breeding system as well as selecting the genetic material to be used (Hayman, 1954; Gardner & Eberhart, 1966; Chukwu *et al.*, 2016). The diallel method II is more effective if reciprocal effect are negligible (Chukwu *et al.*, 2016). It provides maximum information about the genetic structure of a character, the parents as well as allelic frequencies (El-Maghraby *et al.*, 2005; Iqbal *et al.*, 2007). Therefore, a study of the combining abilities of a set of genotypes, through diallel analysis, will undoubtedly contribute to the achievement of the desired goal. The combining ability studies cover: (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.

The objective of this study was to (i) determine the general combining ability (GCA) of cowpea for resistance to *Alectra vogelii* and (ii) the specific combining ability (SCA) involved in cowpea crosses.

5.2 Materials and methods

5.2.1 Genetic material

In this study, nine cowpea lines: Moussa Local, KVx30-309-6G, IT82D-849, Nafi, Tiligre, Komcalle-P5, IT98K-205-8, IT81D-994 and B301 were selected as parents from the screen house screening and their characteristics are showed in Table 5.1. The genotypes B301 and IT98K-205-8 were highly resistant. The lines: IT81D-994, Komcalle-P5, Tiligre, Nafi, Moussa local, KVx30-309-6G and IT82D-849 were moderately resistant to highly susceptible in that order. Tiligre, Nafi and Komcalle-P5 are improved lines possessing farmers' and consumers' preferred characteristics.

Moussa local is one of the most accepted local cowpea varieties but susceptible to numerous constraints (*Alectra*, *Striga*, CABMV, drought, etc.). The other lines were selected for their good level of resistance (B301, IT81D-994 and IT98K-205-8) or for their high susceptibility (IT82D-849 and KVx30-309-6G).

Table 5.1: Characteristics of the nine (9) cowpea genotypes used in the half diallel crosses

Variety	Type of variety	Seed size	Seed colour	<i>Alectra vogelii</i>
Moussa Local	Local	Medium	White	S
KVx30-309-6G	Improved	Big	White	S
IT82D-849	Improved	Big	Red	S
Nafi	Improved	Big	White	MR
Tiligre	Improved	Big	White	MR
Komcalle-P5	Improved	Big	White	MR
IT98K-205-8	Improved	Medium	White	R
IT81D-994	Improved	Big	White	MR
B301	Local	Small	Brown	R

S= susceptible, *MR*= moderately resistance, *R*= resistant

The selected parents were hand crossed (Rachie *et al.*, 1994) in a 9x9 half diallel mating design in a screen house at INERA Kamboinsé research station in Burkina Faso from June 2015 to March 2016. The parents (9) and their F₁ progenies (36) were evaluated in screen house under artificial infestation. *Alectra vogelii* seeds used for the infestation originated from Koupela. The seeds were collected in cowpea infested field at the end of the 2014 rainy season and kept at room temperature until use.

5.2.2 Experimental design and data collection

The experiment was conducted in a screen house at INERA in Kamboinsé research station in Burkina Faso from April to June 2016 in a Randomized Complete Block Design (RCBD) with three replications. Each block comprised 45 pots of 12 L representing the experimental unit. The

pots were filled with a substrate composed of three volumes of sand for one volume of clay (3:1) and infested with about 1000 *Alectra* seeds (from Koupela). The seeds were thoroughly mixed with sterile sand before infestation. After preconditioning *Alectra* seeds in the infested pots for 14 days, to break their dormancy to enable their optimal germination, a single cowpea seed was planted per pot. NPK fertilizer (14-23-14) was applied a day before planting cowpea at a rate of five grams (g) per pot. Two insecticide sprays were done as recommended in cowpea production in Burkina Faso.

Data collected were as follows:

1. Number of days to cowpea first flowering (DTF);
2. Number of days to *Alectra vogelii* shoots emergence (DAEMG);
3. Severity of *Alectra vogelii* attack 70 days after planting (SEV) and
4. Cowpea 100 seed weight (HSW).

5.2.3 Data analysis

The diallel analysis software DIAL win 98 Ukai (1998) reviewed in 2002 was used for data analysis. The data were analysed according to Griffing's (1956) and Walters & Morton's (1978) methods.

Griffing's method II was used to determine general combining ability (GCA) effects of the parents and specific combining abilities (SCA) effects of specific crosses as follows: $X_{ij} = \mu + g_i + g_j + s_{ij}$

Where, μ = the population mean, g_i = the general combining ability effect of the i^{th} parent, g_j = the general combining ability effect of the j^{th} parent, s_{ij} = the specific combining ability effect of the cross between i^{th} and j^{th} parents

The estimate of general combining ability (GCA) effects of and the significance of the GCA effects of each genotype were determined using the formula described by Dabholkar, (1999):

$$G_i = \frac{1}{p+2} [(Y_{i.} + Y_{ii}) - \frac{2}{p} Y_{..}] \text{ and}$$

$$t_{cal} = \frac{G_i}{S.E.Gi} \quad \text{where} \quad S.E.Gi = \sqrt{\frac{p-1}{p(p+2)} \sigma^2}$$

Where:

G_i : general combining ability effect of the i^{th} parent, $Y_{i.}$: mean of the i^{th} parent, $Y_{..}$: grand mean, $S.E.Gi$: standard error, σ^2 : error mean square, p : number of parents.

Walters and Morton's (1978) method allowed to determinate the gene actions involved the expression of the different parameters and estimate the genetic parameters as well. The mathematical equation of the model is written as:

$y_{ij} = m + g_i + g_j + l + l_i + l_j$ for off-diagonal elements and $y_{ii} = m + 2g_i$ for elements along the diagonal.

Additive and dominance gene effects in Walters and Morton's model were estimated as in Hayman (1954) where: $a = g_i$ =additive effects of genes; b = dominance effects of genes. The b factor is divided into $b_1 = l$ = mean dominance effects; $b_2 = l_i$ = additional dominance deviation due to the parents, $b_3 (l_{ij})$ = residual dominance effects (effects of epistasis and failure of assumptions).

The genetic parameters were estimated by the software and broad sense (H^2) and narrow sense (h^2) heritabilities were calculated as a proportion of genotypic variance (σ_g^2) on phenotypic variance (σ_p^2) and additive variance (σ_A^2) on phenotypic variance (σ_p^2) respectively.

To determine the relative importance of the GCA and SCA in the genes actions involved in the expression of the parameters, the Baker's ratio $2\sigma^2_{GCA} / (2\sigma^2_{GCA} + \sigma^2_{SCA})$ was computed (Baker, 1978).

5.3 Results

5.3.1 Combining ability effects for *Alectra* resistance parameters

General and specific combining abilities are presented in Table 5.2. The general combining ability (GCA) effects were significant ($P < 0.01$) for all the traits. However, the specific combining ability effects were significant ($P < 0.01$) for only days to flowering (DTF) and severity of *Alectra* (SEV). The SCA effects were not significant ($P > 0.05$) for days to *Alectra* shoot emergence (DAEMG) and cowpea 100 seed weight (HSW).

The ratio of the GCA variance over the SCA variance was greater than 1 for DAEMG, SEV and HSW except DTF (0.341) meaning that the GCA components were more important than the SCA for these three parameters; on the other hand the SCA was higher than the GCA for DTF.

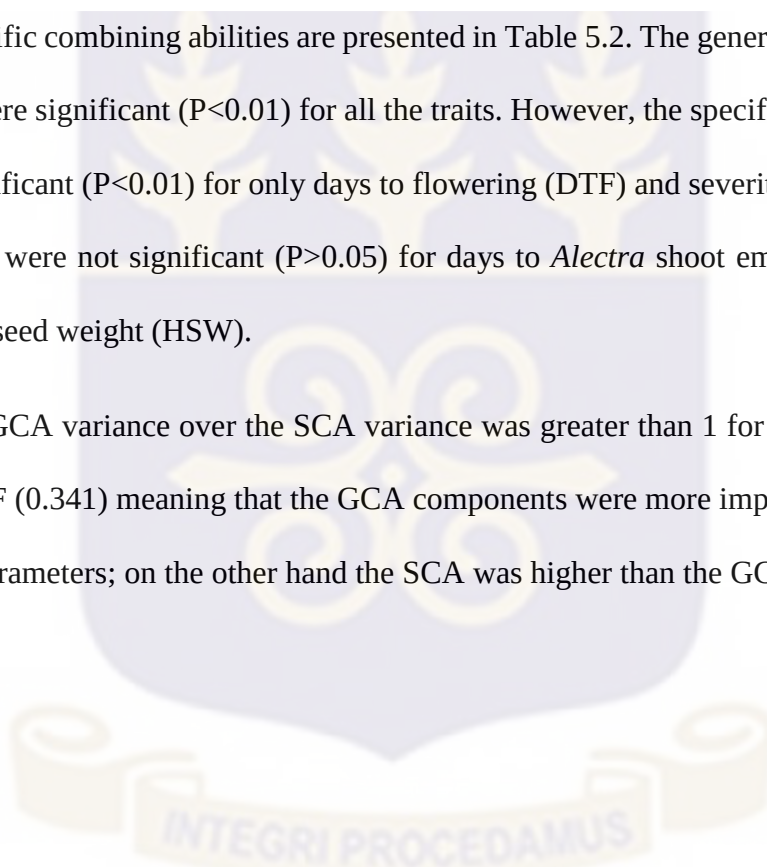


Table 5.2: Mean squares of GCA and SCA of 9x9 half diallel for the studied parameters

Sources	df	DTF	DAEMG	SEV	HSW
Rep	2	79.7 ^{ns}	100.36 ^{ns}	0.86 ^{ns}	3.75 ^{ns}
GCA	8	299.57 ^{**}	5476.81 ^{**}	2.02 ^{**}	204.76 ^{**}
SCA	27	125.58 ^{**}	366.04 ^{ns}	4.77 ^{**}	5.15 ^{ns}
Error	70	61.43	256.56	0.28	5.15
Total	107				

^{**}: significant ($p < 0.01$), ^{ns}: not significant, *df*: degree of freedom, *DTF*: days to first flowering, *DAEMG*: days to Alectra shoot emergence, *SEV*: severity of Alectra, *HSW*: 100 seeds weight.

The general combining ability (GCA) effects of the nine varieties for the studied parameters are presented in Table 5.3. For DTF the highest GCA (4.29) was observed with the variety IT81D-994 whereas IT82D-849 presented the lowest GCA (-5.59). The varieties Tiligre (12.44) and B301 (-27.38) showed the highest and lowest GCA respectively for DAEMG. The highest value of GCA for SEV was exhibited by IT82D-849 (1.06) whilst B301 (-1.12) showed the lowest GCA for the same parameter. B301 (-6.73) also had the lower value of GCA for HSW. The greater GCA were observed with Tiligre (2.31) and KVx30-309-6G (2.38).

Table 5.3: General combining ability effects of the nine cowpea genotypes

	DTF	DAEMG	SEV	HSW
Moussa local	1.41 ^{ns}	8.29 ^{ns}	0.7*	0.36 ^{ns}
KVx30-309-6G	-1.04 ^{ns}	7.92 ^{ns}	0.73**	2.38**
IT82D-849	-5.59*	4.56 ^{ns}	1.06**	-0.45 ^{ns}
Nafi	-2.07 ^{ns}	6.11 ^{ns}	0.21 ^{ns}	-0.52 ^{ns}
Tiligre	-1.98 ^{ns}	12.44*	0.1 ^{ns}	2.31**
Komcalle-P5	-0.35 ^{ns}	7.59 ^{ns}	0.12 ^{ns}	1.34*
IT98K-205-8	-0.71 ^{ns}	-18.29**	-0.91**	0.09 ^{ns}
IT81D-994	4.29*	6.16 ^{ns}	-0.21 ^{ns}	1.67*
B301	3.08 ^{ns}	-27.38**	-1.12**	-6.73**

***: significant (p<0.01), **: significant (p<0.05) ns: not significant, DTF: days to first flowering, DAEMG: days to Alectra shoot emergence, SEV: severity of Alectra, HSW: 100 seeds weight.**

5.3.2 Gene action of *Alectra* resistance

The results of analysis of variance (ANOVA) with Walters and Morton's (1978) method are presented in Table 5.4. Both the additive effects of genes (a) and the dominance effects of genes (b) were significant ($P<0.01$) for all the traits except DAEMG where b was significant at $P<0.05$. Within b, b_1 was significant ($P<0.05$) for SEV; b_2 and b_3 were both significant ($P<0.01$) for DTF and HSW and significant ($P<0.05$) for DAEMG. On the other hand, for SEV b_2 and b_3 were significant at $P<0.05$ and $P<0.01$ respectively.

Narrow sense heritability (h^2) was high for DAEMG (0.74), SEV (0.78) and HSW (0.82). A low narrow sense heritability was detected for DTF (0.26) (Table 5.5).

The average degree of dominance ranged from 0.82 to 1.81. It was less than one for SEV and HSW. In contrast the average degree of dominance was greater than one for DTF and DAEMG.

The average direction of dominance was negative for all the parameters with medium to high proportion of dominant genes (Table 5.5).

Table 5.4: Mean squares of 9x9 half diallel for the studied parameters

Sources	df	DTF	DAEMG	SEV	HSW
Rep	2	88.01 ^{ns}	129.62 ^{ns}	0.14 ^{ns}	4.24 ^{ns}
a	8	289.04**	6261.33**	5.42**	79.03**
b	36	143.67**	389.12*	4.19**	49.38**
b ₁	1	2.96 ^{ns}	416.07 ^{ns}	8.82**	0.57 ^{ns}
b ₂	8	222.29**	515.33*	0.56*	34.49**
b ₃	27	125.59**	350.73*	5.09**	55.6**
Error	88	53.43	209.61	0.22	4.76
Total	134				

******: highly significant ($p < 0.01$), ***** significant ($p < 0.05$), **ns**: not significant. *df*: degree of freedom, *DTF*: days to first flowering, *DAEMG*: days to Alectra shoot emergence, *SEV*: severity, *HSW*: hundred seeds weight. *a*: additive effects of genes, *b*: dominant effects of genes. *b*₁: mean dominance effects; *b*₂: additional dominance deviation due to the parents, *b*₃: residual dominance effects

The graphical representations of the regression W_r on the variance of the offspring V_r for DTF, DAEMG, SEV and HSW are presented in Figure 5.1, 5.2, 5.3 and 5.4 respectively. The regression coefficient of W_r on V_r for the different traits investigated varied from 0.297 (DTF) to 0.893 (SEV). The regression slope to the parabola passed below the origin for DTF and DAEMG, but for SEV and HSW it passed above the origin.

The W_r/V_r graphs showed that for the parameters days to flowering (DTF), varieties Moussa local, KVx30-309-6G and Nafi were nearest to the origin. Komcalle-P5, IT98K-205-8 and B301 were farthest from the origin whilst IT82D-849 and IT81D-994 were in medium position. In this graph

the variety Tiligre was completely separate from the rest. Figure 5.3 showed varieties B301 and IT98K-205-8 at the nearest position to the origin followed by Moussa local, KVx30-309-6G, IT82D-849 and Tiligre, the rest were far from the origin. For the severity, the varieties B301 and IT98K-205-8 were closest to the origin, three varieties Tiligre, Komcalle-P5 and IT81D-994 were intermediate, and the remaining four were far from the origin. The graph of W_r on V_r for 100 seeds weight presented only B301 associated with its origin, Moussa local, Nafi, Komcalle-P5 and IT98-205-8 were intermediate and the others on the other hand were farthest from the origin.

Table 5.5: Genetic variation and heritability for the studied parameters

Genetic parameters	DTF	DAEMG	SEV	HSW
Additive variance (D)	51.83	340.21	1.72	24.67
Dominance variance (H1)	184.24	404.46	1.15	17.76
Dominance variance (H2)	128.84	300.64	1.01	8.16
Environment variance (E)	18.75	75.84	0.08	1.64
Average degree of dominance $(H1/D)^{1/2}$	1.81	1.09	0.82	0.85
Proportion of dominant genes (kd)	0.68	0.23	0.39	0.52
Average direction of dominance (h)	-0.66	-7.85	-1.28	-0.29
Balance of positive and negative alleles (uv)	0.175	0.86	0.22	0.12
Broad sense heritability (H^2)	0.73	0.87	0.95	0.92
Narrow sense heritability (h^2)	0.26	0.74	0.79	0.82

DTF: days to first flowering, DAEMG: days to Alectra shoot emergence, SEV: severity, HSW: 100 seeds weight.

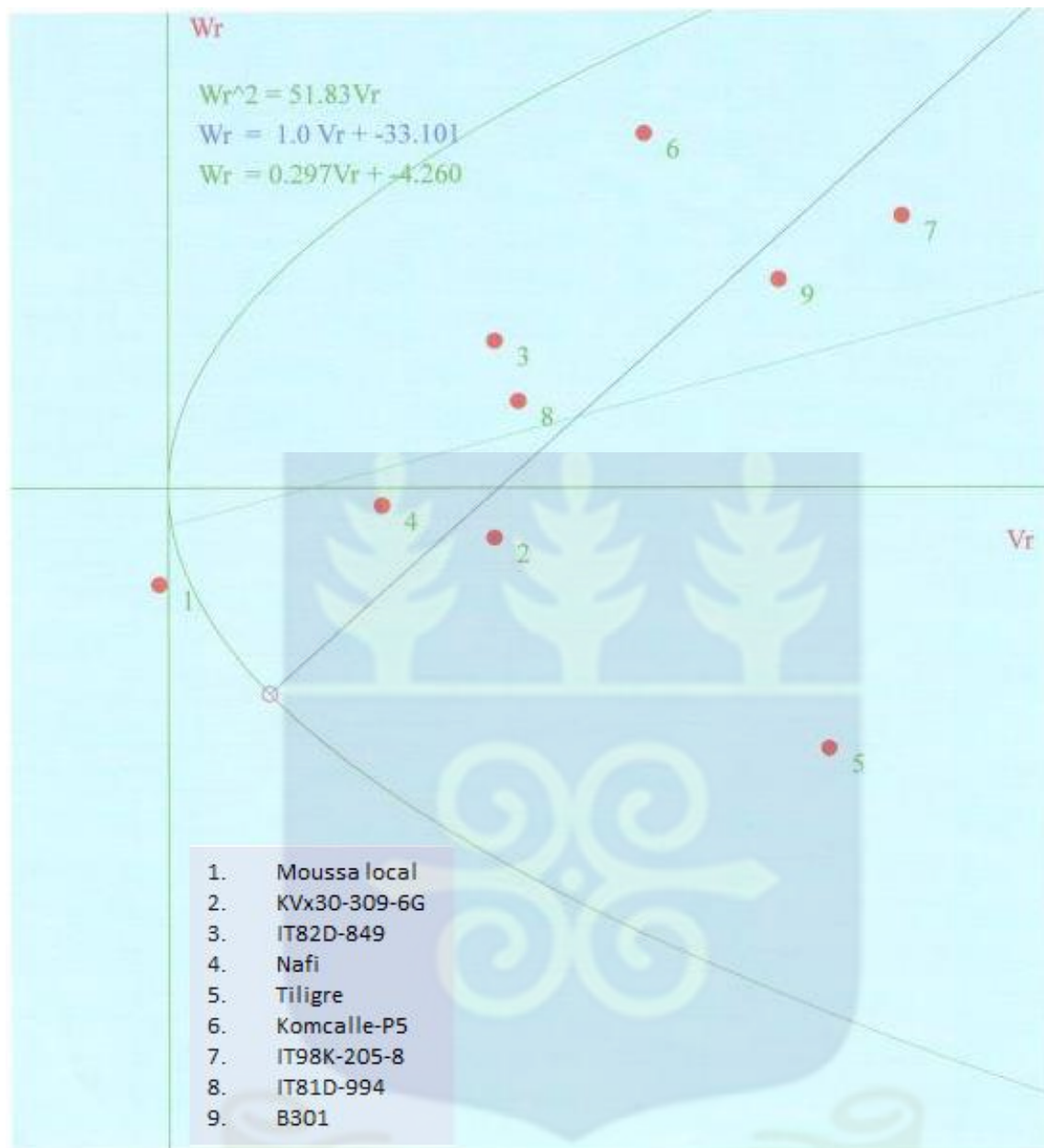


Figure 5.1: W/Vr graph of number of days to cowpea flowering (DTF) of 9x9 half diallel

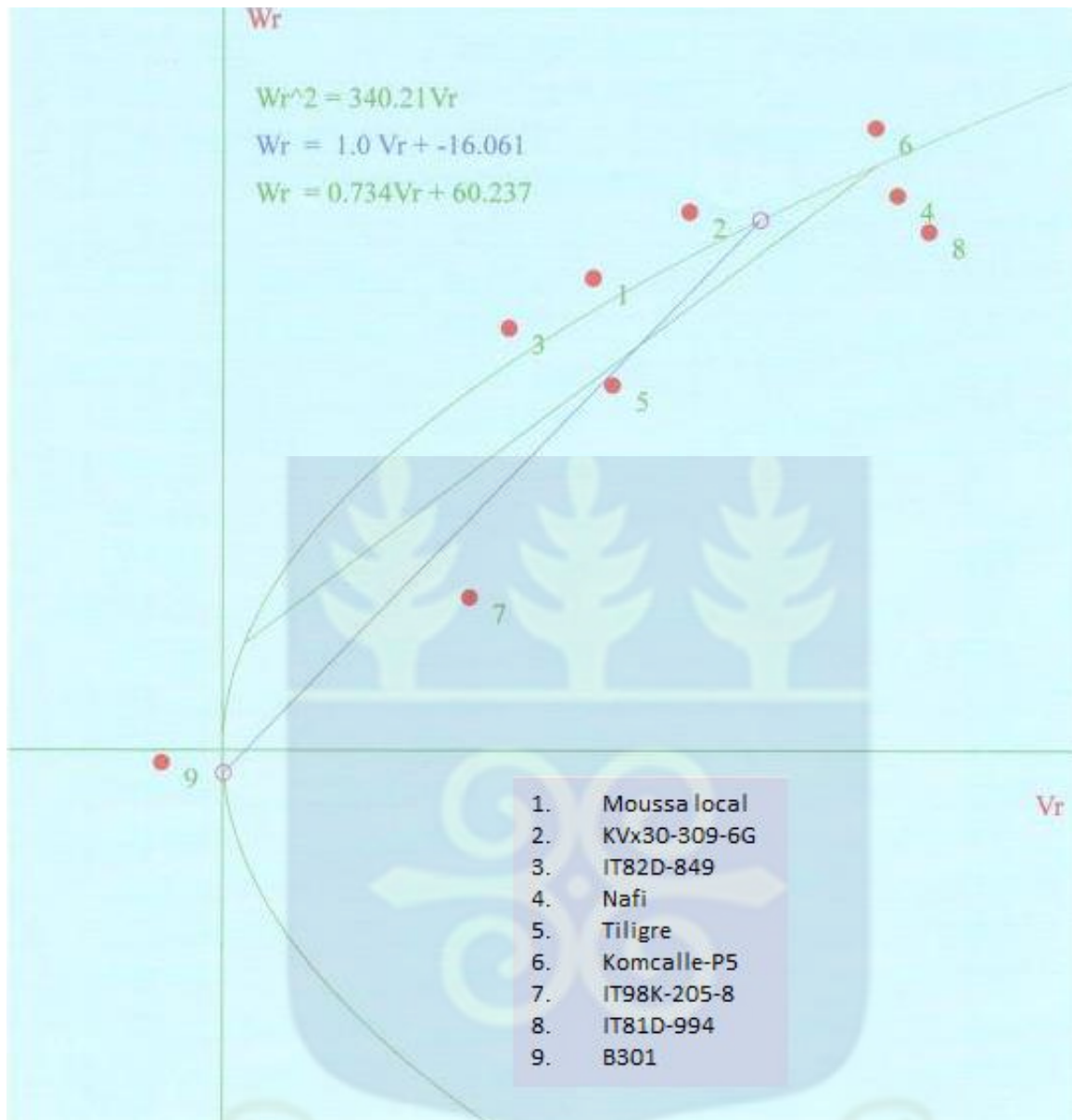


Figure 5.2: Wr/Vr graph of days to *A. vogelii* shoot emergence (DAEMG) of 9x9 half diallel

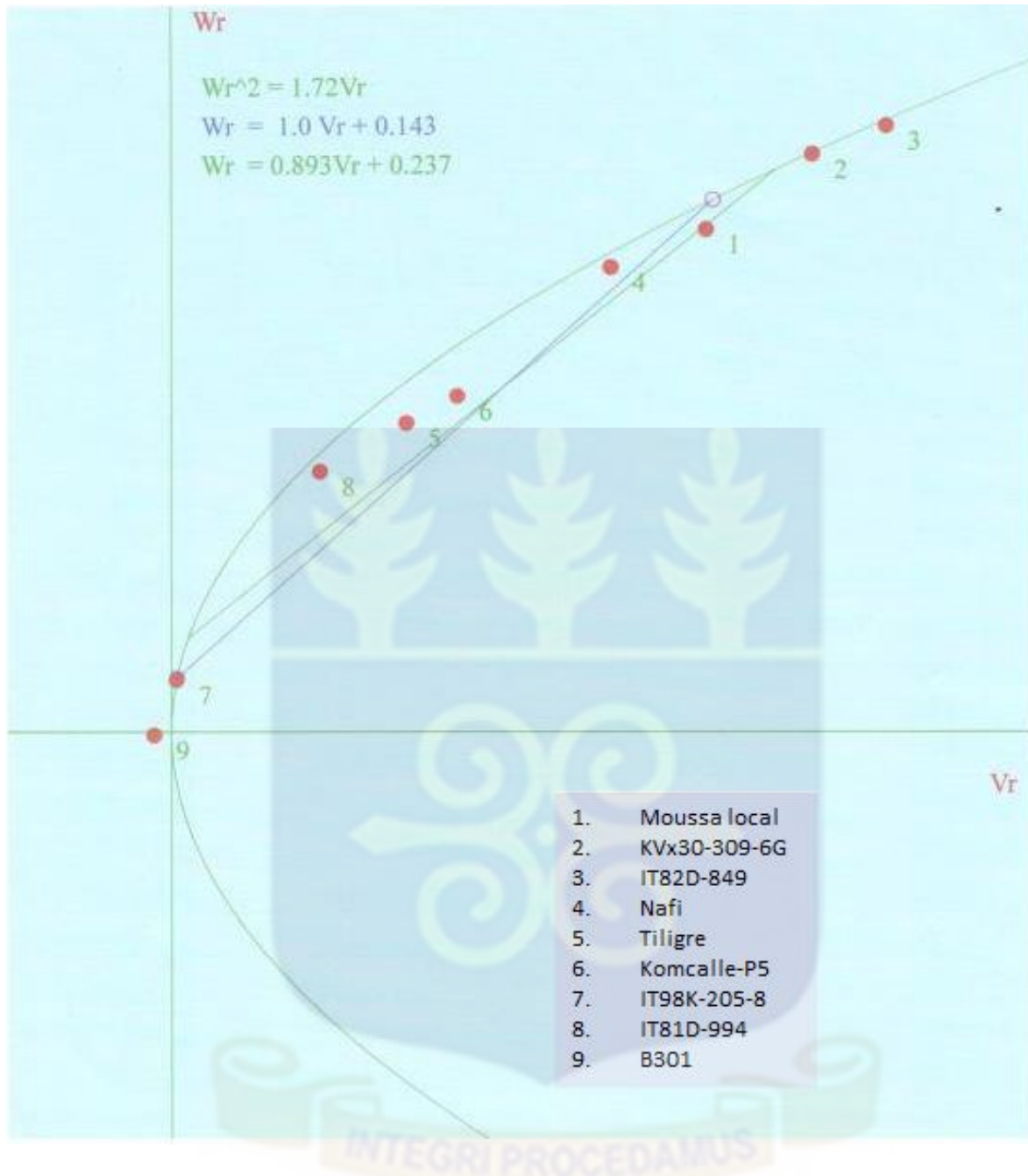


Figure 5.3: W_r/V_r graph of *Alectra vogelii* severity (SEV) of 9x9 half diallel

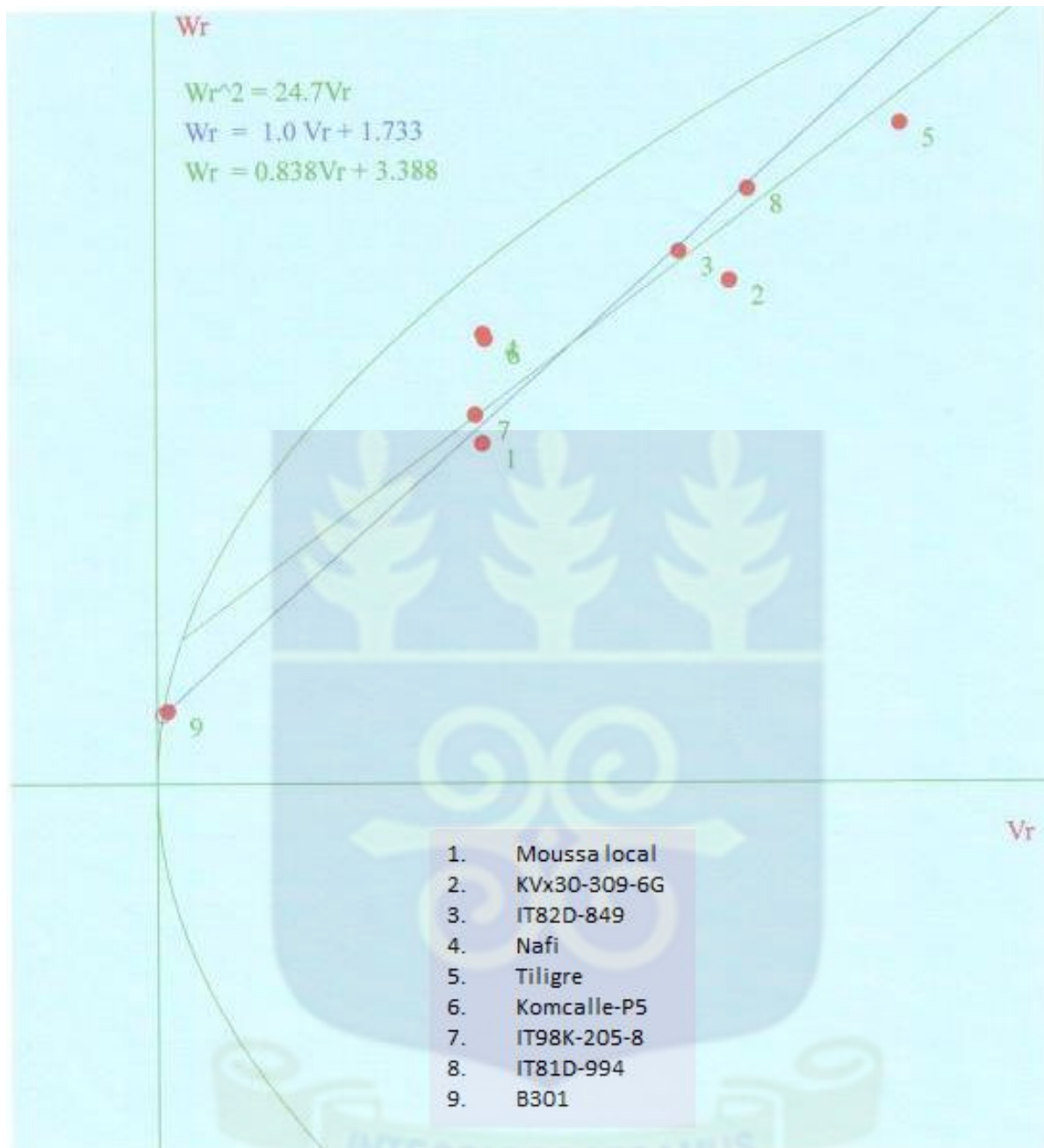


Figure 5.4: Wr/Vr graph of cowpea hundred seed weight (HSW) of 9x9 half diallel

5.4 Discussion

The results from this study showed that both additive or/and no-additive genes effects were all involved in the expression of all the investigated traits. Mbwando *et al.* (2016) also reported the existence of additive and non-additive actions in cowpea resistance to *Alectra* parameters. The proportion of additive gene effects was more important for DAEMG, SEV and HSW with $2\sigma^2_{GCA} / (2\sigma^2_{GCA} + \sigma^2_{SCA})$ values more than unity. However, for DTF the ratio was less than unity indicating the predominant influence of non-additive genes effects (Baker, 1978; Mather & Jinks, 1982; Tchiagam *et al.*, 2011). The predominance of non-additive genes effects reported in the present study are in agreement with the findings of Idahosa & Alika (2013) who asserted that DTF was mostly under non-additive components control. The relative importance of additive and non-additive gene effects was confirmed by the proportion of dominant genes which were low when additive effects were more important and high (0.68) when it was the opposite. Non-additive gene effects are composed of dominance and epistasis. The significance of b_2 observed implies that there was not uniform distribution of dominant genes among the parents, therefore, some parents were carrying more dominant genes than others. In addition, the significance of b_3 indicated the presence of specific combining ability for some crosses.

Non-additive gene effects including epistasis were present in all the characters, so it could be difficult to predict the outcome of the breeding since non-additive effects are not heritable for self-pollinating crops like cowpea. Similar conclusion was reported by Tignegre (2010) for some cowpea resistance parameters to *Striga gesnerioides*, a closely related parasitic weed to *Alectra vogelii*. However, the narrow sense heritability which is the actual breeding value passed on from parents to offspring was high for all the parameters (74%-82%) except for the parameter days to flowering (26%).

Very few studies have been undertaken to investigate gene actions involved in cowpea resistance to *Alectra vogelii*. Recently, Mbwando *et al.*, (2016) studied the genetic factors involved in cowpea resistance to *Alectra* for two parameters (number of *Alectra* shoots emerged and number of cowpea plant infested). The outcome of this study showed medium narrow sense heritability for each trait, 41.28% and 44.39% respectively. The same range of narrow sense heritability was reported by Tignegre (2010) for cowpea resistance to *Striga gesnerioides* parameters. In addition, high narrow sense heritability (60%) was observed in a diallel study for cowpea resistance to the cowpea aphid-born mosaic virus disease in Burkina Faso (Barro *et al.*, 2017)

The high narrow sense heritability for 100 seeds weight reported in this study is in agreement with the findings of previous studies where medium to high narrow sense heritability effects were reported (Umaharan *et al.*, 1997; Idahosa *et al.*, 2010; Tignegre, 2010; Ameen *et al.*, 2014). However, predominant non-additive effects indicating low heritability was also reported for this character (Raut *et al.*, 2017).

The high narrow sense heritability effects detected confirmed that these characters were largely controlled by additive factors. The narrow sense heritability enable a breeder to quantify the progress rate that can be made during the selection process. In addition, the high broad sense heritability (73%-95%) means that these traits are mainly under genetic factors control. Therefore, it is possible to improve for such characters through bulk, pedigree, single seed descent or back-cross selection.

The graphical representation showed that the regression coefficient of the slope was not significantly different from unity for all the parameters and the regression coefficients were high for three of them meaning that the additive-dominance model was satisfied (Jinks & Hayman, 1953; Hayman, 1954). Although, a low regression coefficient was observed for DTF (0.297)

synonymous of a failure of the model for this trait and then suggesting that non-allelic interactions were predominantly involved in the expression of the character (Tchiagam *et al.*, 2011). Therefore, epistasis could be operative for some specific crosses.

The W_r on V_r graph showed that the varieties were scattered along the regression line for all the characters, then genetic variability exist among the parents (Dubey & Ram, 2007). The regression line passed below the origin of the graph, then over-dominance was operative for DTF and DAEMG. Average dominance values $(H_1/D)^{1/2}$ for these traits were greater than 1 (1.81 for DTF and 1.09 for DAEMG) confirming the over-dominance genes effects revealed from the graphical analysis. Partial dominance genes action was rather present for SEV and HSW with the regression line crossing above the origin. These results were also in agreement with the average dominance values. Similar results were reported by Alam *et al.* (2013) on groundnut yield related traits.

For each of the graphs varieties which were closer to the origin carried large proportion of dominant alleles and those that were in extreme position from the origin possessed recessive ones. For instance for DAEMG and SEV, varieties B301 and IT98K-205-8 accumulated large frequency of dominant alleles as they were nearest to the origin. The recessive alleles were found in varieties Komcalle-P5, Nafi and IT81D-994 for DAEMG on one hand; on the other hand recessive alleles were mostly found in IT82D-849, KVx30-309-6G, Moussa local and Nafi for the severity. The varieties at mid-distance were those with balanced frequencies of both dominant and recessive alleles. Hence, it could be inferred that partial resistance pattern is operative in IT81D-994, Komcalle-P5 and Tiligre. Varieties B301 and IT98K-205-8 possess vertical resistance.

For 100 seed weight only variety B301 possessed a maximum frequency of dominant alleles and recessives alleles were found in varieties such as IT82D-849, KVx30-309-6G, IT81D-994 and Tiligre. The latter varieties, as opposed to B301, had large sized grains. Therefore, it can be

deduced that recessive alleles are responsible for big seed size in these varieties. This statement is in agreement with the findings of Noubissié *et al.* (2011) who mentioned that yield components were mostly controlled by recessive genes. Moreover, the present results corroborate those of Fatokun & Singh (1987). These authors asserted that the inheritance pattern of small grain size was partially dominant to big grain size.

The varieties KVx30-309-6G and Tiligre had higher general combining ability (GCA) effects for HSW followed by IT81D-994 and Komcalle-P5. Parents exhibiting high GCA effects for yield component traits are the best combiners which are valuable in breeding (Dabholkar, 1999; Machida *et al.*, 2010; Machikowa *et al.*, 2011). KVx30-309-6G had the highest GCA for HSW; however, it is *Alectra* susceptible and exhibited positive significant (GCA) for SEV. Therefore, it is not a good donor parent in breeding for *Alectra* resistance. The varieties Tiligre, Komcalle-P5 and IT81D-994 did not exhibit significant GCA effects for SEV and therefore these varieties offer advantage in both *Alectra* control and seed size increase. In addition, the varieties Tiligre and Komcalle-P5 are farmers' preferred varieties with medium to large seed size and *Striga* tolerance (Tignegre, 2010). Therefore, they can be good combiners to be used for improving for yield and resistance to both *Alectra* and *Striga*. The landrace B301 confers resistance to both parasitic weeds, as such it could be a good donor parent. However, the dominance gene action (not heritable) involved in the resistance coupled with the recessive inheritance for seed weight (lower GCA) render it difficult for selection in early generations when B301 is used as donor parent. The variety IT98K-205-8 could be the best donor since it possesses resistance and balanced allele frequencies for grain weight. With regard to the high narrow sense heritability for *Alectra* resistance parameters as well as for seed weight, a good selection progress can be achieved through bulk, pedigree, back-cross or single seed descent breeding method. The existence of partial male sterile cowpea line has

been reported (Singh & Adu-Dapaah, 1998). However, the use of this line in hybrids production, in cowpea breeding programmes, will be a difficult task due to the low success rate of hybridization (10%) even though dominance genes actions or heterosis are involved in the expression of several characters.

5.5 Conclusion

Significant general and specific combining abilities were observed for most parameters. Additive gene effects were more important in the inheritance of cowpea HSW and cowpea resistance to *Alectra vogelii* parameters (DAEMG and SEV). Non-additive gene interactions including non-allelic interaction were predominantly operative in the inheritance of DTF.

Dominant and recessive alleles were unharmoniously distributed among the parents for all the parameters. Genotypes B301 and IT98K-205-8 accumulated dominant alleles for *Alectra* resistance parameters whilst lines such as Komcalle-P5, Tiligre and IT81D-994 carried both dominant and recessive alleles. For yield components, recessive alleles were carried by varieties with large sized seeds (IT82D-849, KVx30-309-6G, IT81D-994 and Tiligre).

High narrow sense heritability was observed for HSW, DAEMG and SEV. Therefore, noticeable breeding progress can be achieved through self-pollinating crops improvement methods when parents to be used are judiciously selected. The varieties Tiligre and Komcalle-P5 were the best combiners for HSW; therefore, they could be used as recurrent parents in breeding programme with regards to resistance to *Alectra vogelii*.

CHAPTER SIX

6.0 INHERITANCE AND ALLELIC RELATIONSHIP OF *Alectra vogelii* RESISTANCE IN COWPEA

6.1 Introduction

The parasitic weed *Alectra vogelii* is a major cowpea production constraints in Africa. Total yield losses related to *A. vogelii* have been reported (Mbwaga *et al.*, 2011; Karanja *et al.*, 2013). Several control measures have been used with ineffective results. Therefore, genetic resistance remains the only most efficient, affordable and environmental protective method for controlling this weed (Rubiales *et al.*, 2006). Varieties conferring resistance to *Alectra vogelii* have been identified. However, their grain quality do not meet farmers' requirements. In addition, the inheritance of the resistance in most of these varieties is yet to be investigated. Atokple *et al.* (1993) and Singh *et al.* (1993) reported two independent genes, namely R_{av1} and R_{av2} , in land race B301 from Botswana. For an efficient transfer of genes for resistance to *Alectra vogelii* into farmers' adopted varieties, it is necessary to understand the inheritance and the allelic relationships among these genes in the context of the breeding programme in Burkina Faso.

The inheritance and allelic relationship studies of *Alectra* resistance in an improved variety with some farmers' preferred traits could greatly contribute to progress in breeding programme.

The objectives of this study were to (i) determine the inheritance pattern of the resistance in the varieties B301 and KVx414-22-2 (ii) determine the allelic relationship between the genes conferring resistance to *Alectra vogelii* in these varieties.

6.2 Materials and methods

6.2.1 Experiment management and data collection

Three genotypes IT82D-849 (susceptible), B301 (resistant), KVx414-22-2 (resistant) and their F₁ (IT82D-849xB301, IT82D-849xKVx414-22-2 and B301xKVx414-22-2) and F₂ offspring were used in this study. On one hand, the susceptible line was crossed with each of the resistant lines and on the other hand the resistant lines were crossed between themselves to develop F₁ and F₂ progenies. Ten (10) individuals of each parent as well as the F₁ populations were screened in a screen house, at Kamboinsé research station, for their reaction to *Alectra vogelii*. For each of the three F₂ populations two hundred (200) individuals were evaluated.

The experiment was conducted in screen house at Kamboinsé research station from June to August 2017. Plants were screened in plastic pots of ten (10) L filled with 12 kg of sterile soil. The pots were infested with about 1000 *Alectra vogelii* seeds from Koupela (Burkina Faso) and preconditioned for germination. The preconditioning consisted of watering the infested pots for two weeks in order to break the parasite seeds dormancy. A single seed was planted per pot. The pots were kept moist by daily watering when it was necessary. From six (6) to ten (10) weeks after cowpea planting, pots were carefully checked to record *Alectra vogelii* shoots emergence. Later on, cowpea plants were carefully uprooted after deep watering to check *haustorium* attachment. Plants which supported *Alectra* emergence were considered as susceptible; otherwise they were classified as resistant.

6.2.2 Data analysis

The data collected were subjected to Chi-square “goodness of fit” test at 5% level of significance. For the inheritance studies, the segregation ratios were compared to Mendelian’s segregation ratio for one and two genes. The null hypothesis “H₀” was rejected when the p-value was significant

(the calculated chi-square was greater than the theoretical chi-square) otherwise it was accepted (the calculated chi-square was less than the theoretical chi-square).

To determine the allelic relationship between the genes for resistance in the two parents, the Mendelian's ratios for two genes (15R: 1S) and three genes (63R:1S) were tested. The assumptions underlying this analysis are as follows:

- (i) If two dominant genes A and B confer the resistance and each of the homozygous parent carry different resistance gene, then the parents can be AAbb and aaBB respectively. F₁ progenies derived from a cross between them will be AaBb which are resistant because of the presence of A and B genes;
- (ii) If the genes are allelic, then both the first (F₁) and the second (F₂) generations derived from a cross between these two resistant parents are expected to comprise only resistant progenies;
- (iii) If not segregation ratio in the F₂ generation will be consistent with the normal Mendelian ratio: 9A_B_: 3A_bb: 3aaB_: 1aabb. All progenies carrying at least a dominant allele are expected to be resistant whilst susceptible progenies are those with homozygous recessive alleles (aabb);
- (iv) If three dominant genes A, B and C confer the resistance and one of the homozygous parents carries two different resistance genes all different from the resistance gene in the second homozygous parent, then the parents can be AAbbcc + aaBBcc and aabbCC respectively. A cross between them generates F₁ progenies of fully heterozygous genotype AaBbCc which are resistant because of the presence of A, B and C genes.
- (v) If the genes are allelic, then a cross between two resistant individuals would generate only resistant progenies in both the F₁ and F₂ generations;
- (vi) If not segregation ratio in the F₂ generation will be in agreement with the normal Mendelian ratio: 27A_B_C_: 9A_B_cc: 9A_bb_C_: 9aaB_C_: 3A_bbcc: 3aaB_cc: 3aabbC_:1aabbcc. All

progenies carrying at least a dominant allele are expected to be resistant whilst susceptible progenies are those with homozygote recessive alleles (aabbcc).

$$\chi^2 = \sum_{i=1}^k \frac{(O_i - E_i)^2}{E_i}$$

Where: χ^2 = Chi-Square value; O_i = observed frequency of class i ; E_i = expected frequency of class i ; k = number of classes.

6.3 Results

6.3.1 Inheritance patterns of the resistance

Results from the screening of the non-segregating populations are as follows: all the 10 individuals of the susceptible parent (IT82D-849) screened supported severe *Alectra* infestation. The resistant parents (B301 and KVx414-22-2) as well as both F_1 populations were free of *Alectra* infestation.

Among 200 F_2 progenies derived from a cross between IT82D-849 and B301, 18 individuals were susceptible to *Alectra*. In the second F_2 population (IT82D-849 x KVx414-22-2) 62 individuals over 200 supported *Alectra* shoots emergence. The segregation ratios are presented in Table 6.1. The chi-square “goodness-of-fit” test was not significant ($P > 0.05$) for both F_2 populations. The χ^2 values were 2.58 and 3.09 for the first and second populations, respectively. The F_2 progenies derived from the cross between IT82D-849 x B301 segregated into a ratio of 15 resistant: 1 susceptible. The F_2 offspring derived from cross between IT82D-849 and KVx414-22-2 resulted in a segregation ratio of 3 resistant: 1 susceptible.

Table 6.1: Segregation ratios of the inheritance for *Alectra* resistance in two F₂ populations

Cross	Total	observed frequencies		expected frequencies		Ratio	χ^2	p-value
		R	S	R	S			
IT82D-849 X B301	200	182	18	187.5	12.5	15:1	2.58	0.108
IT82D-849 X KVx414-22-2	200	138	62	150	50	3:1	3.09	0.079

R: resistant, S: susceptible, χ^2 : Chi-Square value

6.3.2 Allelic relationship

The segregation ratios of F₂ progenies derived from cross between two resistant genotypes (B301 x KVx414-22-2) are presented in Table 6.2. For the 200 F₂ plants tested only four were susceptible to *Alectra vogelii*. The χ^2 goodness-of-fit test was not significant ($P > 0.05$). So the F₂ population segregated into a ratio 63 resistant: 1 susceptible.

Table 6.2: Segregation ratios of the allelic relationship for *Alectra* resistance in F₂ population

Cross	Total	observed frequencies		expected frequencies		ratio	χ^2	p-value
		R	S	R	S			
B301 X KVx414-22-2	200	196	4	192.59	7.41	63:1	1.63	0.202

R: resistant, S: susceptible, χ^2 : Chi-Square value

6.4 Discussion

The resistant parents (B301 and KVx414-22-2) and all F₁ progenies derived from the different crosses were resistant to *Alectra vogelii*. The susceptible parent (IT82D-849) showed high degree of infestation. The homogeneity of the F₁ for resistance to *A. vogelii* demonstrated that at least one dominant gene is responsible for the resistance in each of the varieties. A dominant inheritance pattern was reported for B301 (Atokple *et al.*, 1993; Singh *et al.*, 1993).

The F₂ progenies derived from cross between IT82D-849 and B301 segregated into a ratio of 15:1 implying that two dominant genes confer the resistance to *Alectra vogelii* in B301. These findings are in agreement with those of Atokple *et al.* (1993) and Singh *et al.* (1993). The F₂ offspring from IT82D-849xKVx414-22-2 assorted into 3 resistant: 1 susceptible. The segregation ratio conforms with the Mendelian's segregation ratio for one dominant gene. Therefore, a single dominant gene governs resistance in KVx414-22-2. Total resistance is mostly reported in cowpea resistance to parasitic weeds. Single dominant gene inheritance pattern was reported for *Alectra* resistance in IT81D-994 (Atokple *et al.*, 1995; Kouakou *et al.*, 2009). Several dominant genes (*Rsg*₁, *Rsg*₂, *Rsg*₃ and 994-*Rsg*) have been reported for cowpea resistance to *Striga gesnerioides* in different genotypes including B301, IT82D-849 and IT81D-994; among them *Rsg*₁ and *Rsg*₂ are allelic (Atokple *et al.*, 1993, 1995; Ouedraogo *et al.*, 2001; Singh *et al.*, 1993; Tignegre, 2010).

For the allelic relationship study, the observed segregation ratio was similar to the inheritance pattern of a character governed by three independent dominant genes. The independent inheritance pattern of the two genes conferring resistance in B301 has been reported by Atokple *et al.* (1993) and confirmed by the present study. Thus if one of these two genes was allelic to the resistance gene in KVx414-22-2, then the segregation ratio of the F₂ progenies derived from B301xKVx414-22-2 should be consistent with Mendelian's segregation pattern for two independent genes.

However, this hypothesis has been rejected ($p < 0.05$) indicating that the three genes are all located on three different loci. Therefore, it could be concluded that the two dominant genes conferring resistance to *Alectra* in B301 are not allelic with the gene responsible for resistance in KVx414-22-2. Non allelic relationship between the genes conferring resistance in B301 and IT81D-994 has also been reported (Atokple *et al.*, 1995). Therefore, the symbols *Rav*₁, *Rav*₂ and *Rav*₃ were proposed for the different resistance genes in B301 and IT81D-994 respectively (Atokple *et al.*, 1995; Singh *et al.*, 1993). The allelic relationship between the resistance genes in IT81D-994 and KVx414-22-2 was not investigated in the present study. However, KVx414-22-2 and IT81D-994 are not related. KVx414-22-2 derives from a multi-level cross involving the following genotypes: Ouahigouya local, IAR1696, Suvita-2, Pobe local and Vita-3. The variety IT81D-994 was developed from a single cross between TVx1193-7D and TVu625. In addition these two genotypes showed differential reaction to the ecotype of *Alectra* used in this study. If the genes conferring resistance to *Alectra* were the same for each of the genotypes, then the same level of resistance should have been observed. But that was not the case. Therefore, the two genes conferring resistance in these varieties are different. The symbol *Rav*₄ could be proposed for the resistance gene in KVx414-22-2. The variety KVx414-22-2 is an improved line from Burkina Faso possessing farmers' preferred traits (large and white seeds) but it is *Striga* and virus susceptible. Nevertheless, it can be an ideal donor parent for improving cowpea for both *Alectra* resistance and grain quality through backcross breeding.

The co-occurrence of *Alectra vogelii* and *Striga gesnerioides* in some cowpea production areas in Burkina Faso render necessary to breed for combined resistance to both parasitic weeds. The landrace B301 confers resistance to both *Alectra vogelii* and *Striga gesnerioides* although the resistance to each of these related weeds is governed by different genes with one dominant gene

conferring resistance to *Striga* (Atokple *et al.*, 1993). These authors also mentioned that whilst selecting for *Striga* resistance using B301 as donor parent, nearly 94% of the outcome varieties will be simultaneously resistant to *Alectra*. However, it is difficult to select for grain quality and weeds resistance at the same time using B301 because of the dominant inheritance pattern of small seed size. In addition breeding based on a few dominant genes is not much reliable because of the risk of breakdown of resistance (Rubiales *et al.*, 2006). Breeding for strong and durable resistance will require multi levels of crosses. That gives a more complex task to plant breeders. Fortunately, fine resolution molecular makers with (SNP and SSR) are now available for most crops and allow accurate transfer of targeted traits of interest. The use of these modern breeding molecular tools to assist conventional breeding programs can help to overcome some of the difficulties. Marker-assisted selection permits to accelerate the breeding process with early generation selection. SSR markers are available for resistance to some races of *Striga gesnerioides* but molecular markers linked with *Alectra* resistance genes are still to be identified.

6.5 Conclusion

The results of this study showed that the resistance to *Alectra vogelii* is conferred by two independent dominant genes in the genotype B301. On the other hand, for the variety KVx414-22-2, the resistance is conferred by a single dominant gene. The symbol *Rav₄* was proposed for the resistance gene in KVx414-22-2. The *Rav₁* and *Rav₂* genes present in B301 and the proposed *Rav₄* in KVx414-22-2 are all non-allelic.

CHAPTER SEVEN

7.0 GENERAL CONCLUSION AND RECOMMENDATIONS

7.1 General conclusion

Cowpea is a major legume crop in food security system in West Africa. It serves as an important component for balancing diet of millions of people in developing countries who live under the poverty line. The income generating potential of the crop has also been demonstrated. But cowpea supply is in deficit as compared to the demand due to several constraints threatening its production. *Alectra vogelii* is one of the devastating parasitic weeds limiting cowpea yield. The importance of *A. vogelii* in cowpea production has not been previously assessed in Burkina Faso. The present investigation constitutes the first step in cowpea breeding for resistance to *A. vogelii* in Burkina Faso. As such, it was important to: (i) identify farmers' varietal preferences and assess their opinion on the parasitic weed *A. vogelii*; (ii) identify cowpea sources of resistance to *A. vogelii* in cowpea germplasm from Burkina Faso; (iii) determine gene action involved in cowpea resistance to *A. vogelii* and (iv) determine the genetic inheritance and the allelic relationship of the resistance genes.

Striga gesnerioides, insects and *A. vogelii* were the main biotic constraints identified by farmers. Farmers from western Burkina Faso knew more about the noxious effects of *Alectra* than those from centre east. More than 50% yield loss related to *Alectra* was registered in farmers' fields. Drought, low soil fertility, limited access to improved varieties seeds and lack of training were also important constraints from farmers' opinion. Farmers preferred varieties with large sized and white grain with rough texture because they meet both consumption and market requirements. Short duration cycle varieties were demanded by farmers for their ability to escape terminal drought.

Highly *Alectra*-resistant genotypes were identified. The varieties Komcalle, IT98K-205-8 and IT99K-573-2-1 are farmers' adopted varieties conferring resistance to the three ecotypes of *Alectra*. They can be recommended to farmers in *Alectra* prone areas. B301, IT93K-693-2, KVx414-22-2, also conferred high resistance to *Alectra* but they are either rejected by farmers or susceptible to other constraints (*Striga*, drought, virus diseases). These varieties are potential donor parents for cowpea improvement for resistance to *A. vogelii*. All landraces from Burkina Faso enable *Alectra* shoot emergence. The best *Alectra* tolerant landraces were Djouroum local and Pouytenga-9. Djouroum local is a drought-tolerant line with large sized grain. Therefore, it could be an ideal recurrent parent in breeding programme. All the cowpea wild relatives were highly resistant to the three ecotypes of *Alectra* and can also serve as alternative donor genotypes. Differential reaction of cowpea genotypes to the ecotypes of *A. vogelii* was observed, suggesting the presence of different strains of the weed in Burkina Faso.

Significant effects of general combining ability (GCA) and specific combining ability (SCA) observed shows the presence of both additive and non-additive gene effects in the expression of the parameters. Non-additive gene effects included partial dominance, over-dominance, and non-allelic interactions (epistasis and failure of assumption). Dominant and recessive genes were not harmoniously distributed among the parents. The ratio of GCA variance over SCA variance showed the importance of additive gene effects. High narrow sense heritability was also observed. Therefore, breeding progress can be achieved through backcross and single seed descent breeding methods.

Different segregation patterns were observed for each of the two resistant genotypes. Two dominant genes inheritance pattern was observed with the landrace B301. The resistance in KVx414-22-2 is conferred by a single dominant gene. The segregation ratio of the F₂ population

derived from the cross between the two resistant genotypes B301 and KVx414-22-2 indicated that the *Alectra* resistance genes present in these genotypes are not allelic. The symbol Rav₄ was proposed for the resistance gene in KVx414-22-2. These genes can be pyramided into an elite variety to build a strong and durable resistance.

7.2 Recommendations

Cowpea production in Burkina Faso is hampered by several important constraints such as drought, *Striga gesnerioides*, insect pests and *Alectra vogelii*; therefore a breeding programme should address all these threats and select for combine resistance.

Breeding objectives should also give priority to farmers' preferred varietal characteristics which are mainly large sized white grain with rough texture that meet both consumers and market requirements.

The high yielding *Alectra*-resistant and tolerant varieties possessing farmers' preferred traits should be recommended to farmers in the *Alectra* prone areas.

Pyramiding the different *Alectra* resistance genes into elite varieties will build stronger and durable resistance in the outcome varieties.

Fields infected with *Alectra vogelii* have been observed in others areas different from where the studied ecotypes were collected. Therefore, a large collection of *Alectra* seeds across the country should be done to establish its strain or race variability at the country level.

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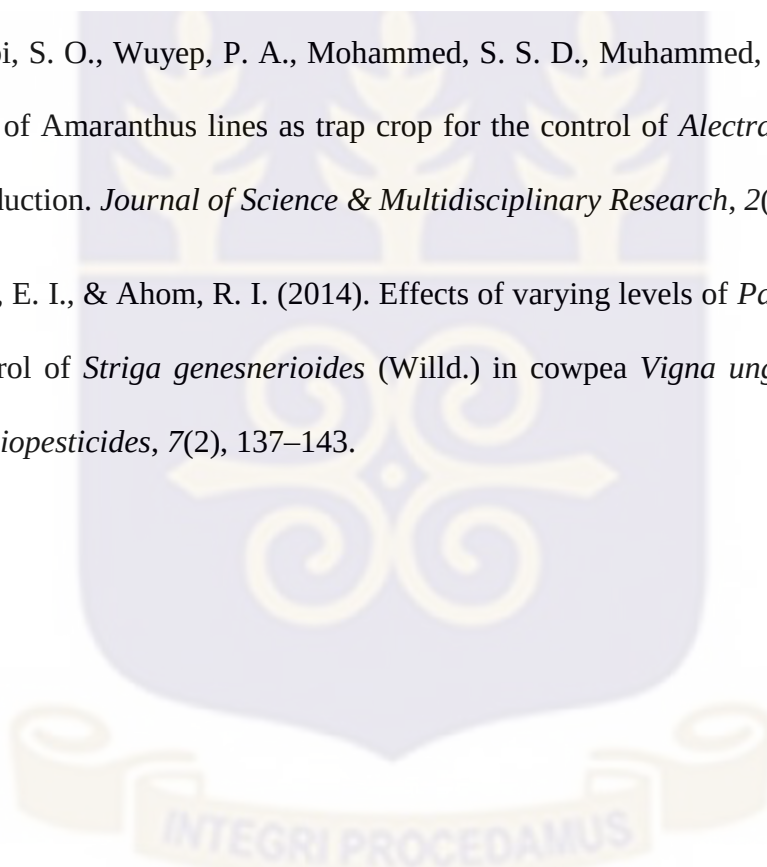
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APPENDICESAppendix 1: Origin and grain colour of cowpea genotypes screened for resistance to *Alectra*

Order	Variety	Origin	Grain colour
1	Woango-1	Burkina Faso	White
2	KVX402-5-2	Burkina Faso	Brown
3	IT95K-627-4	IITA/Nigeria	White
4	KVX780-6	Burkina Faso	White
5	KVX780-9	Burkina Faso	White
6	KVX771-10x693-2GB	Burkina Faso	White
7	Gorom local	Burkina Faso	Brown
8	IT84S-2049	IITA/Nigeria	White
9	KVX421-2J	Burkina Faso	Brown
10	Nafi HT2	Burkina Faso	White
11	SR-1	Burkina Faso	White
12	KVX165-14-1	Burkina Faso	Brown
13	KVX775-33-2x20F8 Bulk F9-P2	Burkina Faso	White
14	KVX396-4-5-2Dx693-2 BC4F8-P8	Burkina Faso	White
15	KVX-775-33-2x693-2 BC4F8-P13-1	Burkina Faso	White
16	KVX 295-2-124-99	Burkina Faso	White
17	IT98K-1111-1	IITA/Nigeria	White
18	Moussa local	Burkina Faso	White
19	Youngou local	Burkina Faso	White
20	KVX775-33-2 x693-2 BC4F8-P7	Burkina Faso	White
21	B301	Botswana	Brown
22	KVX780-1	Burkina Faso	White
23	58-57	Senegal	White
24	KVX61-1	Burkina Faso	White
25	IT82D-849	IITA/Nigeria	Brown
26	KVX780-3	Burkina Faso	White
27	524B	UCR-USA	White
28	Nafi HT1	Burkina Faso	White
29	KVX745-11P	Burkina Faso	White
30	IT98K-205-8	IITA/Nigeria	White
31	IT99K-573-2-1	IITA/Nigeria	White
32	KVX30-309-6G	Burkina Faso	White
33	KVX780-4	Burkina Faso	White
34	KVX65-114	Burkina Faso	Brown
35	IT97K-499-35	IITA/Nigeria	White
36	IT81D-994	IITA/Nigeria	White
37	HTR	Niger	White

Appendix 1: Origin and grain colour of cowpea genotypes screened for resistance to *Alectra* (continue)

Order	Variety	Origin	Grain colour
38	TVU14676	IITA/Nigeria	Black
39	IT93K-693-2	IITA/Nigeria	Brown
40	KVX771-10x693-2 BulkF8-P2	Burkina Faso	White
41	KVX396-4-5-2Dx693-2 BC4F8-P8-2	Burkina Faso	White
42	KVX402-8-1x693-2 BC4F8	Burkina Faso	White
43	KVX775-33-2x693-2 BC4F8 -P14-2	Burkina Faso	White
44	Komcalle-P5	Burkina Faso	White
45	KVX771-10x693-2 Bulk BC4F8-P2	Burkina Faso	White
46	KVX775-33-2x205-8 Bulk F9-P3	Burkina Faso	White
47	KVX404-8-x693 BC4F8-P4	Burkina Faso	White
48	KVX771-10x693-2 Gr blanche	Burkina Faso	White
49	N°2300	Cameroon	Brown
50	KVX775-33-2 x693-2 BC4F8-P11	Burkina Faso	White
51	KVX404-8-1x205-8 BC4F8-P1	Burkina Faso	White
52	KVX771-11x771-10 Bulk F9-P1	Burkina Faso	White
53	KVX775-33-2G (Tiligre)	Burkina Faso	White
54	KVX396-4-5-2D x693-2 BC4F8	Burkina Faso	White
55	KVX775-33-2x693-2 BC4 F8-P14	Burkina Faso	White
56	Mx499-BC3F3-4P67	Burkina Faso	White
57	Mx499-BC3F3-48-P85	Burkina Faso	White
58	Mx499-BC3F3-44-P19	Burkina Faso	White
59	SR-2	Burkina Faso	White
60	Moussax693-2 Gr brune	Burkina Faso	Brown
61	Moussax205-8 F8-P1	Burkina Faso	White
62	KVX775-33-2 x693-2 BC4F8-P2	Burkina Faso	White
63	KVX771-10x693-2 Bulk BC4F8-P3	Burkina Faso	White
64	KVX404-8-1x693-2 BC4F8	Burkina Faso	White
65	KVX775-33-2x693-2 BC4 F8-P9	Burkina Faso	White
66	Mx499-BC3F3-48P90	Burkina Faso	White
67	IT93K-503-1	IITA/Nigeria	White
68	Moussax693-2 Bulk F8-P2	Burkina Faso	White
69	Mx499-BC3F3-48P93	Burkina Faso	White
70	Mx503-BC3F3-92 P27	Burkina Faso	White
71	NS Farakoba	Burkina Faso	Brown
72	Koankin local	Burkina Faso	White
73	NS1	Burkina Faso	Black

Appendix 1: Origin and grain colour of cowpea genotypes screened for resistance to *Alectra* (continue)

Order	Variety	Origin	Grain colour
74	KVU 150	Burkina Faso	White
75	SARC1-57-2	Ghana	White
76	SARC1-91-1	Ghana	White
77	KVX771-10G (Nafi)	Burkina Faso	White
78	TVX3236	IITA/Nigeria	Brown
79	KN-1	Burkina Faso	Brown
80	IT86D10-1	IITA/Nigeria	White
81	IT93K-1381	IITA/Nigeria	White
82	SR-4	Burkina Faso	White
83	CB27	UCR-USA	White
84	IT00K-901-6	IITA/Nigeria	White
85	KVX 404-8-1x 693-2 BC4F8-P4	Burkina Faso	White
86	IT99K-499-39	IITA/Nigeria	White
87	IT95M-190	IITA/Nigeria	White
88	Iron clay	UCR-USA	White
89	Komcalle	Burkina Faso	White
90	TZ-1 (Gourgou)	Burkina Faso	White
91	KVX404-8-1	Burkina Faso	White
92	Komsare	Unknown	cream
93	Sanzi (Sanzisabinli)	Ghana	Black
94	Vita-5	Burkina Faso	Brown
95	Diebougou local	Burkina Faso	White
96	Melakh	Senegal	White
97	IT82E-32	IITA/Nigeria	Brown
98	Ife Brown	Nigeria	Brown
99	Danilla	Nigeria	White
100	IT95K-238-3	IITA/Nigeria	Brown
101	IT86D-716	IITA/Nigeria	White
102	Pobe local	Burkina Faso	White
103	Dossin local	Burkina Faso	White
104	KVX295-2-124-51	Burkina Faso	White
105	Vita-4	Burkina Faso	White
106	Solenzo local	Burkina Faso	White
107	Djouroum local	Burkina Faso	White

Appendix 1: Origin and grain colour of cowpea genotypes screened for resistance to *Alectra*
(continue)

Order	Variety	Origin	Grain colour
108	IT93K-687-1	IITA/Nigeria	White
109	CR06-07	Ghana	Brown
110	ITN87-71-21	Niger	White
111	Lama local	Burkina Faso	White
112	KVX396-4-5-2D	Burkina Faso	White
113	Sakoula local	Burkina Faso	White
114	KVX414-22-2	Burkina Faso	White
115	Goinkoro-2	Burkina Faso	White
116	SR-3	Burkina Faso	White
117	Bambey 21	Senegal	White
118	Bagre-1	Burkina Faso	White
119	Dimbo local	Burkina Faso	White
120	Pouytenga-9	Burkina Faso	White

Appendix 2: Days to flowering, days to *Alectra* shoot emergence, cowpea hundred seed weight and *Alectra* severity in screen house

Genotypes	DTF			DAEMG			HSW			SEV70		
	Kp	Tenk	Tssina	Kp	Tenk	Tssina	Kp	Tenk	Tssina	Kp	Tenk	Tssina
Woango-1	61	55.25	58	42.66	46.68	44.67		18.05	17.49	5	5	5
KVX402-5-2	59.43	56.6	55.67	50.69	57.72	55	16.79	18.61	17.95	3.33	3	3
IT95K-627-4	39	40.69	45.67	64.32	52.36	60	19.65	22.52	21.33	2	2	2
KVX780-6	42.33	39.99	39.67	46.32	60.71	51.67	20.82	21.68	22.18	3	3	3
KVX780-9	42.9	44.4	40.33	50.03	46.41	50.67	23.22	21.77	21.73	3	3	3
KVX771-10x693-2GB	42	42.75	41.67	44.64	48.27	46	25.9	27.42	23.4	5	4.67	5
Gorom local	44.67	46.29	50	46.01	45.08	47	14.94	17.34	17.49	5	4	4.67
IT84S-2049	39	52.61	47.33	45.36	43.65	51	13.12	12.87	12.12	4.66	4.33	4.33
KVX421-2J	40	39.01	41.33	41.31	46.2	49	19.95	19.37	16.87	3	2.67	3
Nafi HT2	44.67	49.54	42	46.33	48.29	49	22.73	20.23	23.9	3	3	3
SR1		43.94	45.33	49.32	44.02	43.67	17.41	16.16	18.58	3.34	4	4.67
KVX 165-14-1							10.43			1	1	1
KVX775-33-2x20F8 Bulk F9-P2	43	39.99	43	50.99	45.31	51.67	22.17	25.07	20.91	3.01	3	3
KVX396-4-5-2Dx693-2 BC4F8-P8	44	42.74	40.67	50.31	56.59	56	22.01	21.54	21.32	3	3	3
KVX-775-33-2x693-2 BC4F8-P13-1	40	38.42	41.33	47.32	54.88	57.67	19.74	19.5	20.25	3	3	3
KVX 295-2-124-99	0	71.61	72.8	46.69	53.98	54.33	14.23	16.32	20.09	4	4	4
IT98K-1111-1	42.67	41.44	44.33	57.67	65.39	55	17.76	16.45	16.81	3	3	3
Moussa local	47.67	48.7	45.67	45.99	45.1	47.67	14.97	15.26	14.65	4	4	4
youngou local	58.33	46.26	59.33	48.34	46.25	46.33	16.71	15.06	16.72	4.33	4	4
KVX775-33-2 x693-2 Bc4F8-P7	43.33	38.67	43	46.36	49.27	44.33	16.03	14.83	15.2	2	2	2
B301	52.33	47.15	49				2.18	7.21	8.31	1	1	1
KVX780-1	40.33	46.16	43.33				23.1	20.86	25.84	1	1	1
58-57			45	42.98	44.26	44				4.01	4.67	4.33
KVX61-1	42.67	41.92	40.67	45.32	47.46	46	15.67	18.16	16.07	5	4.33	4.67
IT82D-849	40	42.86	41.67	43.34	43.66	46.67	17.15	19.19	17.44	5	4.67	4.67

Appendix 2: Days to flowering, days to *Alectra* shoot emergence, cowpea hundred seed weight and *Alectra* severity in screen house

Genotypes	DTF			DAEMG			HSW			SEV70		
	Kp	Tenk	Tssina	Kp	Tenk	Tssina	Kp	Tenk	Tssina	Kp	Tenk	Tssina
524B	38	39.83	37	45.32	47.03	45.33	22.09	20.51	23.39	4.33	3.67	3.67
Nafi HT1	39.33	38.09	39	49.7	55.69	53	21.83	19.85	23	3.33	3	3
KVX745-11P		69.7		48.33	45.77	49		12.15	9.79	5	4.33	4.67
IT98K-205-8 (Niizwe)	40	40.57	40.67				16.44	17.47	17.98	1	1	1
IT99K-573-2-1 (Yiisyande)	44.67	41.35	42				20.94	20.4	21.35	1.01	1	1
KVX30-309-6G	44.33	44.19	43.33	45.65	45.9	42.33	19.04	23.24	21.23	4.34	4	4.33
KVX780-4	42	44.09	41	53	49.09	54.33	23.65	23.25	22.51	3	3	3
KVX65-114	46	45.41	44.67	48.98	45.72	47	16.89	19.47	19.44	4	4.33	4
IT97K-499-35	43.67	40.2	45.67	51.67		49	17.33	15.82	16.38	3.34	1	4.33
IT81D-994	41.67	43.16	44.33	57.33			22.92	20.01	20.02	2.34	1	1
HTR	44.67	48.16	39.67		50.01	55.33	16.18	15.44	17.73	1	3	3
TVU14676	49	40.96	43.6	66.64	79.09			14.91	16.12	2	1.33	1
IT93K-693-2	45	45.56	41				15.98	15.48	16.23	1	1	1
KVX771-10x693-2 BulkF8-P2	41	39.56	35.33	47.99	48.19	48.33	15.42	13.59	18.87	4.33	4	4
KVX396-4-52Dx693-2 BC4F8-P8-2	40	42.1	38	52.34	55.25	55.04	21.72	21.66	19.78	3	3	3
KVX402-8-1x693-2 BC4F8	40.33	40.43	40.33	43.99	53.11	53.33	18.43	20.22	17.55	4	4	4
KVX775-33-2x693-2 BC4 F8 -P14-2	40	40.02	39.33	57.01	58.38	60.67	15.07	15.42	16.06	3	3	3
Komcalle plant-5	42.33	43.26	41	54			20.4	17.08	18.83	2.66	1	1
KVX771-10x693-2 Bulk BC4F8-P2	41.67	45.95	40.33	54	59	59.33	19.24	20.62	19.2	3	3	3
KVX775-33-2x205-8 Bulk F9-P3	41.67	42	40	55.34	65.01	62.33	23.42	22.74	21.54	3	3	3
KVX404-8-x693 BC4F8-P4	49	42.73	45	54.32	49.94	56.67	21.91	19.31	22.42	3	3	3
KVX771-10x693-2 Gr blanche 1	39.33	40.79	41.67	52.31	53.92	54.67	23.49	19.98	21.37	3	2	3
N 2300		59.74						3.62		1	1	1
KVX775-33-2 x693-2 BC4F8-P11	41.33	44.66	43.67	48.37	58.98	50.67	17.03	21.11	18.66	4	3.67	4

Appendix 2: Days to flowering, days to *Alectra* shoot emergence, cowpea hundred seed weight and *Alectra* severity in screen house

Genotypes	DTF			DAEMG			HSW			SEV70		
	Kp	Tenk	Tssina	Kp	Tenk	Tssina	Kp	Tenk	Tssina	Kp	Tenk	Tssina
KVX404-8-1x205-8 BC4F8-P1	38.67	36.78	38.67	55	60.62	53	12.9	15.38	13.63	3	3	3
KVX771-11x771-10 Bulk F9-P1	45	43.24	44.67		57.74	57	14.78	18.25	18.74	1	3	3
KVX775-33-2G (Tiligre)	44	40.1	44	45.67	50.96	49.33	22.42	19.31	23.97	3	3	3
KVX396-4-5-2D x693-2 BC4F8	41	41.95	38	41.33	48.05	47.67	13.14	14.21	13.1	4	3	4
KVX775-33-2x693-2 BC4 F8-P14	45.33	45.36	39.51				19.54	16.37	17.99	1	1	1
Mx499-BC3F3-4P67	41.67	45.3	43.67	43.01	47.93	45	16.19	11.95	16.95	4.67	4.33	4.33
Mx499-BC3F3-48-P85	44.67	43.26	42.33	46.31	47.02	46	15.03	14.6	16.57	4	4	4
Mx499-BC3F3-44-P19	56.67	48.63	45.67	44.67	49.12	45.33		20.53	18.93	3.99	4	4
SR2	52.33	41.95	47	44.66	49.55	49	10.9	15.83		4	4	4
Moussax693-2 Gr brune	42.33	42.7	43.67	46	48.06	48	18.18	16.85	16.3	4	4	4
Moussax205-8 F8-P1	47	45.82	44.67				16.12	18.9	17.59	1	1	1
KVX775-33-2 x693-2 BC4F8-P2	50.33	40.37	40.67	44.69	43.7	44.67	19.65	20.99	22.22	3.33	3	3.33
KVX771-10x693-2 Bulk BC4F8-P3	44	41.75	42.33	43.32	45.1	45.67	22.25	19.04	22.4	3	3	3
KVX404-8-1x693-2 BC4F8	42.33	40.04	40.33	45.66	47.97	45.67	15.04	13.14	15.86	3	3	3
KVX775-33-2x693-2 BC4 F8-P9	46.33	38.66	47.33	47.67	47.69	50	19.28	19.35	19.36	2	2.67	3
Mx499-BC3F3-48P90	41.67	45.03	43	47.31	46.7	48.67	21.44	17.73	18.55	4.34	4	4.33
IT93K-503-1 (b)	46	45.68	46	57.65	60.95	62	15.91	15.52	14.22	2	2	2
Moussax693-2 Bulk F8-P2	44	37.15	44	42.99	45.62	46	18.05	15.78	17.89	4	3	3
Mx499-BC3F3-48P93	42.67	44.41	41.33	46.01	41.87	45.33	18.54	18.94	22.53	4.33	4	4
Mx503-BC3F3-92 P27	46	42.72	41.33	45.36	49.27	48.33	14.5	16.55	16.11	4.67	4	4
NS Farakoba	42.33	50.18	35.8				2.95	3.58	3.73	1	1	1
Koankin local	58	51.73	53.97	48.66	49.62	48	18.43	16.54	17.37	4.33	4.33	4.33
NS1	62.67	62.32	47.33					2.44	3.62	1	1	1
KVU 150	50	46.69	48	44.32	48.15	48	13.66	12.82	8.97	5	4	4
SARC1-57-2	42.33	42.31	37	48.02	47.94	48.33	21.41	19.65	17.12	3	3.67	3.67
SARC1-91-1	43	42.07	42.67	43.66	47.01	46.67	16.14	15.68	18.54	5	4.33	4.33

Appendix 2: Days to flowering, days to *Alectra* shoot emergence, cowpea hundred seed weight and *Alectra* severity in screen house

Genotypes	DTF			DAEMG			HSW			SEV70		
	Kp	Tenk	Tssina	Kp	Tenk	Tssina	Kp	Tenk	Tssina	Kp	Tenk	Tssina
KVX771-10G (Nafi)	43.67	40.46	43.33	46.02	49	48.67	21.27	20.02	19.25	3	3	3
TVX3236	51.33	50.95	46	46.68	48.87	48.67	11.43	12.7	11.96	4	3.67	4
KN-1		59.12	48.23	59.33						2	1	1
IT86D10-10	38	39.43	37.33				17.7	15.78	18.01	1	1	1
IT93K-1381	38.67	35.35	36	49.98	52.02	51.33	18.04	19.27	18.15	4	4	4
SR4	45	45.26	43.67	49.66	49.99	48.33	17.77	21.04	18.06	3	3	3.33
CB27	38	36.41	37.67	43.69	46.36	41.33	21.85	20.97	19.39	3	3	3.33
IT00K-901-6	44.67	52.07	45.33	48	43.64	46.67	14.89	13.42	14.3	4.66	4	4.67
KVX 404-8-1x 693-2 BC4F8-P4	43	41.32	42.33	47.67	50	49.33	17.04	20.68	17.97	3.33	3	3
IT99K-499-39	45.67	44.41	42	50.34	56.99	54.67	16.21	14.25	14.99	4.33	3.33	4
IT95M-190	40.33	42.08	43.33	52.34	50.34	51.33	20.68	18.8	19.64	3	3.33	3.33
Iron clay	44	59.49	43.33	48.37	52.66	53.33	21.04	18.94	17.04	3.66	4	4
Komcalle	40.67	43.46	43.33				19.93	19.65	18.96	1	1	1
TZ-1 (Gourgou)	41.67	39.94	40.67	45.33	47.91	47.67	23.19	23.33	21.44	3	3	3
KVX404-8-1	39	43.49	39.67	50.33	45.61	47.33	15.85	19.03	15.82	3	3	3.33
Komsare	44.67	59.41		43.04	47.6	43	16.33	13.41	21.98	4.99	4.67	4.67
Sanzi	49	42.03	47.67	43.34	42.95	45.33	10.73	7.28	8.66	5	5	5
Vita-5	49.67	49.68	46	42.99	42.79	44		15.89	16.46	5	5	5
Diebougou local		59.13	59.33	49.63	44.66	45.33		21	18.52	4.01	4.33	4.67
Melakh	46.33	39.29	43.33	49.35	50.36	49.67	15.31	14.16	17.9	3.33	3	3
IT82E-32	63.15			47.01	45.68	46		17.02		4	4.33	4
Ife Brown	43.33	46.35	41.67	49.69	47.91	45	14.52	14.12	13.59	4	4	4
Danilla	40.67	39.25	42.33	46.67	52.64	51.67	26.79	23.29	24.07	3.67	3.33	3.33
IT95K238-3	43.33	47.67	42	48.01	45.01	47.33	12.79	12.67	13.88	2.67	3	3
IT86D-716	58	53.38	58	42.68	46.97	44.33	12.46	13.09	13.27	4.66	4	4.33

Appendix 2: Days to flowering, days to *Alectra* shoot emergence, cowpea hundred seed weight and *Alectra* severity in screen house

Genotypes	DTF			DAEMG			HSW			SEV70		
	Kp	Tenk	Tssina	Kp	Tenk	Tssina	Kp	Tenk	Tssina	Kp	Tenk	Tssina
Pobe local				45.97	44.13	45	28.41	0	15.93	4.66	4	4.67
Dossin local	50.68	43.55	45.33	53.36	45.96	49.33	12.35	17.11	16.4	2.99	4.33	3.33
KVX295-2-124-51	43	43.27	46.33	53.01	51.66	51.33	18.83	23.1	22.74	3	3	3
Vita-4	59.67	49.78	59.39	44.36	43.41	47.33		11.37		5	4.67	5
Solenzo local	57	61.36	58	46.96	50.98	51		14.88	13.29	4	4	4
Djouroum local	43.33	45.29	48	59.34	61.94	60.67	18.62	23.74	19.38	3	3	3
IT93K687-1	40.67	40.59	41	48.66	47.34	45.33	16.87	16.25	16.65	3.34	3.67	3.67
CR06-07	63	58.64	60.33	60.02		63.67	16.87	13.55		2	1	2
ITN87-71-21	46.67	47.2	44.33	49	49.01	48	16.89	17.45	16.65	4.33	4	4.33
Lama local				43.33	42.01	45.67		24.86		5	4.67	4.67
KVX396-4-5-2D	40.33	44.83	39.33	43.68	48.22	44	16.38	13.71	16.05	3	3	3.33
Sakoula local	59.93	46.14	52.33	43.01	49.08	45.67	17.87	15.24	16.37	5	4	4.33
KVX414-22-2	47.33	42.15	41.67				18.27	19.02	18.05	1	1	1
Goinkoro-2	64.21	46.18	60.33	45.36	45.31	46.33		20.76	19.26	4	4.33	4.33
SR3		46.43	40.67	44.34	50.43	46.33		16.63	16.61	3.34	3.33	4.67
Bambey 21	37	37.9	37.67	44.98	45.08	47.33	21.48	20.54	19.93	3.34	3.33	3.33
Bagre-1	60	59.4	58.33	60.32	53.67	54.33	15.45	16.08	16.85	3	3.33	3.67
Dimbo local			59.97	46.67	47.68	45.33				4.67	4.67	4.67
Poytenga-9	48.67	54	46.33	54.65	45.99	47.67	17.54	15.53	15.46	3	3.33	3

Appendix 3: PRA questionnaire

I SOCIAL AND DEMOGRAPHIC DATA

1. Name of the district

1. Centre East ☐ 2. Hauts bassins ☐

2. Name of the province

1. Kouritenga ☐ 2. Boulgou ☐ 3. Houet ☐

3. Name of the locality

1. Koupela ☐ 2. Tenkodogo ☐ 3. Toussiana ☐

4. Nome of the village

1. Bikbaskoure ☐ 2. Boangtenga ☐ 3. Zougo ☐ 4. Zano ☐
5. Dabre ☐ 6. Laylay ☐ 7. Wempea I ☐ 8. Tapoko-Deni ☐
9. Wempea II ☐

5. Farmer's name:

6. Farmer's sex

1. Male ☐ 2. Female ☐

7. Please are you:

1. Single ☐ 2. Married ☐ 3. Divorced ☐

8. Please how old are you?

9. Level of education

1. Illiterate ☐ 2. Local language ☐ 3. Primary school ☐
4. Secondary school ☐ 5. High school ☐ 6. Arabic ☐

10. Farmers' social charges

1. 1 ☐ 2. 2 ☐ 3. 3 ☐ 4. 4 ☐ 5. 5 ☐ 6. 6 ☐ 7. 7 ☐
8. 8 ☐ 9. 9 ☐ 10. 10 ☐ 11. >10 ☐

II. FIELD BACKGROUND

11. For how long have you been exploiting this field?

12. What are the mains speculations you have been grown?

1. Sorghum ☐ 2. Pearl millet ☐ 3. Maize ☐ 4. Cowpea ☐
5. Groundnut ☐ 6. Soybean ☐ 7. Rice ☐ 8. Bambara groundnut ☐
9. Sesame ☐ 10. Cotton ☐

13. Which cultural practice do you use?

1. Crop association ☐ 2. Crop rotation ☐ 3. Pure culture ☐ 4. All ☐

III. PRODUCTION CONSTRAINTS

14. Have you seen *Alectra* before?

1. Yes ☐ 2. No ☐

15. When did you see *Alectra* in your field for the first time?

1. >20 years ☐ 2. <20 years ☐ 3. >15 years ☐
4. >10 years ☐ 5. >5 years ☐ 6. <5 years ☐

16. On which crops have you seen it?

1. Cowpea ☐ 2. Groundnut ☐ 3. Soybean ☐ 4. Bambara groundnut ☐
5. Pearl millet ☐ 6. Sorghum ☐ 7. Rice ☐ 8. Other crops

17. Have you heard about *Alectra* before?

1. Yes ☐ 2. No ☐

18. If yes, how do you call it in your local language?

19. What could be the channel of introduction of this weed in your area?

1. Animals ☐ 2. Seeds ☐ 3. Water ☐ 4. Wind ☐
5. Farming tools ☐ 6. Low soil fertility ☐

20. Did you know that *Alectra* reduce cowpea productivity?

1. Yes ☐ 2. No ☐

21. If yes what are its effects on cowpea?

22. On what type of soil did you see *Alectra*?

1. Sandy soil ☐ 2. Clayey soil ☐ 3. Loamy sandy soil ☐

23. Do you think that *Alectra* is more prevalent in humid zones?

1. Yes ☐ 2. No ☐

24. How much do you estimate yield losses due to *Alectra*?

1. <5% ☐ 2. 5% ☐ 3. 10% ☐ 4. 15% ☐
5. 20% ☐ 6. 25% ☐ 7. 30% ☐ 8. 35% ☐
9. 40% ☐ 10. 45% ☐ 11. 50% ☐ 12. >50% ☐

25. Do know *Striga gesnerioides*?

1. Yes ☐ 2. No ☐

26. Have you ever observed coinfection of both *Alectra* and *Striga* in a field?

1. Yes ☐ 2. No ☐

27. What are the cowpea main constraints you encounter?

1. Foliar diseases ☐ 2. Stem diseases ☐ 3. Insects ☐
4. *Striga gesnerioides* ☐ 5. *Alectra vogelii* ☐

28. What are the most important?

1. Foliar disease ☐ 2. Stem diseases ☐ 3. Insects ☐
4. *Striga gesnerioides* ☐ 5. *Alectra vogelii* ☐

29. What are your ranking criteria?

IV. CONTROL MEASURES

30. How do you control this *Alectra*?

1. Manual uprooting ☐ 2. Crop rotation ☐ 3. Crop association ☐
4. Use of resistant varieties ☐ 5. Nothing/others methods

31. Which one is the most efficient?

1. Manual uprooting ☐ 2. Crop rotation ☐ 3. Crop association ☐
4. Use of resistant varieties ☐

32. Do you think that the use of resistant varieties is the best control measure?

1. Yes ☐ 2. No ☐

V. FARMERS' VARIETAL PREFERENCES

33. What type of cowpea growth habit do you prefer?

1. Prostrate variety ☐ 2. Semi erect variety ☐ 3. Erect variety ☐ 4. All ☐

34. What type of variety do you prefer in terms of cycle?

1. Short ☐ 2. Intermediate ☐ 3. Long ☐

35. What is your preferred grain colour?

1. White ☐ 2. Red ☐ 3. Black ☐
4. Black hilum ☐ 5. Red hilum ☐

36. Which type of grain size do you prefer?

1. Big ☐ 2. Intermediate ☐ 3. Small ☐

37. Which of these grain texture do you prefer?

1. wrinkled ☐ 2. Smooth ☐