Influence of Farmers' Cropping Systems on Striga Management Options and its Resistance in Rice

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Influence of Farmers' Cropping Systems on Striga Management Options and its Resistance in Rice

根寄生雑草 Striga 管理選択における農家の作付体系の影響と稲における Striga 抵抗性

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Influence of Farmers' Cropping Systems on Striga Management Options and its Resistance in Rice

A thesis submitted for the Degree of Doctor of Philosophy

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ABSTRACT

Striga, commonly known as witchweed, is a noxious, hemi-parasitic weed infecting several crops in semi-arid, sub-Saharan Africa and, is responsible for food shortage and poverty of millions of Africans. The parasite infest in land planted with sorghum, pearl millet, finger millet, maize, upland rice and cowpea. The most severe problems with *Striga* occur where soils are degraded, fields are continuously cropped with host crops, and organic and inorganic nutrient inputs are low. Severe *Striga* infection can cause 70-80% crop loss and the losses can be much higher under heavy infestations, even resulting in total crop failure. The objectives of this study was to elucidate the factors that are limiting farmers to adopt *Striga* control mechanisms, assess tolerance level of **Ne**w **Ric**e for **A**frica (NERICA) cultivars to *Striga* infections and map out quantitative trait loci (QTLs) for *Striga* resistance in rice. The study focused on two devastating *Striga* strains to cereals, *Striga hermonthica* (Del.) Benth. and *Striga asiatica* (L.) Kuntze in Kenya and Malawi, respectively.

Recent trends away from traditional prolonged fallow, continuous cereal mono-cropping to meet the needs of increasing population has intensified the *Striga* problem. In addition to many factors already known, grazing animals, crop seeds and wind contribute to distribution of *Striga* to new areas. About 71.4% and 67% of the farmers had *Striga* in their fields in Kenya and Malawi, respectively. Several *Striga* control options have been developed over the years, but farmers have not adopted them. According to the farmers in a survey conducted in Kenya, the most popular control measures for *Striga* were hand-pulling, crop rotation and intercropping, even though rotational systems might need a longer timeframe to reduce the soil seed bank of *Striga.* However, in Malawi, the farmers perceived manure application to be the best method to control *Striga*, followed by crop rotation, fertilizer application and hand pulling. The

reason for the low adoption level of the control methods by the farmers is because they are "too risky" as there is no guarantee of a direct pay-off in increased crop yield.

Following the adaptability studies conducted in Kenya for the 18 upland NERICA cultivars from Africa Rice Center (ARC), four NERICAs (NERICA 1, NERICA 4, NERICA 10 and NERICA 11) were released to farmers' even to areas known to be prone to *S. hermonthica*. Our study on the response of NERICA cultivars to *Striga* infections showed different levels of tolerance despite the fact that their progenies are from the same parents WAB 56-104 and CG14. The earlier maturing NERICA 1 and NERICA 10 cultivars were resistant to *S. hermonthica* from Alupe, Kenya. Among the NERICAs tested, our result showed that NERICA 4 was more susceptible. Generally, comparing the NERICAs with the local cultivar Dourado precoce, they were more tolerant to *S. hermonthica* infections.

In order to understand the genetic basis of resistance in rice cultivars, a QTL analysis was undertaken utilizing a mapping population of Nipponbare and *O. rufipogon*. We infected 141 (BC_2F_{10} generation) backcross recombinant inbreed lines (BRILs) derived from a cross between *Oryza sativa* cv. Nipponbare and a wild accession *O. rufipogon* W630 with *S. hermonthica* from Alupe, Kenya. Putative QTL for *S. hermonthica* resistance was estimated using single-point analysis (qGene program) at $p<0.01$ significance level. The QTL for *S. hermonthica* resistance was detected near RM242 marker on chromosome 9 contributed by Nipponbare allele as explained by 6.6% of the phenotypic variation in the mapping population. It is important that *S. hermonthica* resistance QTLs are validated under different environments since there is likelihood of genetic variations within its ecotypes as this species is an obligate out breeder.

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Acronyms

AATF	African Agricultural Technology Foundation
ANOVA	Analysis of Variance
APS	Agricultural Production Systems
ARC	African Rice Center
ARICA	Advanced Rice Varieties for Africa
BASF	Badische Anilin-und Soda-Fabrik
BILs	Backcross Inbred Lines
BRILs	Backcross Recombinant Inbred Lines
CIMMYT	International Maize and Wheat Improvement Centre
CSSLs	Chromosome Segment Substitution Lines
DADOs	District Agricultural Development Offices
DAS	Days After Seeding
DASE	Days After Seed Emergence
DNA	Deoxyribonucleic acid
EPAs	Extension Planning Areas
FAO	Food and Agriculture Organization
FISP	Farm Input Subsidy Program
GAPs	Good Agricultural Practices
GDP	Gross Domestic Product
GM	Genetically Modified
GoK	Government of Kenya
ICIPE	International Centre of Insect Physiology and Ecology
ICRISAT	International Crops Research Institute for the Semi-Arid-Tropics

IITA	International Institute of Tropical Agriculture
IR	Imazapyr Resistant
IRRI	International Rice Research Institute
ISC	Integrated Striga Control
JSPS	Japanese Society for Promotion of Science
KARI	Kenya Agricultural Research Institute
LBDA	Lake Basin Development Authority
LOD	Log of Odd
MoA	Ministry of Agriculture
NERICA	New Rice for Africa
NGO	Non Governmental Organization
PCR	Polymerase Chain Reaction
PRAs	Participatory Rural Appraisals
QTL	Quantitative Trait Locus
RAPD	Randomly Amplified Polymorphic
SP	Starter Pack
SSA	sub-Saharan Africa
SSRs	Simple Sequence Repeats
TSBF-CIAT	Tropical Soil Biology and Fertility Program of the International Centre for Tropical Agriculture
UPS	Upland Production Systems
WARDA	West Africa Rice Development Association

CHAPTER 1

General Introduction

Agricultural production and the associated losses in sub-Saharan Africa

Food security is a key global challenge in this century. The Food and Agriculture Organization (2006) forecast that global food production will need to increase by 40% by 2030 and 70% by 2050 because of increasing demand due to population growth and changing eating habits. Human population levels are projected to reach 9 billion in 2050 (Cohen, 2003) and therefore, modern farming systems need to be sustainable to produce enough food for the surging population. To feed the world in 2050, investments in agricultural research and extension must be increased in developing countries, particularly in sub-Saharan Africa (SSA) countries, where agricultural productivity generally lags behind the rest of the world.

SSA is an enormous region comprising of 39 countries with a combined area of about 24 million km^2. Agriculture in SSA (excluding South Africa) employed 62% of the population and generated 27% of the GDP in 2005 (FAO, 2006). The agricultural production systems are largely based on smallholder farms. Smallholder farm is defined as a holding of 2 ha or less of land which represent 80% of all farms in SSA, and contribute up to 90% of the food production in most if not all SSA countries (Livingstone *et al.*, 2011). Agriculture in particular is vulnerable to weather in SSA where 97% of agricultural land is rain-fed. In the region, crop production is the most important as it forms the main source of food and livelihood.

Due to conflicts, natural disasters, crop failures, and other factors, thirty countries globally, and twenty in Africa, needed external assistance with food supply in 2010

(FAO, 2009). The major challenge to food security in many African countries is underdeveloped agricultural sector coupled with low soil fertility, minimal use of external farm inputs, environmental degradation, pre- and post-harvest crop losses, weed infestation and inadequate food storage preservation methods.

Crop losses in the world to weeds, pests and diseases have been estimated for the staple cereals (wheat, rice and maize) as 36% in 1965 and 42% in 1991–1993 (Bruce, 2010). These crops are hampered by competition from weeds which are the most important pest group. It estimated that the loss potential of weeds is 37%, which is higher than the sum of the loss potentials of animal pests 15%, fungal and bacterial pathogens (11%) and viruses (3%) (Oerke & Dehne, 2004). Studies show that yield losses due to uncontrolled weed growth in both lowland and upland systems in Africa can be within the range of 28-100% (Sibuga, 2009). In Kenya, average yield loss due to uncontrolled weeds has been approximated to be 50-60% (Mwanda, 2000). However, Kiran (2004) reported that yield loss due to weeds, insect pests and poor storage facilities is as high as 60% in Kenya. It is accepted that 10% loss of agricultural crops can be attributed to the competitive effect of weeds. However, in rice ecosystem, weeds account for yield losses of about 2.2 million tons per year with a value of $1.45 billion in SSA (Rodenburg and Johnson, 2009). Infected farmers' fields with parasitic *Striga* weed may cause crop losses of 30–100% (Bruce, 2010).

Rice- the model plant and host for Striga

Rice is the world's most commonly used cereal food, feeding half of humanity. It belongs to the genus of *Oryza* and has two cultivated and 22 wild species (Veasey *et al*., 2004). The cultivated species are *Oryza sativa* L., which originated from South and South-East

Asia from *O. rufipogon* and is grown worldwide; and *Oryza glaberrima* Staud. which was domesticated is west Africa from *O. barthii* (Linares, 2002). The cultivated rice species share the same AA genome with the following wild species distributed throughout the tropics of Asia (*O. rufipogon* and *O. nivara*), sub-Saharan Africa (*O. longistaminata* and *O. barthii*), South America *(O. glumaepatula)*, and Oceania (*O. meridionalis*) (Morishima, 1998).

Rice can be a good model cereal crop for studies of molecular genetics since it has a small genome size (389Mb) (International rice genome sequencing project, 2005) in comparison to that of other cereal crops such as sorghum (730Mb) (Paterson *et al.*, 2009), maize (2500Mb) (Chandler & Brendel, 2002), wheat (17000Mb) (Brenchley *et al.*, 2012) and barley (51000Mb) (International barley genome sequencing consortium, 2012). According to Devos (2005) rice has one of the best synteny which can be used in other cereals for breeding. The International Rice Genome Sequencing Project formally established in 1998, pooled the resources to start the sequencing of rice. The researchers obtained a complete quality sequence of rice genome (*Oryza sativa* L. spp. Japonica cv. Nipponbare). Rice is also said to be a better model plant for research because of the availability of high density molecular linkage maps and mapping populations which will go a long way to facilitate characterization of quantitative trait loci (QTL) for breeding purposes.

Globally, the total area under rice cultivation is estimated to be 150 million hectares with annual production of 500 million metric tons. This represents 29% of the total output of grain crops worldwide while Africa accounts for about 10 to 13 per cent (Tsuboi, 2005; Onyango, 2006). Currently, rice is grown in over 75% of the African countries, with a total population close to 800 million people (ARC, 2009). Rodenburg and Demont (2009) reported that presently, rice is the fifth cereal in area harvested and fourth in production in the SSA. Rice production in the continent is increasing faster than any other cereal. Over the past 30 years, harvested area has risen by 105% and production by 170%. Despite the enormous growth, the region is yet not self sufficient in rice and importation of the cereal is of great concern. Rice is the main staple food for the populations in West and North Africa. Across the continent, average per capita consumption stand at 27kg (Rodenburg *et al.*, 2010).

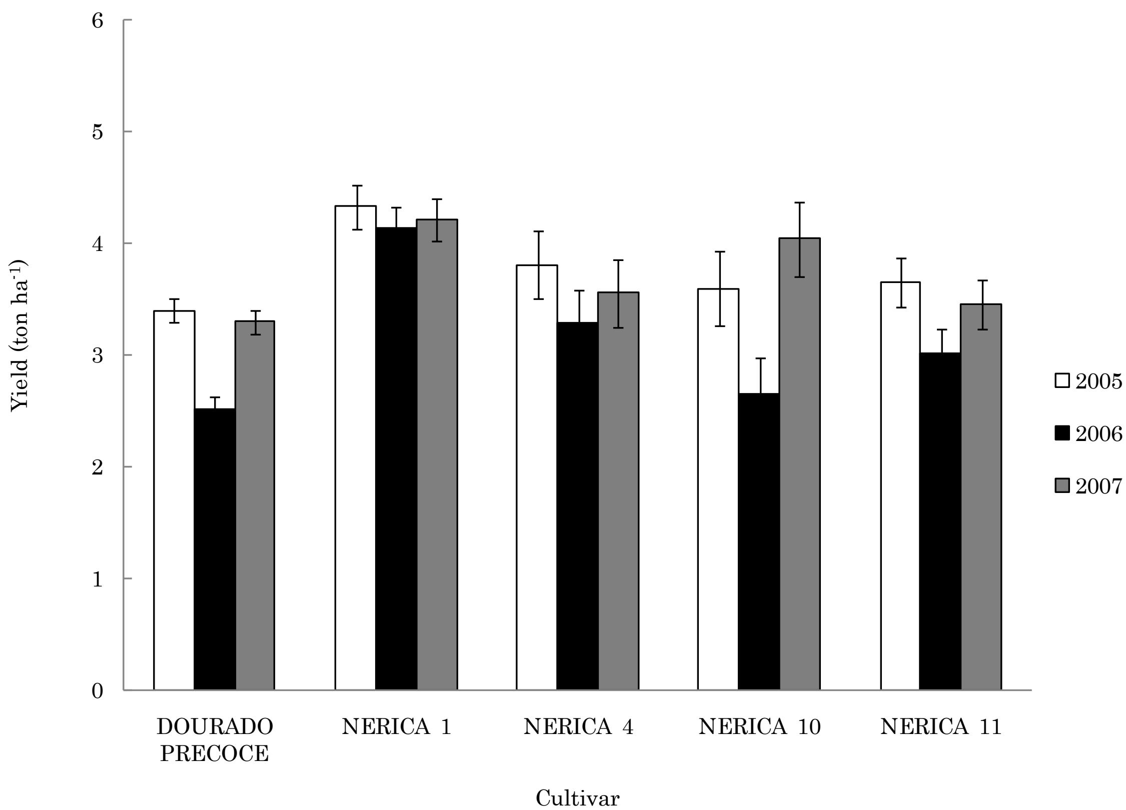

Fig. 1.1 Grain yield of NERICA cultivars in 2005, 2006 and 2007 cropping seasons in Kenya. Error bars indicate standard error of treatments over the years.

The West Africa Rice Development Agency (WARDA) now African Rice Center (ARC) with assistance from the International Rice Research Institute (IRRI) developed reliable rice variety for Africa christened **Ne**w **Ric**e for **A**frica (NERICA). NERICA is the inter-specific hybridization between *Oryza sativa* (Asian rice) and *O. glaberrima* (African rice).

These varieties are high yielding with low inputs requirements, early maturing, resistant to local stress and higher protein content. Development of NERICA targeted upland rice ecology where there is still plenty of land for exploitation. To date over 3,000 family lines of NERICA for upland and lowland have been developed. There are 18 upland NERICA varieties which have been tested in ARC and released to several African countries for adaptability studies. Currently, NERICA 1, 2, 3 and 4 are the top varieties planted by farmers in West Africa. In the East Africa countries, NERICA 1, 4, 10 and 11 have been released to farmers. These varieties are grown in the moist savanna areas where parasitic weeds are a problem (Fig. 1.2). In Kenya NERICA 1 is regarded as the highest yielding more than 4.0 tons (Fig. 1.1) while NERICA 4 is the most popular with farmers in Uganda (Miyamoto *et al.*, 2012). The adoption of the NERICAs by smallholders may largely depend if they can withstand the scourge of parasitic weeds as well as maintain their yield potential.

Recently new generations of high performing rice cultivars named ARICA (**A**dvanced **Ric**e Varieties for **A**frica) were launched by ARC. Five ARICA varieties (three lowland and two upland) out yielded the checks which were the NERICAs (IRRI, 2013). The two upland (ARICA 4 and ARICA 5) varieties yielded 15% more than NERICA 4, a favorite cultivar in East Africa while the three lowland cultivars (ARICA 1, ARICA 2 and ARICA 3) have yield advantage of 30-50% over NERICA-L19. The varieties ARICA 4 and ARICA 5 have been released in Uganda while ARICA 2 and ARICA 3 have been released in Mali and Nigeria, and ARICA 1 in Mali (Africa Rice Center, 2013). The issue that ponders in the minds of many researchers is whether the new ARICA cultivars will be the turning point for Africa towards the green revolution.

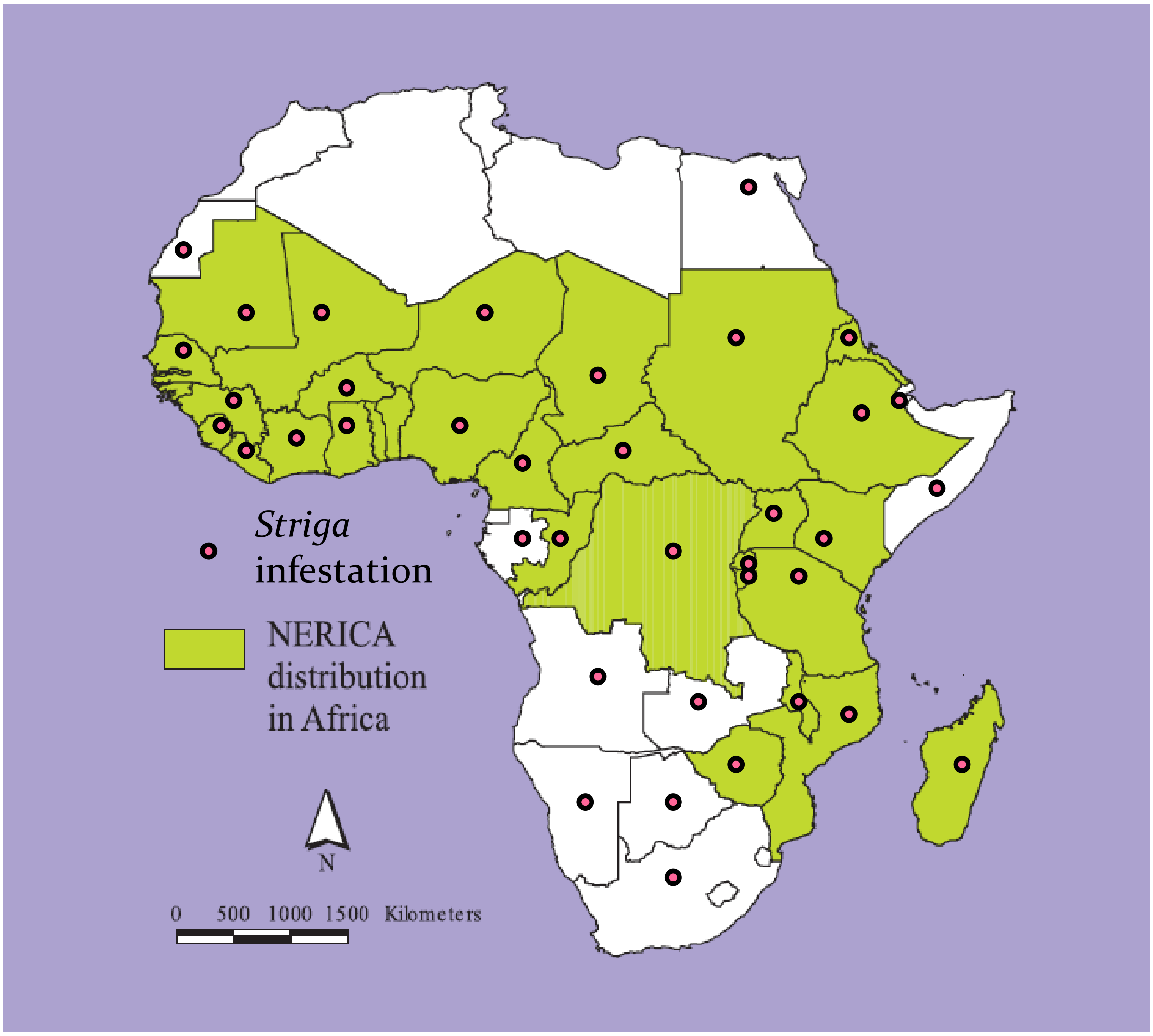

Fig.1.2 NERICA rice distribution and *Striga* infestation in sub-Saharan Africa. Adapted from Africa Rice Center (2008).

Parasitic plants

Parasitism is a coexistence of two different organisms of which one (the parasite) lives at the expense of the other (host). Parasitic higher plants are the most destructive agricultural pests known (Parker & Riches, 1993; Sauerborn, 1991). Today, about 4,100 species of parasitic plants from 19 families have been recognized as serious pests causing considerable economic damage (Nickrent & Musselman, 2004). According to

Yoder (1997) parasitic weeds adopt different forms to invade host plants. Some (dodders and mistletoes) invade aerial parts, whereas others invade the underground roots (Orobanche and Striga). Root parasites are more common and are found in diverse taxonomic groups. Some of the most economically important root pathogens are in the broomrape family, Orobanchaceae. Parasitic plants are classified as holoparasites, hemiparasites, obligate parasites, or facultative parasites. In Africa, the most problematic is the root hemi-parasitic plant, *Striga*.

Striga: the life cycle and impact on the host

Witchweeds (*Striga* spp.) are pernicious, root-attaching parasitic plants, a genus of 42 currently described species in the world of which 28 species occur naturally in Africa (Barker, 1990; Cochrane & Press, 1997). The genus is classified in the family of Orobanchaceae. The parasite does not have its own roots and therefore it compensates by penetrating the roots of host plant to siphon the essential nutrients for growth (Watson *et al.*, 1998). The host plants are stagnated and sometimes die from phytotoxic effects within days of attachment (Frost *et al.*, 1997; Khan *et al.*, 2007). A small parasite biomass attachment to the host plant can result in a large reduction in height, biomass and grain yield (Gurney *et al.*, 1999; Rodenburg *et al.*, 2006). The parasite attack the host plant underground and by the time the flowering stem of the parasite appears above the ground damage has been caused (Westerman *et al.*, 2007).

Most witchweeds are characterized by bright-green stems and leaves and small, brightly colored flowers. A mature *Striga* plant has high reproductive capacity, and is capable of producing 10,000 to 200,000 tiny seeds per plant that can survive in the soil for more than 10 years (van Ast & Bastiaans, 2006; Hearne, 2009). The life cycle of

Striga is complex and it is tied to development stages of the host plant from seed to seed (Fig. 1.3). After dispersal, *Striga* seeds are in a state of dormancy for about six months (Gbehounou *et al.*, 2004).

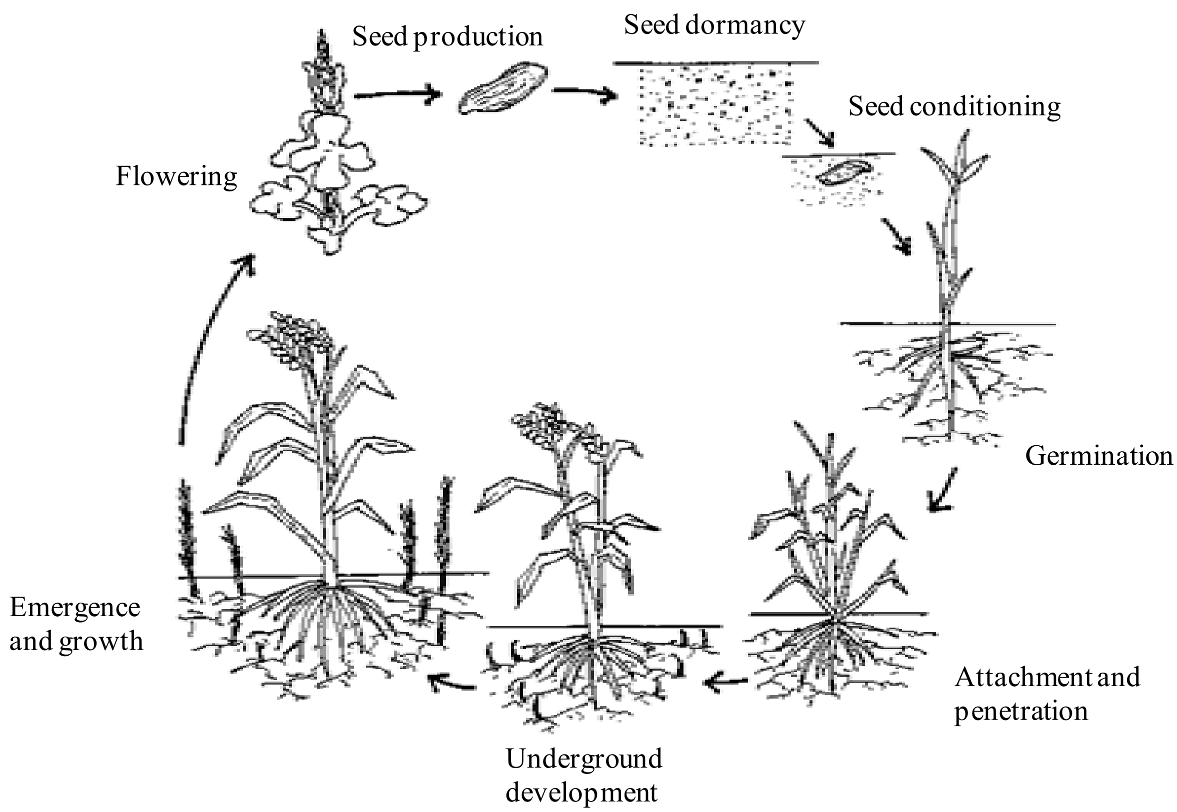

Fig. 1.3 Life cycle of *Striga* spp.

The most important step in the life cycle is germination of *Striga* seed which involves: - pre-conditioning of the seeds which requires humid and warm conditions, radicle growth to the host root, haustorium formation and attachment to the host root (Spallek *et al.*, 2013). However, pre-conditioning of *Striga* seeds also requires secondary metabolites derived from host plants and non-host plants to induce germination (Yoder, 2001; Gurney *et al.*, 2006; Hooper *et al.*, 2009). These germination stimulants are exuded at the tip of roots of host plants (Parker & Riches, 1993; Yoder, 1999). After germination, the parasite must find the host plant for attachment within 4 days if not it will die (Gurney *et al*., 2006). On successful contact with the host plant, the haustorium begins to grow and invades tissues of the host plant where it establishes vascular connection for siphoning the hosts' resources (Tebene & Kamara, 2002).

The parasitic seedling grows underground totally depending on the host for growth and development for about 3 to 6 weeks (Gurney *et al*., 2006). After emergence *Striga* seedling forms the stem and leaves with chlorophyll but becomes hemi-parasite that produces assimilates, partially depending on the host for nutrients, water and minerals. Within one month after emergence, *Striga* plant initiates flowers and seeds. The plant produces many seeds which enable the parasite to build its soil seed bank (Gbehounou *et al*., 2003).

Even though most *Striga* spp. do not affect agricultural production, some have devastating effects on crops particularly those planted by subsistence farmers (Mohamed *et al*., 2001; Westerman *et al*., 2007). *S. hermonthica* and *S. asiatica* are well known to be infecting C3 and C4 grasses. They are the most widespread and dangerous species parasiting on cereal crops such as sorghum [*Sorghum bicolor* (L.) Moench], pearl millet [*Pennisetum glaucum* (L.) R. Br.], maize [*Zea mays* L.] and upland rice [both *Oryza glaberrima* (Steud.) and *O. sativa* L.], whereas *S. gesnerioides* (Willd.) Vatke attacks crops such as cowpea [*Vigna unguiculata* (L.) Walp.] and peanut [*Arachis hypogaea* L.] (Parker, 1991; Oswald, 2005). In the recent years, crops such as wheat [*Triticum aestivum* L.] that were previously unaffected by the parasite are now showing serious infestation (Vasey *et al*., 2005) and areas of productive agriculture have been abandoned because of this scourge. *Striga* is therefore, a pandemic of serious proportion because of its vast geographical infection, its economic impact and posses a potential threat to smallholder livelihoods.

Research objectives

The overall aim of this study is to evaluate the factors that potentially curb farmers from adopting the existing *Striga* control options and understand *Striga* infection on rice. The first objective is to assess the level of *S. hermonthica* infestation in Kenya and the control mechanisms available to farmers since research has been going on for many years. The second objective is to determine the farmer's knowledge and perception on *Striga* and its control in Kenya and Malawi to guide on the development, evaluation, and adaptation of the control options. The third objective is to evaluate and determine the tolerance level of NERICA cultivars to *S. hermonthica* in Kenya. The fourth and final is to carry out quantitative trait loci (QTLs) analysis for *S. hermonthica* resistance using backcross recombinant inbreed lines (BRILs) derived from across of *O. sativa* (cv. Nipponbare) and *O. rufipogon* W630.

Outline of the thesis

Following the above introduction, chapter 2 provides a detailed description of ecologies of *Striga* spp. and its infestation in crop fields in SSA. The chapter reviews the factors responsible for spreading of *Striga* in SSA, significance of cereals as part of diet to African households and tolerance of cereals to *Striga* infections. In chapter 3, *Striga* incidence, distribution and control options in Kenya is investigated. Both chapters 4 and 5 focus on farmers' views on *S. hermonthica* and *S. asiatica* as a problem and their perception on the control mechanisms in Kenya and Malawi, respectively. Assessment on the response of NERICA cultivars to *S. hermonthica* infections is highlighted in chapter 6. In chapter 7, quantitative trait loci (QTL) analysis for *S. hermonthica* resistance using backcross population derived from the cross between *O. sativa* cv. Nipponbare and *O. rufipogon* W630 is presented. Finally, the overview findings on the study and future *Striga* research outlook are discussed in chapter 8.

The **Ecologies and Severity of Striga infections in Cereal Crops in the sub-Saharan Africa**

Abstract

Striga spp. is renowned for causing great losses in cereal production in sub-Saharan Africa. Crop competitiveness with parasitic weeds such as *Striga* is an important criterion for selection in an initiative to produce and release varieties of crops to farmers that are able to give high and stable yields under low-input conditions. The symptoms of *Striga* infected plants are chlorosis, wilting and stunted growth. Cereal yield is reported to be reduced by more than 50% in areas that are infested by the weed. In addition, areas that are heavily infested have been abandoned and rendered unfit for crop production. Notable advances in *Striga* weed control technology have been made, yet the weed continues to be a major cause of low agricultural production. This is an indication of poor linkage between research institutions and agricultural extension which is a bottleneck to research findings to benefit farmers.

Key words: *Striga* spp., host plants, cereals, *Striga* occurrence, tolerance

Introduction

Parasitic weeds are problematic in Agricultural Production Systems (APS) in the world today. The weeds compete with crops for nutrients, water and harbor disease causing organisms. Root parasitic weeds such as *orobanche* (broomrape) and *Striga* (witchweed) compensates for lack of their own root system by penetrating the roots of host plants and thus depriving the essential nutrients for plant growth. This brings about stagnation of the host plants with the end result of low yield (Watson *et al*., 1998). *Striga* species predominantly found in Africa infest land planted with sorghum [*Sorghum bicolor* (L.)], pearl millet [*Pennisetum glaucum* (L.)], finger millet [*Eleusine coracana* (L.) Gaertn.], maize [*Zea mays* L.], upland rice [both *Oryza glaberrima* (Steud.) and *O. sativa* L.] and cowpea [*Vigna unguiculata* (L.) Walp] (Musselman, 1980; Rodenburg *et al*., 2006; Scholes & Press, 2008).

Striga, the parasitic angiosperm weed is said to be the major problem in cereal production causing huge losses in grain yield. The diversity of *Striga* spp. populations in African countries need to be understood to identify the races found in the different agro-ecological zones. This will enable improvement on the existing crop material through breeding of varieties that can withstand the stress of the weed. *Striga hermonthica* (Del.) Benth. has particularly assumed economic importance in upland cereal growing areas in West and East African countries.

The epicenter of *Striga* is believed to be in the tropical savannah between Semien Mountains of Ethiopia and Nubian hills of Sudan in SSA before spreading to other parts of the continent (Ejeta, 2007). This area is also recognized as the origin of sorghum and pearl millet which are readily infected by *Striga*. Over 70 years, several world institutions both private and public have dedicated substantial amount of money towards developing appropriate mechanisms to control the parasite (Ahmed *et al*., 2001). Despite the efforts made to control the *Striga* problem, farmers have not adopted the control options developed (Oswald, 2005). This is one of the greatest tests to be synthesized by the researchers and unearth the reasons behind the farmers not embracing the preventive measures (Emechebe *et al*., 2004).

Striga seed production paradox need to be underscored as the parasite produces many tiny seeds which are capable of existing in the soil for more than 10 years (Hearne, 2009). This has enhanced the parasites' persistence and increase in magnitude. Therefore, this review focuses on the distribution and effect of *Striga* spp. on cereal crops. The paper first reviews the importance of cereals and the extent of infestation of *Striga* spp. in SSA. Assessment on the occurrence of the parasite in their current habitat is highlighted. Finally, infestation of *Striga* in cereal crops and those that are tolerant to the parasite are discussed.

Significance of cereal crops

Farming systems in SSA comprise of many fields' crops that form part of the diet in most African households. The main field crops are cereals (maize, sorghum, wheat, rice and millets), legumes (common beans, green grams and soybean) and root tubers (cassava, yams and potatoes). However, among these field crops, cereals are extremely important crops grown for daily consumption and contribute to household income (Fig. 2.1). They are grown mostly by resource poor smallholders.

Cereals are the major dietary energy suppliers (about 80%) and provide significant amount of protein, minerals (potassium and calcium) and vitamins (vitamin A and C) (Ismaila *et al.*, 2010). They are consumed in different forms including pastes, noodles, cakes, breads, drinks etc. depending on the ethnic or religious affiliation. After the cereals are processed, several residues are obtained which include flour for making ugali and porridge for human consumption and, bran, husk etc for animal feed and micro-organism culture. Wax syrup and gum can also be extracted from cereals for industrial purposes.

The relatively low cereal production in SSA is due to a number of abiotic and biotic constraints. The major abiotic constraints include drought and declining soil fertility (Vanlauwe *et al.*, 2008) whilst the biotic constraints comprise of diseases, stem borers and

Striga infestation. *Striga* is considered to be one of the most serious constraints to cereals productivity (Fig. 2.2) in African agriculture.

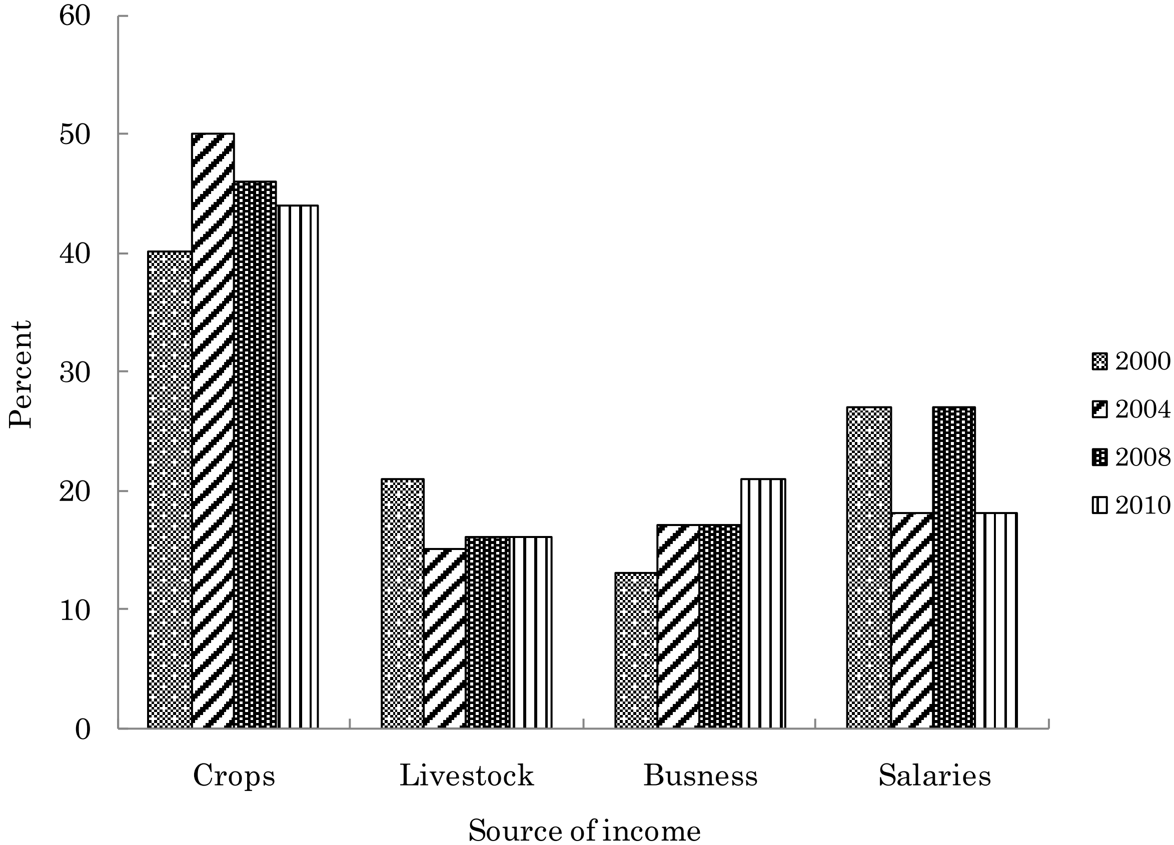

Fig. 2.1 Contribution towards household income in East African countries. Adapted from Bhargava (2011).

Distribution and infestation of *Striga* in SSA

Striga weed infestation and occurrence

There are 28 *Striga* species occurring naturally, infecting grasses and legumes in SSA. Most of the crop host species for *Striga* are cereals which Africans depend on as food (Table 2.1). The parasite infests some 40% of the cereal-producing areas of SSA resulting to crop losses estimated at US$7 billion annually, affecting livelihoods of approximately 300 million people (Ejeta, 2007). The most affected are subsistence farmers losing about 20–80% of their yield (Gethi *et al*., 2005).

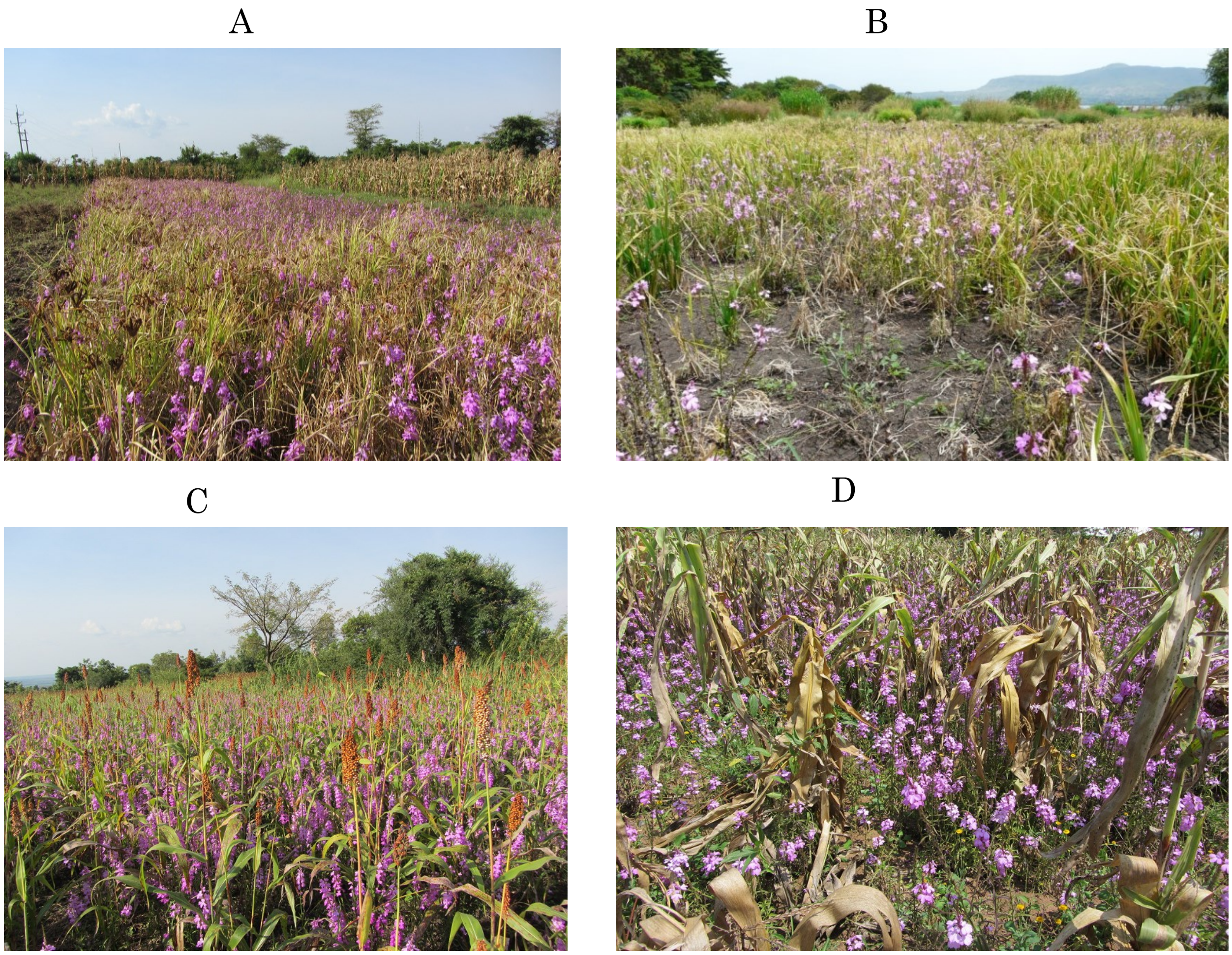

Fig. 2.2 *Striga hermonthica* infestation in cereal crops in Kenya: A. finger millet; B. rice; C. sorghum; D. maize . Plate B adapted from Cissoko (2012).

It has been reported that five of the *Striga* spp. cause devastating effects on crops: *S. hermontica, S. asiatica, S. forbsii, S. aspera* and *S. gesnerioides* (Berner *et al.*, 1997). The distribution and intensity of infestation of *Striga* in Africa is as shown in Fig. 2.3 and *S. asiatica* is said to have a wide world geographic distribution as compared to others (Cochrane & Press, 1997). Dugje *et al.* (2006) stated that in Nigeria three major *Striga* species have been found to be infecting crops: *S. hermonthica* (sorghum, rice and maize), *S. aspera* (rice) and *S. gesnerioides* (cowpea). In the savannas of guinea, *S. aspera* occurs in the hydromorphic areas where rice is grown, while *S. hermonthica and S. asiatica* are found in the free draining upland areas and are regarded as the most infectious (Johnson *et al.*, 1997). Notably, *S. aspera* is predominantly found in West Africa and sporadically exists in Ethiopia and Tanzania overlapping with *S. hermonthica*.

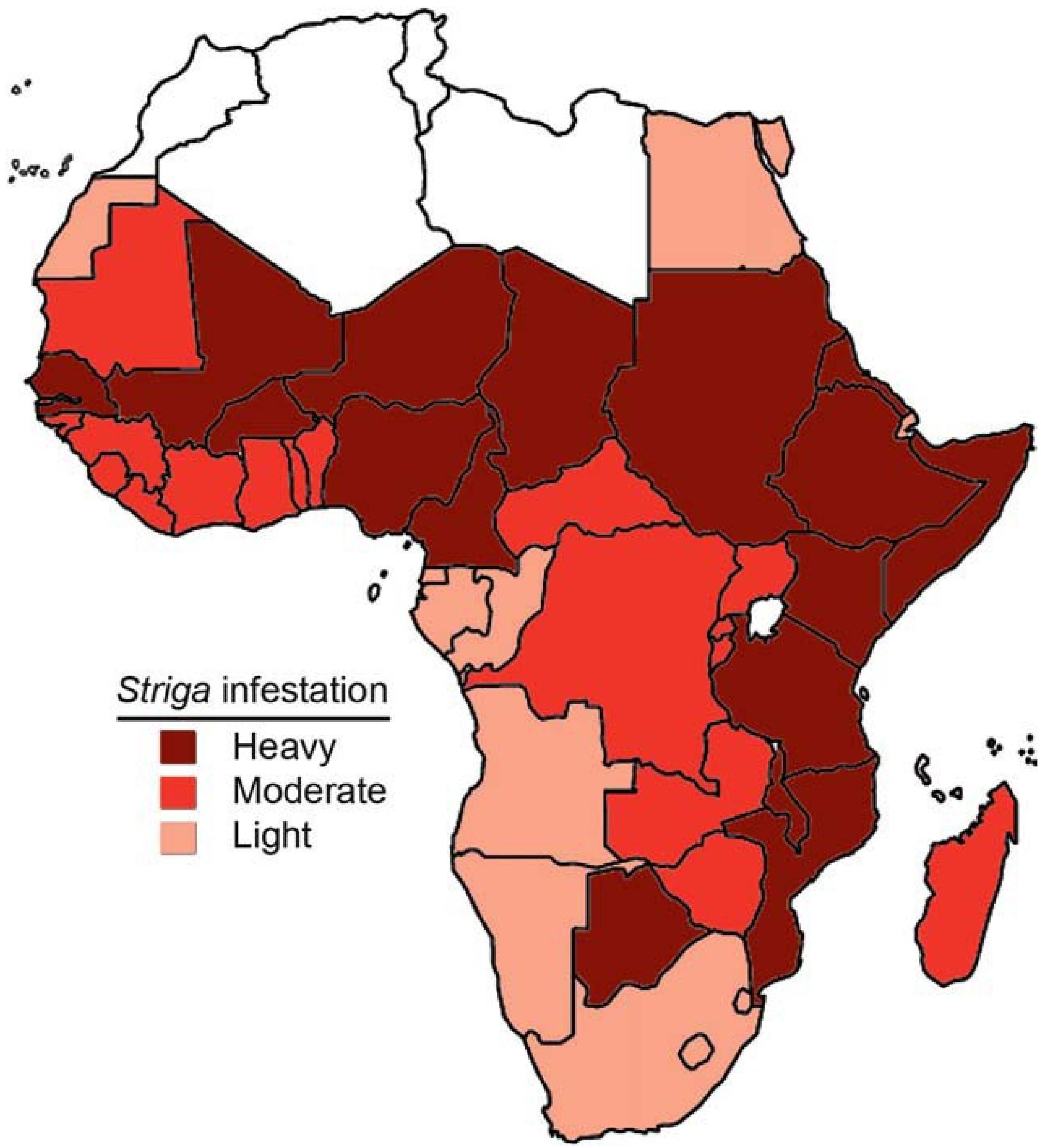

Fig. 2.3 Distribution and intensity of infestation of *Striga* species in Africa. Adapted from Ejeta (2007).

Generally, *Striga* spp. grows in areas with annual rainfall ranging from 25-150cm per year with decrease in severity of infestation in areas of high rainfall (Mohamed *et al.*, 1998). However, *S. forbisii* mainly occurs in wet areas and even in water logged conditions infecting wild grasses in swamps and irrigated crops (Mohamed *et al*., 2001) in Cote d'Ivore and Tanzania. There are records indicating *S. hermonthica* and *S. aspera* infecting rice in Northern Cameroon, Northern Nigeria, Benin, Togo and westwards. It has also been reported that *S. hermonthica* infects upland rice in Western Kenya (Harahap *et al*., 1993) and *S. asiatica* causes serious losses in upland rice along the Indian Ocean Islands.

Table 2.1 Degree of *Striga* infestation on crops in SSA

Striga species	Crops						
	Maize	Sorghum	Rice	Pearl millet	Finger millet	Cowpea	Sugarcane
S. hermonthica	xxx	xxx	xx	xx	xxx	–	xx
S. angustifolia	–	xx	–	–	–	–	xx
S. asiatica	xxx	xxx	xx	xx	xx	–	x
S. forbesii	x	x	x	–	–	–	x
S. aspera	xx	x	xx	–	x	–	x
S. gesnerioides	–	–	–	–	–	xxx	_
S. latericea	–	–	–	–	–	–	x
S. pubiflora	–	–	–	–	–	–	x

xxx-Serious infection, xx-Moderate infection, x-Less infection, - No infection
Adapted from Parker and Riches (1993)

Conditions favoring Striga growth

Striga infestation is steadily increasing as a result of continuous cultivation of cereal crops. Overused, depleted and infertile soils have resulted to high infestation of *Striga*. Pressure on land for continuous cropping of cereal crops without rotation or moving to other new areas has resulted to exhausted soils. These are the soils that favor *Striga* infestation in addition to soil moisture stress conditions (Khan *et al*., 2007). Less shading due to poor growth of the host crop on poor soils contributes to heavy infestation. This has compounded the problem for small-scale farmers who can least afford inputs on unproductive land, and thus continues mono-cropping (planting of the same crop on the same area) for several years. Infestation in some areas has reduced yield to the extent that abandonment and migration is necessary. Improper management of *Striga* weed has contributed persistence and to its existence in SSA for a long time.

Poverty level of small scale farmers has enhanced the spread of *Striga* through sharing of seeds collected from the previous crop harvest. In addition, *Striga* pandemic in SSA has increased due to non advocacy of nutrient replenishment of the soils as a result of mono-cropping, a factor for increased infestation of the weed in size and severity (Woomer, 2004).

Striga produces several seeds, and during tillage the seeds are incorporated into the soil where they can be dormant for many years. Over time they are spread to new areas by human beings through the tools used for land preparation and weeding (Oswald, 2005). The seeds are also spread by animals moving from one field to another for grazing purposes (Hearne, 2009). This has culminated to a complex system of spreading the weed to new areas thus reducing crop yield of farmers who are not aware of the devastating effect.

Soil fertility and Striga weed

Parasitic weeds such as *Striga* establish preferentially in poor nutrient fields which have been exhausted by continuous cropping (Kim, 1996). Most *Striga* infested areas are characterized by APS exhibiting low productivity. These areas tend to be managed traditionally with low inputs and continuous cereal cropping without crop rotation. The use of inorganic nitrogen and organic fertilizers such as manure and compost has been reported to reduce *Striga* infestations (Kuiper *et al.*, 1998). Manure applications have been shown to be as effective as fallowing in maintaining soil productivity. The positive benefits of applying manure include an increase in pH, water holding capacity, hydraulic conductivity, infiltration rate and decrease in bulk density. Manure is also an important source of N, P and K (Kim, 1996). To enhance the quality and effectiveness of traditional soil fertility maintenance strategies such as manure application, a fertilizer augmented soil enhancement strategy need to be adopted to reduce the infections of *Striga*.

The on-station and on-farm field trials in Western Kenya showed reduction in *Striga* infestation in maize with the application of mineral nutrients but the results were less consistent than in the greenhouse. Increasing levels of N showed a fair reduction of *Striga* in the field of maize especially during the first year, whereas P application did not have much effect in contrast to the greenhouse study where both N and P clearly reduced *Striga* infection (Jamil *et al.*, 2012). Kim *et al.* (1997) showed that continuous cropping of maize and high N application (120 kg ha^{-1}) reduced *Striga* infestation significantly within five years. Only artificial less inoculation with a large quantity of *Striga* seed (3000 germinable of seeds per maize plant), low N application (30 kg ha^{-1}) and ridge slowing sustained high *Striga* infestation.

Table 2.2 Yield of maize in permaculture and monoculture farming system in 2009/2010 and 2010/2011

Farming system	Yield (t ha^{-1})
Permaculture†	1.20±0.03
Monoculture‡	0.86±0.05

†Permaculture–the field mulched and maize intercropped with soybean, pigeon pea, bambara bean, cotton and marigold, ‡Monoculture - sole maize was planted.

Legumes are known to enrich soil with N through rhizobium. They infect the root hairs and cortical cells and ultimately form root nodules which are the sites for N fixation. A study conducted in Malawi on two farming systems namely permaculture and intercropping (legumes intercropped with maize) to control *Striga asiatica* showed all maize-legume intercrop plots had lower *Striga* counts than sole planted maize (Fig. 2.4). Maize-cowpea intercrop indicated a significantly reduced *Striga* infestation up to 50% in maize in the two years. In permaculture cropping system, the result showed higher yield (28.3%) of maize compared to mono-culture (Table 2.2). In all intercrops except for cowpea and groundnut which significantly controlled *Striga*, it was only in pigeon pea and soybean intercrops where yield increases were higher. The study confirmed the potential in cowpea as a food trap intercrop and permaculture as a cropping system in the management of *Striga*, which should be incorporated in cropping systems in subsistence farmers' fields.

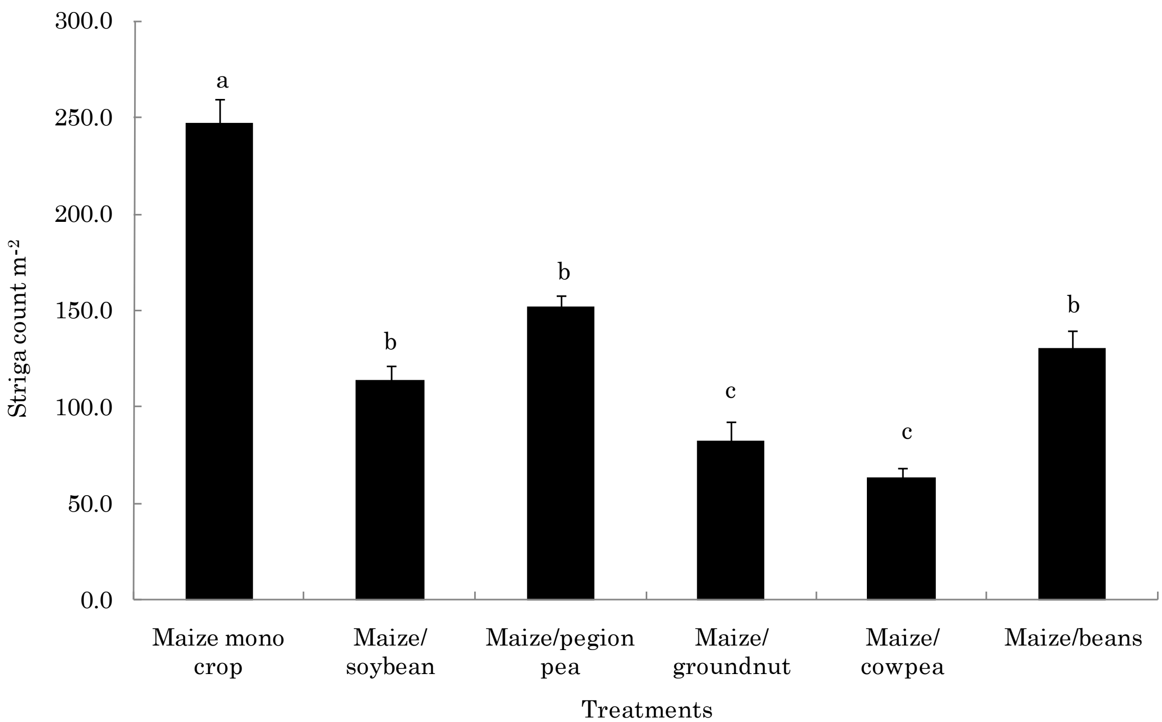

Fig. 2.4 Mean *Striga* count m^{-2} of sole maize and maize-legume intercrops in 2009/2010 and 2010/2011. Within each bar marked with different letters are significantly different and the differences are significant at 0.001 probability level.

Field trials conducted in the dry and wet seasons in the northern Guinea Savanna ecological zone to study the effect of nitrogen rates on upland rice (*Oryza sativa* L.) varieties to *S. hermonthica* indicated that FARO 48, a variety normally susceptible to *S.*

hermonthica exhibited resistance, FARO 11 exhibited tolerance, while FARO 38, FARO 46 and FARO 45 exhibited susceptibility. The application of 90 and 120 kg N ha^{-1} delayed and reduced *Striga* emergence on the crop and induced a low crop reaction score producing grain yields that were significantly high. Significant differences in *Striga* infestation were observed between nitrogen rates of 30-120 kg N ha^{-1} (Adagba *et al.*, 2002). The significant interaction between upland rice varieties and nitrogen rates indicate that the susceptible varieties require higher rates of nitrogen to ameliorate the effect of *Striga* compared with the resistant varieties. In addition, Johnson *et al.* (1997) showed that the proportion of *0. glaberrima* and *0. sativa* plants that appear stunted, is related to the number of *Striga* plants present. The increasing incidences and severity of *Striga* damage is linked to poor soil fertility which is due to lack of farm yard manure and inorganic fertilizers (Emechebe *et al.*, 2004).

Incidence and severity of *Striga* in cereal crops

Striga is a common parasitic weed which alone reduces yields of cereal crops more than 50% (Johnson *et al.*, 1997). As shown in Table 2.1 there are four known *Striga* spp. that infect cereals:- *S. hermonthica*, *S. asiatica*, *S. aspera* and *S. forbesii*. The minor *S. angustifolia* infects sorghum and sugar cane in its limited ecology. In the rural communities of Northern Nigeria, it has been reported that crop yield losses due to *S. hermonthica* infections were about 70-100% (Emechebe *et al.*, 2004).

According to Kurel *et al.* (2006) severe *Striga* infection can cause 70-80% crop loss in maize and sorghum and losses can be much higher under heavy infestations, even resulting in total crop failure. Farmers often have to abandon infested agricultural lands as a result of high soil infestation by *Striga*. Recent trends away from traditional prolonged fallow and intercropping towards continuous cereal mono-cropping to meet the needs of increasing population have intensified the *Striga* problem. It has also been reported that crops can show resistance characteristic in one area and succumb in another because resistance can be broken by the existing biotypes (Gethi *et al.*, 2005). This was observed in Tanzania where sorghum was planted in different locations (Doggett 1952) and similar observations have been made in West Africa (Ramahiah, 1987).

Susceptible and resistant cereals to Striga

Despite susceptibility of maize to *Striga* infections (Fig 2.2), there are reports of *Striga* resistance in maize or its wild relatives. In a collection of accessions of wild maize (*Zea diploperennis*) screened in a pot experiment, the result showed that about 10% of the entries were resistance (Rich & Ejeta, 2008). Resistant individuals had fewer attached *S. hermonthica* able to establish vascular connection. Among parasitic seedlings able to reach the vascular bundle of the resistant plants, many died within a few days of penetration and those few parasites that eventually emerged in the resistant *Z. diploperennis* pots were smaller than those on the non-resistant types. Another wild relative of maize, *Tripsacum dactyloides*, expressed resistance such that *S. hermonthica* attached at a frequency 25% that on *Z. mays*, and those attached *Striga* were much less likely to progress to the developmental stages reached by those on maize during the six weeks of observation (Rich & Ejeta, 2008).

Breeding for high yielding *Sorghum bicolor* varieties with effective resistance and tolerance against the hemi-parasitic weed *S. hermonthica* requires suitable selection measures. Noubissie *et al.* (2012) recommended S35, CS54 and Defe Gala as the most promising resistant cultivars of sorghum to obligate root parasite *S. hermonthica* in Cameroon. The cultivars were recommended to be considered for future use in breeding programs. However, Huang *et al.* (2013) has reported that plant breeders have to be careful and need to understand the genetics of root parasitic plants as they can easily break the resistance. According to Showemimo and Kimbeng (2005), KSV-4 and SK-5912 sorghum cultivars are least affected by *Striga* activities in Nigeria, with their resistance dominant over susceptibility and therefore they are promising resistant cultivars. Genetic analysis revealed genetic component of variance which was high for shoot weight, *Striga* count and grain yield than those of genotype x year and error component of variance.

Table 2.3 Reaction of rice cultivars to *S. hermonthica*, *S.asiatica* and *S.aspera*

Reaction	Genotype	*Striga* spp.	Refs
Resistant	ACC102196	*S. aspera*	5
	B3913F-16-5-ST-42	*S. hermonthica*	3
	Ble Chai	*S. hermonthica*	3
	CG14	‡*S. hermonthica,* §*S. aspera*	2, 6, 7
	FARO 40	*S. hermonthica*	1
	FARO 48	‡*S. hermonthica*	1
	IG10	*S. aspera*	5
	IR38547-B-B-7-2-2	‡*S. hermonthica*	3, 5
	IR47255-B-B-5-4	*S. hermonthica, S. aspera*	3, 5
	IR47697-3-4-1	*S. hermonthica*	3, 6
	IR49255-B-B-5-2	*S. hermonthica, S. aspera*	3, 5
	Jean louis	*S. asiatica*	4
	Nipponbare	*S. hermonthica*	2, 7
	WAB928-22	*S. hermonthica, S. aspera*	6
	WAB935-5	*S. hermonthica, S. aspera*	6
	WAB937-1	*S. hermonthica, S. aspera*	6
Tolerant	Azucena	*S. hermonthica*	7
	FARO 11	*S. hermonthica*	1
	Kasalath	‡*S. hermonthica*	2, 7
	M27	‡*S. hermonthica,* †*S. aspera*	2, 5
	Makassa	*S. hermonthica,* †*S. aspera*	5
	T2	*S. hermonthica, S. aspera*	2, 5
Susceptible	Bala	*S. hermonthica*	7
	Dourado precoce	*S. hermonthica*	3, 4
	Namroo	*S. hermonthica*	2 ,3
	IR64	*S. hermonthica*	7

Refs: 1-Adagba *et al.*, 2002, 2-Gurney *et al.*, 2006, 3-Harahap *et al.*, 1993, 4-Itoh *et al.*, 2008, 5-Johnson *et al.*, 1997, 6-Johnson *et al.*, 2000, 7-Kaewchumnong & Price, 2008. Contradictory reaction reported with the same species: †Resistant, ‡Susceptible, §Tolerant.

It has also been reported that two sorghum lines P9405 (Hakaki) and P9406 (Wahi) exhibited good levels of grain yield when infected in the field with *S. hermonthica* and *S. asiatica* compared to their uninfected controls, an indication that the lines are quite tolerant to infection (Mbwaga *et al.*, 2001).

Johnson *et al.* (1997) describes two *O. sativa* cultivars, IR47255-B-B-5-4 and IR49255-B-B-5-2, having resistance to *S. hermonthica* and limited susceptibility to *S. aspera* enabling to support 2-3 emerged parasite stems per rice plant compared to over 20 on the susceptible cultivars which are widely grown in the infested areas of Cote d'Ivore (Table 2.3). However, in general cultivars of African rice species, *O. glaberrima* more often show *Striga* resistance as compared to *O. sativa* (Johnson *et al.*, 1997). Johnson *et al.* (2000) reported that *O. glaberrima* cultivar CG14 is resistance to *S. hermonthica* and *S. aspera* which is one of the parents of NERICA rice, currently being promoted for food security in SSA for their short maturity period, drought resistance and high yield. However, it has also been shown by some post-attachment studies to be susceptible to *S. hermonthica* (Gurney *et al.*, 2006). The screening of NERICAs against *Striga* spp. is necessitated as the most productive areas for upland rice are heavily infested. Furthermore, the contradictory information on CG14 on resistance and susceptibility to *Striga* infections need to be confirmed. Gurney *et al.* (2006) reported a robust resistance in Nipponbare rice cultivar to *S. hermonthica* in post-attachment experiment. In this cultivar, the parasite failed to form xylem to xylem connection to the host plant root. Other studies have also shown Nipponbare having low numbers of *Striga* and emerging late thus concluding that the variety is resistant (Swarbrick *et al.*, 2009).

Conclusion

Africa has complex systems of agricultural development ranging from bush clearing and cultivation to convectional agricultural production. Cereals (maize, rice and sorghum) are the most important food crops in SSA. With the increasing population which surges pressure on cultivated land, investments in agricultural research and extension must be increased. The area under production of cereals is under threat from *Striga* weed infestation. This therefore calls for suitable *Striga* management strategies aimed at improving and filling the gaps of the available mechanisms which have not been widely adopted by farmers. Priority should be directed towards understanding the parasite and the farmers farming systems so that any mechanism developed will be able to fit into the farmers' requirements. In addition, breeding of cultivars that are resistant to *Striga* will be cost-effective to control the parasite as cultivation of resistant varieties does not require any extra inputs from farmers.

CHAPTER 3

Observations on the Current Status, Distribution and Management of *Striga* Problem in Kenya

Abstract

Striga spp. is considered to be the greatest biological constraint to food production in sub-Saharan Africa, a more serious problem than insects, birds and plant diseases. They are among the most specialized root-parasitic plants inflicting serious injury to their host depriving them water, minerals and photosynthate. The greatest diversity of *Striga* spp. occurs in grassland. However, *Striga hermonthica* mainly occurs in farmland infecting grasses. The parasite devastating effect is accomplished prior to its emergence from the soil. It may cause yield losses in cereals ranging from 15% under favourable conditions to 100% where several stress factors are involved, thereby affecting the livelihood of millions of resource-poor farmers. Piecemeal approach to address one aspect of *Striga* problem at a time has been a setback in technology transfer to producers. Future *Striga* control programs should not be conducted separately, but should rather be conducted by an integrated approach that combines the research talents of various institutions. This will facilitate collaborative research and achieve qualitative interaction between stakeholders, which can easily produce reliable technologies that are practical and available to farmers. *Striga* being a pervasive pest, time is of essence in controlling it. There is an urgent need for the establishment of policies to promote, implement, and ensure a long-term sustainable *Striga* control program.

Key Words: Control options, genetic diversity, occurrence, *S. hermonthica,* Kenya

Introduction

Striga, commonly known as witchweed, is the most economically important parasitic weed seed plant in the world. It is a genus of 28 species of parasitic plants that occur naturally in parts of Africa, Asia and Australia. The genus is now classified in the family of Orobanchaceae although earlier authors placed it in Scrophulariaceae (Gethi *et al.*, 2005). Even though most *Striga* spp. do not affect agricultural production, some have devastating effects on crops particularly those planted by subsistence farmers (Mohamed *et al.*, 2001; Westerman *et al.*, 2007). The major agricultural *Striga* species are *Striga hermonthica* (Del.) Benth. and *S. asiatica* (L.) Kuntze infecting cereals (maize, sorghum, millet and upland rice) and *S. gesneriodes* (willd.) Vatke legumes (cowpea). Other species such as *S. forbesii* (Benth.) and *S. aspera* (Willd.) Benth have been reported to have sporadic effects on cereal crops in their limited locations (Parker, 2009). Crops such as wheat (Ejeta, 2007) and napier grass (Atera & Itoh, unpublished data, 2012) previously unaffected by *Striga* are now showing serious infestation in Sahel.

S. hermonthica problem has been in existence as early as 1936 in the fields of farmers within Lake Victoria Basin, western Kenya (Watt, 1936; Khan *et al.*, 2006). During the last 20-30 years, it has attained devastating proportions due to cereal mono-cropping (Oswald, 2005). The parasite is reported to be infecting about 217,000 ha in Kenya, causing annual crop loss of US $53 million (Woomer & Savala, 2009). These losses largely depend on *Striga* density, host species and genotype, land use system, soil nutritional status and rainfall patterns (Atera *et al.*, 2012a). The most affected are the poor subsistence farmers, who are not aware of the threat that *Striga* poses to their land quality and food security as the weed continues to increase its soil seed bank and spreading to new areas.

A survey conducted in the Sudan savannah zone of Ghana showed that an average number of 9,384 seeds m^{-2} was found in the Land that had been returned to cultivation after fallow. However, some fields had seeds in excess of 14,900 seeds m^{-2} (Abunyewa & Padi, 2003). Van Delft *et al.* (1997) disclosed that a single *Striga* plant could produce up 4,827 seeds, excluding an approximately similar amount of seeds present in maturing capsules in western Kenya. They estimated the average number of seeds produced per mature *Striga* seed capsule to be 1,188. According to Woomer and Savala (2009), *Striga* has infected farmer's fields in western Kenya with an average of 161 million seeds per ha resulting in three parasitic stems per maize plant. Other studies in the region showed that *Striga* density was at least 14 plants per m^2 (MacOpiyo *et al.*, 2010). These results imply that only a few *Striga* plants are required to make cereal production unsustainable in this region.

The purpose of this chapter, therefore, was to examine the incidence *Striga hermonthica* in Kenya and research achievements in its control. Some of the concepts in this chapter are drawn from the seven years of my research in *Striga* occurrence and cereal production in western Kenya. Assessment of agricultural production and its constraints and, genetic diversity of *S. hermonthica is* highlighted. Finally, the achievement of research in *Striga* control options available for farmers is discussed.

Agriculture and distribution of *Striga* in Kenya

The agricultural sector in sub-Saharan Africa is the key source of food, incomes, employment, and more often, foreign exchange. In Kenya, agriculture is an important economic activity and accounts for approximately 26% of GDP (Gok, 2010). It is a major contributor to foreign exchange earnings; even though less than 8% of the land is used for crop production. The land suitable for cultivation is about 20%, of which only 12% receive adequate rainfall for agricultural production and about 8% is regarded as medium potential land. The rest of the land is arid and semiarid. Farming in Kenya is carried out by small scale holders with limited technology who own not more than two hectares. These small farm production, operated by about three million farming families, account for 75% of total production in Kenya (Gitau *et al.*, 2009). It is estimated that about 80% of the workforce in the country is engaged in agriculture/food processing.

Crop production

The major food crops grown in Kenya are maize, sorghum, sweet potatoes, wheat, rice, beans, finger millet and cassava (Taylor, 2009; Atera, 2012b). According to FAO (2006), cereal yield in SSA increased by only 29% between 1961 and 2005 compared to 177% in Asia and 144% in Latin America. On the other hand however, in the same period the population grew by 216% in the SSA (United Nations Population Division, 2007). The implication of this statistics is that production of cereals in SSA has to be increased to feed the growing population. In Kenya, the cereal consumption was approximately 3.9 million tonnes (Ministry of Agriculture, 2010) while the production was 2.9 million tonnes in 2009 (Table 3.1). A preliminary forecast by FAO showed that Kenya needs to import 2.3 million tonnes of cereals to bridge a production deficit over 2011/12 cropping season. Cereals play a central role for food supply but their production has lagged behind. The production capacity of the country's food systems has not kept pace with the surging demand for food. The low yield recorded in the country is due to constraints of nutrient depletion, loss of organic matter and drought. Production of cereals is also negatively influenced by incidence of pests and diseases such as bird damage, leaf blight and the parasitic weed *Striga*.

Table 3.1 Cereal production and consumption in Kenya in 2009

Crop	Area under crop cover (ha)	Production (tons)	Consumption (tons)
Maize	1,885,071	2,442,823	3,240,000
Wheat	131,594	219,301	96,480
Rice	21,829	42,202	410,000
Sorghum	173,172	94,555	81,000
Finger millet	104,576	56,417	40,000

Source: Ministry of Agriculture, Kenya, 2010

Food security

Food security situation in Kenya has deteriorated significantly under the umbrella of business-as-usual scenario which calls for anything short of a revolution. The food shortage trends have to be reversed by all means through appropriate agricultural technologies including replenishing soil fertility, use of certified seeds, utilizing Good Agricultural Practices (GAPs), reducing weed soil seed banks, disease and pest pressures (Bruce, 2010). Emphasis should not only be laid on technology transfer, but also on policies that will achieve sustainable productive growth and reduce food insecurity. It is absolutely essential that any interventions to increase crop production must be focused on the farmers. In addition, farmers should be empowered to participate as equal partners in development of new technologies that will fit into their farming systems. *Striga* weed undermines the struggle to attain food security, and so its control must be addressed by all means.

In Kenya, food security means maize [*Zea mays* L.] production. It is regarded as a source of food in the entire nation and produced by almost every farmer. In addition, some farmers consider it as a source of income. Maize is life to some communities in Kenya because of its famous use to prepare the stable dish "*ugali*". Unfortunately, the area which is considered to be the grain basket of the country is heavily infested by *Striga* (Fig. 3.1), reducing yields of farmers' dependence by 30-100% (Bruce, 2010).

Origin and occurrence of Striga

It is believed that *Striga hermonthica* and *S. asiatica* originated in the Nubian hills of Sudan and Semien Mountains of Ethiopia. These areas are also known to be the origin of sorghum and pearl millet which are readily infected by the witchweed (Ejeta, 2007). *S. gesnerioides* may have originated in West Africa. Over the years, *Striga* has spread to other parts of sub-Saharan Africa through the activities of man.

There are nine (9) *Striga* species found in Kenya (Table 3.2). Among them, *S. hermonthica* is considered to be the most dangerous and common particularly in the densely populated regions of Nyanza and Western Province of Kenya (Fig. 3.2) (Dogget, 1965; MacOpiyo *et al.*, 2010). *S. asiatica* is predominantly found in the coastal region infecting upland rice (Gethi *et al.*, 2005) and exists sporadically in Isiolo, Busia and Naivasha (Mohamed *et al.*, 2001). The species that is adapted as a pest of legume crops, *S. gesneriodes*, has a wide geographical distribution in Kenya compared to the other species. It occurs as far as Kilifi (Coastal province of Kenya) spreading to Homa hills (Nyanza province, western Kenya) infecting cow pea.

A B

Fig. 3.1 *Striga hermonthica* infection in Busia, western Kenya: (A) Maize–groundnut intercrop with heavy infestation; (B) Reduction of yield in maize under *Striga* infestation.

Economic importance of Striga

Striga infestation causes a loss of 30-50% to Africa's agricultural economy on 40% of its arable land (Amudavi *et al.*, 2007; Hearne, 2009). A survey conducted in 30 communities in Borno state, northern Nigeria, indicated that farmers' rated *Striga* infestation as leading priority constraint together with low soil fertility (Dugje *et al.*, 2006). Similar surveys (Weber *et al.*, 1995; Kim *et al.*, 1997) showed that *S. hermonthica* had become a serious problem in Guinea savanna of Nigeria and yield losses ranged from 10 to 100%. In western Kenya, a survey of 83 households revealed that 73% of the farms are infected with *S. hermonthica* (Woomer & Savala, 2009). The average losses due to *Striga* are 1.15, 1.10 and 0.99 tons per hectare for maize, sorghum and millet, respectively (MacOpiyo *et al.*, 2010). However, the damage can reach as high as 2.8 tons ha^{-1} in maize and sorghum in some locations with high *Striga* densities (Andersson & Halvarsson, 2011). The loss represents 12.3% of the 2.4 million metric tonnes of maize that Kenya produces annually. This translates to about 39.6 kg of maize loss per capita, amounting to about 20% of a typical person's annual food requirement. Clearly, these shows the consequences of *Striga* infections are severe rendering the small scale farmers helpless and often bewildered. It requires innovative and focused actions to assist them to reclaim health of their soil to overcome this agricultural pest.

Table 3.2 *Striga* spp. distribution and occurance in Kenya

Striga species	Host plants	Occurance
S. asiatica	Maize, rice, sorghum, pearl millet, finger millet, sugar cane, wild grasses	Kilifi, Isiolo, Mathews range, Alupe, Daka Chom, Kiunga
S. bilabiata	Wild grasses	Naivasha, Chyulu hills, Rumbia, Kahawa, Mathews range
S. elegans	Wild grasses	Nairobi, Loitokitok, Laikiapia, Rumuruti
S. forbsii	Sorghum, rice, maize, sugar cane	Narok, Mara plains, Kipini, Chyulu hills, Uasin Gishu plateau, Trans Nzoia
S.gesneriodes	Cow pea	Kilifi, Buna, Homa hills, Rongo, Nairobi, Naivasha
S. hermonthica	Maize, rice, sorghum, pearl millet, finger millet, sugar cane, wild grasses	Alupe, Churaimbo, Miwani, Bungoma, Kendu , Migori, Kuria, Nyamira, Siaya, Homabay
S. latericea	Sugar cane, wild grasses	Samburu, Mariakani, Kwale, Voi, Machakos, Sultan Hamud, Kilifi, Mwea
S. lutea	Wild grasses	Kwale, Shimba hill, Embu, Chyulu hills
S. pubiflora	Sugar cane, wild grasses	Kwale, Shimba hills

Source: Mohamed *et al.,* 2001; Gethi *et al*., 2005; Khan *et al*., 2007; De Groote *et al.,* 2008; Authors' own observations.

Genetic diversity of *Striga* strains

The relatedness of species is commonly assessed by morphological characters. However, reliable closeness of parental species has been evaluated according to the level of successful hybridization and fertility of the resultant progeny (Murray *et al.*, 1993). Based on their morphological similarities, it has been suggested that *Striga* species have formed complex groups (Aigbokhan *et al.*, 2000). Some of these species such *S. hermonthica* and *S. aspera* are found in the same locality; parasitizing the same cereal crops and wild grasses; sharing insect pollinators and can be intercrossed to produce seeds. Mohamed *et al.* (2007) proposed that there are several factors that have contributed to genetic diversity in *Striga*: - (a) persistent seed bank of several generations of populations; (b) hybridization; (c) broad geographic distribution; (d) long distance dispersal and (e) locally adapted host races. Among these factors geographical distribution appears to play the greatest role in determining genetic differences in the species (Aigbokhan *et al.*, 2000).

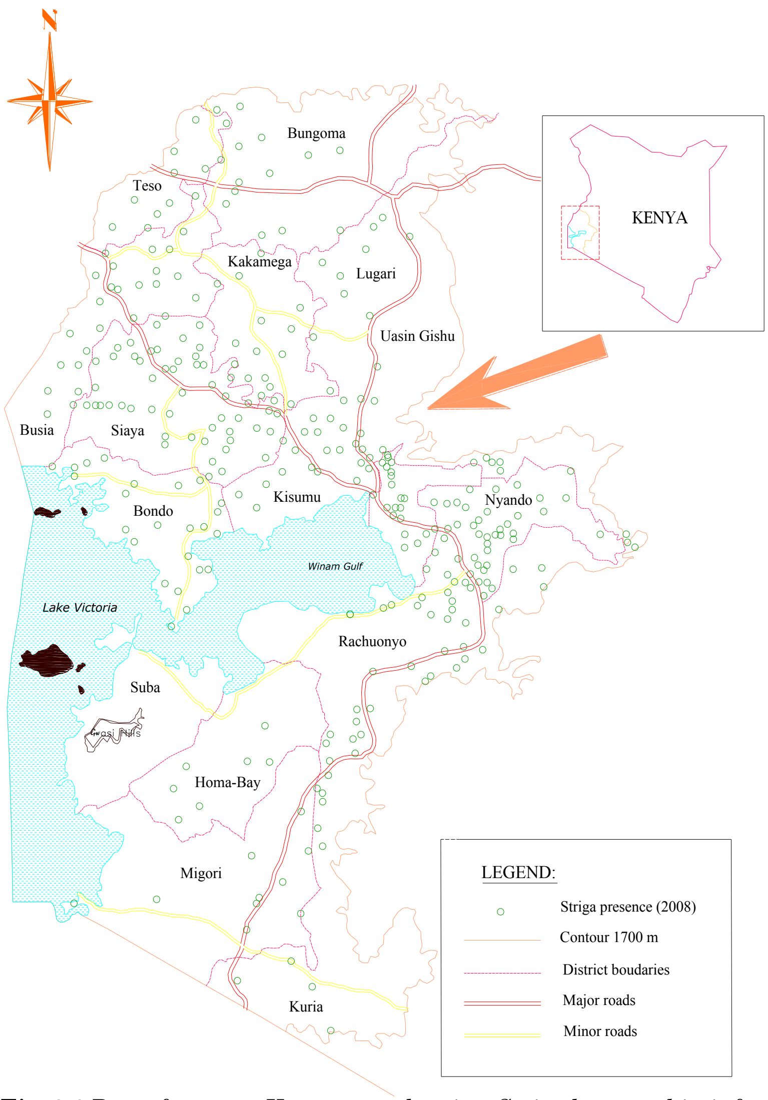

Fig. 3.2 Part of western Kenya map showing *Striga hermonthica* infestation. De Groote *et al.*, 2008; Authors' own observations

Considering the wide range of distribution of *Striga* spp., limited studies on genetic diversity have been conducted in Kenya (Gethi *et al.*, 2005). However, recent molecular advancements have provided the necessary tools that can be used in *Striga* diversity studies. These include simple sequence repeats (SSRs), amplified fragment length polymorphisms (AFLPs) and randomly amplified polymorphic (RAPD) which employs the use polymerase chain reaction (PCR) and offers better characterization due to their high level of polymorphism compared to other markers such as morphological markers. However, in the recent past the most powerful approach to characterizing genetic diversity in *S. hermonthica* would employ a robust set involving Simple Sequence Repeat (SSR) markers.

A Study conducted at Kobe University on genetic diversity of *S. hermonthica* strains collected from different parts (between 0°34'N 34°34'E and 1°03'S 34°28'E) of western Kenya in 2013 using microsatellite markers or simple sequence repeats (SSRs), showed high variations within the population and were genetically different (Fig. 3.3). This study is consistent with the result of Koyama (2000) who reported that genetic diversity on *S. hermonthica* collected from Mali, Kenya and Nigeria showed high levels of variation existing between and within populations. In addition, Welsh and Mohamed (2011) using F_{ST} standards value range (Wright, 1978) of 0.15 to 0.25 for highly differentiated population and 0.05 to 0.15 for moderately differentiated, showed that *S. hermonthica* samples collected from Ethiopia were genetically different and all populations were significantly different from each other.

However, Gethi *et al.* (2005) reported that there is 90% similarity in *S. hermonthica* population collected from Kenya. He argued that there seems to be substantial gene flow between *Striga* populations leading to low differentiation and seed dispersal has been basically through contaminated seeds. Nevertheless, Welsh and Mohamed (2011) attributed Kenyan population similarity to a small area sampled covering only 0.5° latitude and less than 0.1° longitude. Other studies of *S. hermonthica* populations infesting in cereal crops from several countries in western, eastern and central Africa using isozyme markers showed little genetic diversity to genetic diversity levels of up to 6.8% (Bharathalakshmi *et al.*, 1990; Olivier *et al.*, 1998).

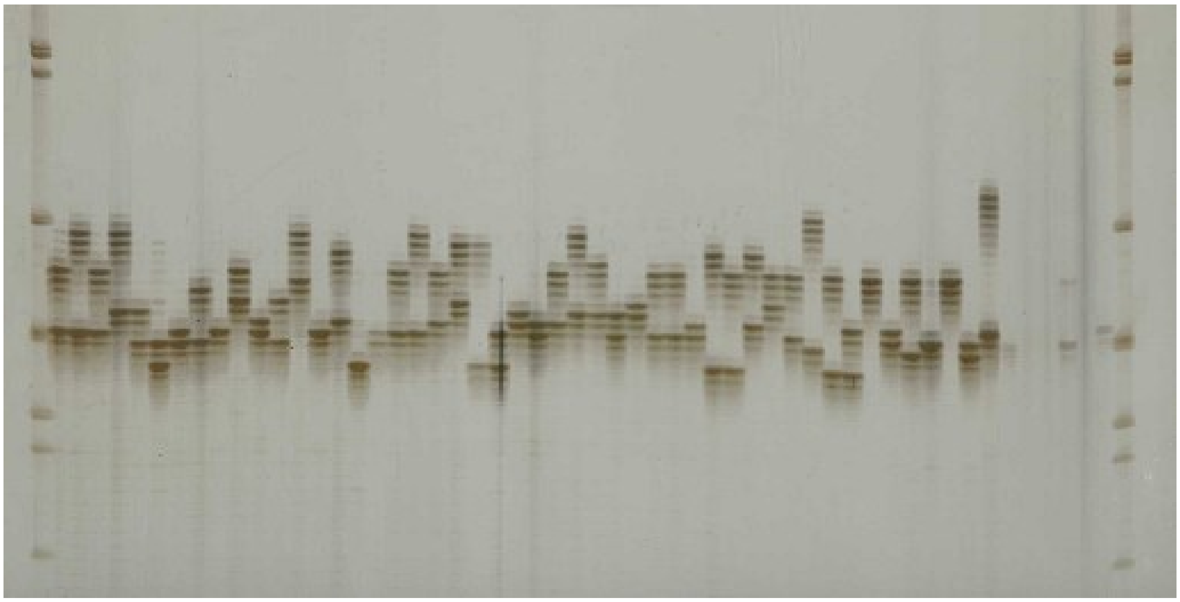

Fig. 3.3 A sample of SSR gel image using marker ShContig827. The 48 individual *Striga hermonthica* plants collected from Kenya in 2013 are represented. The image is created from temperature gradient gel electrophoresis .

More detailed analysis of genetic diversity in *S. hermonthica* population is required so as to understand the parasite well enough for effective management. The parasite is said to have the ability to withstand a wide range of climatic conditions as well as to be quickly adapting to different hosts and environments (Welsh & Mohamed, 2011). This makes it even more difficult to develop universally resistant host crops, and the efforts toward obtaining resistant cultivars may need to take the view that *Striga* species are diverse.

Research achievements

Research on *Striga* control in Africa started from the 1940s onwards (Timson, 1945; Andrews, 1947) and, in the last 20 years these efforts have been increased and considerable resources have been invested in developing control options (Oswald, 2005; Woomer, 2004). Several organizations have been involved in conducting research in Kenya and developing *Striga* control mechanisms:- International Maize and Wheat Improvement Centre (CIMMYT) (Odhiambo & Ransom, 1993); Badische Anilin- und Soda-Fabrik (BASF)- a private chemical company; International Centre of Insect Physiology and Ecology (ICIPE) (Khan *et al*., 2008); International Crops Research Institute for the Semi-Arid-Tropics (ICRISAT) (Haussmann *et al*., 2001); Tropical Soil Biology and Fertility Program of the International Centre for Tropical Agriculture (TSBF-CIAT) (Vanlauwe *et al*., 2008); African Agricultural Technology Foundation (AATF) and International Institute of Tropical Agriculture (IITA) (Manyong *et al*., 2008). Other institutions from advanced countries mostly from Europe (The UK and The Netherlands), USA and Canada have also been involved in conducting research on *Striga* (Kim, 1996; Andersson & Halvarsson, 2011). These organizations and institutions have recommended control options to farmers in Kenya geared towards reducing infestation and damage. The options include:- the use of resistant crop varieties, intercropping of cereals with legumes, crop rotation, use of trap crops that stimulate suicidal germination, and application of manure and nitrogen fertilizer. Generally, it has been accepted that *Striga* control can be possible and sustainable if a wide range of individual technologies are combined into a program of integrated *Striga* control (ISC) to serve a range of bio-physical and socio-economic environments (Ellis-Jones *et al*., 2004; Douthwaite *et al*., 2007). In fact, Franke *et al*. (2006) reported that ISC approach reduced the *Striga* seed bank by 46% and improved crop productivity by 88%. The major objective of ISC is to reduce *Striga* densities in the soil to avoid new plants emerging in the subsequent seasons. However, there is stand-off on the complexity of control options to be involved and farm management as well as the resources required for its implementation.

Conclusion

Striga infestation in Kenya has increased in size and severity despite the 70 years of support in research. Increased pressure on land, as a result of cereal production (particularly mono cropping) and reduction in the use of fallow, is responsible for the worsening situation. The control methods developed have not been adopted by farmers. The reasons for non-adoption are that the farmers doubt them (Khan *et al.*, 2009; Atera, 2010) and they hear rumours that the methods do not work and thus they are unwilling to test them. We strongly recommend that the researchers and farmers should have an active linkage to technology transfer, as currently transfer of technology seems to be the limiting constraint. In our view, the technique of female sterility should be explored in *Striga* control in conjunction with intercropping with crop traps that stimulate suicidal germination. The technique will be based on gene introduction into *S. hermonthica* genome to cause female sterility while maintaining male fertility. On the other hand, intercropping as farming system will be readily acceptable to farmers and able to fit into their farming requirements. The combination of these control options would increase yields and eliminate the need for alternative methods of eradicating the witchweed.

Farmers' Perspectives on the Biotic Constraint of *Striga hermonthica* and its Control in western Kenya

Abstract

Witchweed, *Striga hermonthica* (hereafter, referred to as "*Striga*"), is a major biotic constraint to cereal production in sub-Saharan Africa. The parasitic plant is a socio-economic problem that has forced some resource-poor farmers to abandon their farms due to high infestation. This study was designed in order to elucidate farmers' perceptions of *Striga* control measures and to determine their potential adoption in two villages in western Kenya. Participatory rural appraisals and individual interviews were conducted in 2009 and 2010 in a sample of 128 and 120 households in Kaura and Kogweno-Oriang villages in Homabay and Rachuonyo districts, respectively. The results revealed that crop production was the main occupation in most households. The farmers identified *Striga* as one of the major constraints to maize, sorghum, and finger millet production. According to the farmers, the most popular control measures were hand-pulling, crop rotation, and intercropping, even though rotational systems might need a longer timeframe to reduce the soil seed bank of *Striga*. Although the level of *Striga* infestation and damage were increasing in the farmers' fields, the adoption of the control options was limited. The reason for the low adoption level of the control methods by the farmers is because they are "too risky" as there is no guarantee of a direct pay-off in increased crop yield. Farmer-led evaluation and adaptation of the various *Striga* control technologies in real-life situations will facilitate the choice of appropriate options and facilitate their uptake.

Keywords: control methods, farmers' perceptions, Kenya, participatory research, *Striga*.

Introduction

Striga hermonthica (Del.) Benth. (hereafter, referred to as "*Striga*"), an obligate root hemiparasite, poses a serious threat to cereal production in sub-Saharan Africa. From the east to the west of Africa, farmers have been fighting a losing battle against the *Striga* pandemic (Kanampiu *et al.*, 2003). The parasite infects cereal crops, such as sorghum [*Sorghum bicolor* (L.) Moench], pearl millet [*Pennisetum glaucum* (L.)], finger millet [*Eleusine coracana* (L.) Gaertn], maize [*Zea mays* L.], and upland rice (both *Oryza glaberrima* (Steud.) and *O. sativa* L.], on which Africans depend for food in more than 25 countries (Parker, 2009), affecting about 300 million persons (Aliyu *et al.*, 2004; Ejeta, 2007). The yield losses have been estimated at 10 million tons of grain, worth $US7 billion (Khan *et al.*, 2007; Venne *et al.*, 2009). In Kenya, *Striga* infects about 212 000 ha (Vanlauwe *et al.*, 2008), causing an annual crop loss of $US40.8 million (Gethi *et al.*, 2005). These losses largely depend on the level of infection, crop variety, soil fertility, and rainfall patterns (Melker *et al.*, 2007). The greatest impact of the parasite is on infertile soils and the most affected are the poor subsistence farmers (Kabambe *et al.*, 2008).

One of the most important reasons that *Striga* has a devastating impact on cereal crops relates to its effective competitive ability in depriving the host plant of carbon, nitrogen, and inorganic salts (Gurney *et al.*, 2006), while at the same time inhibiting the growth and impairing the photosynthesis of its host (Khan *et al.*, 2006; Melker *et al.*, 2007). The other reason is associated with the phytotoxic effects of *Striga* within days of attachment. The parasite produces phytotoxic substances that affect the crop's growth, with even low levels of infection resulting in dehydration and a loss of vigor, stunting, and biomass and grain yield reduction (Berner *et al.,* 1995; Musselman & Press, 1995; Frost *et al.*, 1997; Gurney *et al.*, 1999; Swabrick *et al.*, 2009). It attacks the host plant under the ground and, by the time the flowering stem of the parasite appears above the ground, the damage already has been caused (Gurney *et al.*, 2006). This behavior earned this parasitic plant the name of "witch". Its common name, "witchweed" in English, together with the various local African names, refers to the symptoms of the host before the parasite emerges above the ground.

A mature *Striga* plant has a high reproductive capacity and is capable of producing 10 000–200 000 tiny seeds per plant that can survive in the soil for more than 10 years (van Ast & Bastiaans, 2006; Hearne, 2009). Its high fecundity and longevity of the seed in the soil have led to huge amounts of seeds accumulating in the soil seed bank. The parasite's high seed production and the activities of humans have increased the magnitude and severity of its infections. Changes in cropping systems, coupled with an increased human population, have resulted in intensive land use, soil erosion, and nutrient depletion. In addition, demographic pressure has led to mono-cropping, thus increasing the frequency of *Striga* host crops in the cropping system, an ideal condition for *Striga* to thrive.

Research in Africa on the control of *Striga* has been going on for about 70 years (Ahmed *et al.*, 2001). Several promising *Striga* control strategies have been developed, from those that relate to soil fertility improvement to those that directly affect the parasite (Rector, 2009). This has accorded farmers with a variety of options to control the parasite, including the use of chemical herbicides, trap crops, hand-pulling, appropriate fertilizer applications, crop rotation, intercropping, resistant crops, and biological control (Parker & Riches, 1993; Menkir *et al.*, 2007; Hearne, 2009). Despite the efforts that have been made in research to control the parasite, limited success has been achieved. This is partly due to the complex life cycle of *Striga*, which is intimately linked to its host and depends on the response to chemical and tactile cues posing a challenge to control, both before and after attachment to the host (Oswald, 2005; Scholes & Press, 2008). However, investigations have revealed that the fodder crop legume, [*Desmodium uncinatum* (Jacq.) DC.] reduces the impact of *Striga* as it prevents the parasite's attachment (Khan *et al.*, 2007).

There is no doubt that, if the *Striga* problem remains unchecked, it will destroy the ecosystems and the farming communities' livelihoods. Yet to be ascertained is whether or not the developed technologies are appropriate for farmers and can be adopted and adapted beyond the experimental stations. Although the potential of several *Striga* control options has been demonstrated in various research centers across the infected regions in Africa, their adoption has been limited. The objective of this research was to determine farmers' knowledge and perceptions of *Striga* and its control options in western Kenya in order to guide the development, evaluation, and adaptation of control options for use by these farmers.

Methodology

Participatory rural appraisals (PRAs) and individual interviews were conducted in Kenya from October to November 2009 and between January and March 2010 in Kaura and Kogweno-Oriang villages in Homabay and Rachuonyo Districts, respectively (Fig. 4.1). The selected participants in the PRAs and individual interviews included opinion leaders, government officials, men and women, both young and old. A sample of 128 and 120 households in Kaura and Kogweno-Oriang villages, respectively, was selected for the data collection. Detailed information from the household head was collected through structured questions in the individual interview. The survey was designed to capture the farmers' characteristics, such as their sex, age, educational level, farming experience, and access to information on farming. In addition, the farmers provided information on farming technologies, constraints to agriculture, and *Striga* and its control strategies. An analysis from the farmers' perspective in all aspects was undertaken. Part of the research used a participatory approach in order to collect data from the farmers, which enabled the building of common knowledge (Emechebe *et al.*, 2004).

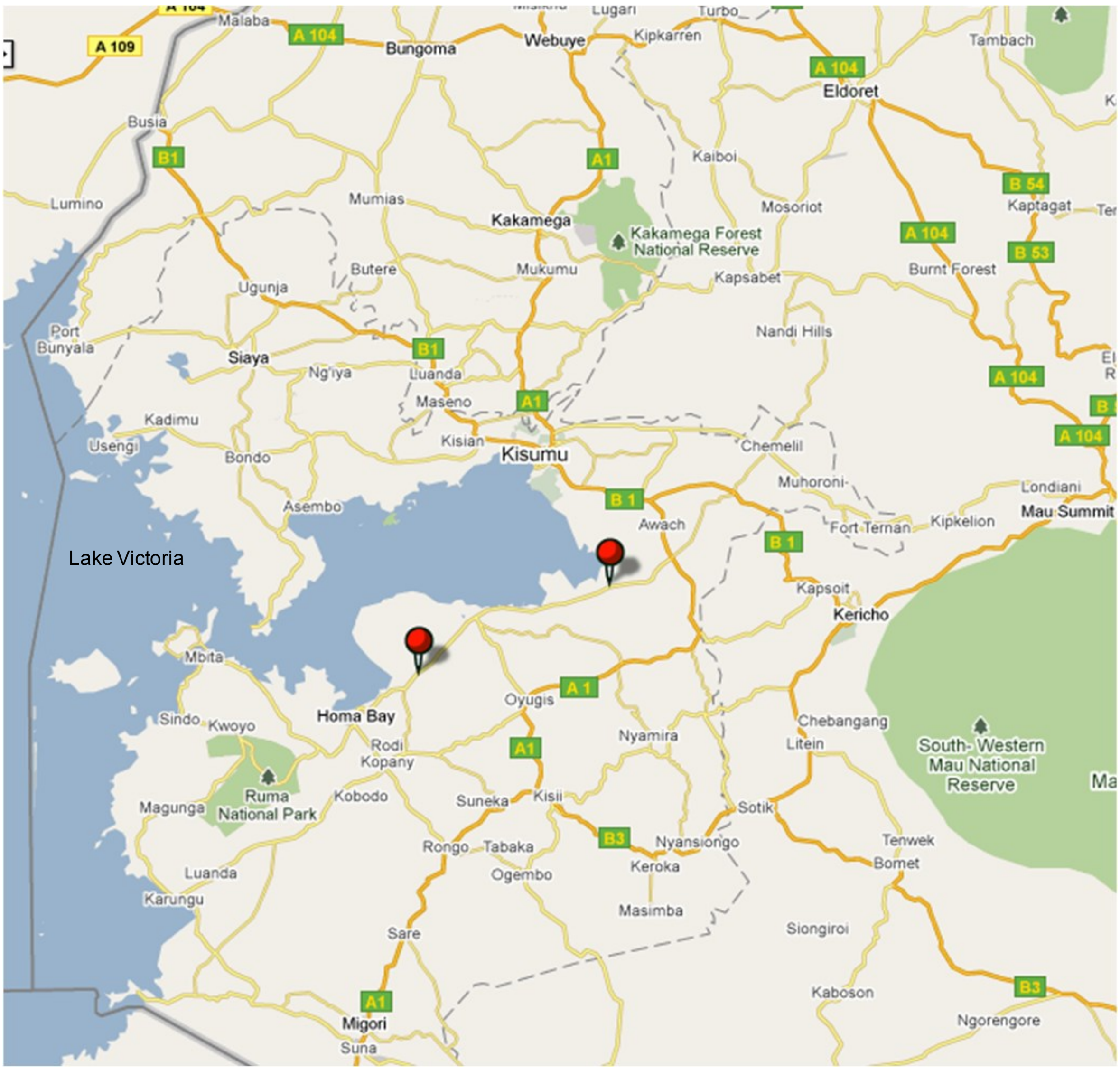

Fig. 4.1 Map of Western Kenya, showing the locations of Kaura (Homabay District) and Kogweno-Oriang (Rachuonyo District) where households were sampled in 2009 and 2010.

The farmers' crop preferences in both villages were ranked. Scores were used to indicate the farmers' perceptions of agricultural technology constraints and approaches to *Striga* management. Relatively simple scores, providing an indication of how well certain farming and *Striga* control strategies met the farmers' preferences, were developed. Ordinary numbers were used by the farmers as benchmarks to rank and score the importance of each technology. The farmers were asked to judge observations along a scale based on their perception. The scores for each factor of the farmers' perceptions were determined by using the following equation:

$$W = \frac{\sum_{n=1}^{N} \sum_{i=1}^{x} a_{in}}{x}$$

where W is the weight of the factor, *i* = 1…x, *n* = 1…N, x is the number of factors, N is the number of samples, and a is the value of factor i for the sample number n.

In testing the control strategies for *Striga*, the authors sought to know the contribution of agriculture to the communities' livelihoods, the crops that were necessary for food security, and which of these crops were affected by *Striga*. The farmers identified and ranked each crop that was grown in the area as a food and/or cash crop. The respondents prioritized the main economic stay in their livelihood, agricultural problems, and the importance of *Striga* in their farming system. The interview sessions with the farmers provided primary information about their opinions on the development, challenges, and expectations regarding both agriculture and *Striga*. Reviews were conducted before the interviews to ascertain the available farming technologies, constraints experienced by the farmers, and ability of the proposed technologies to fit within the farming systems. In identifying the rationale for the non-adoption of the control mechanisms for *Striga*, some of the reasons that were documented by Manyong *et al.* (2008), including a lack of capital, that the traditional methods are better, a lack of improved seeds, and gathering more information, were used.

Results

Characteristics of the sampled households

Most (78.1%) of the sampled households in the study area were headed by men, which is a typical household in most patriarchal African societies. In contrast, a woman assumes headship only after becoming a widow. There were more female-headed households in Kaura than in Kogweno-Oriang. The highest education level of the respondents was found in Kogweno-Oriang, with 5.4% of them having completed a tertiary education, compared to 2.9% in Kaura. However, there were more persons (4.5%) who had attained a primary and secondary school education in Kaura than in Kogweno-Oriang. Of the sampled population, most households owned about 0.8 ha of land.

Role of crop production in the livelihoods of the local communities

Agriculture was the most important (100%) livelihood source for the two villages in the Lake Victoria region in Kenya. Most households in the study area were engaged in the production of maize and sorghum (Table 4.1). These two crops are staple food crops and therefore add very little to the household cash flow as they are hardly ever sold. The study showed that, previously, finger millet was a significant crop and its products continue to be major foods, especially in Kaura (Table 4.1). Beans [*Phaseolus vulgaris* (L.)] and sweet potato [*Ipomea batatas* (L.) Lam.] were popular among the pulses and root crops, respectively, and their production was fairly well spread between the study sites. Green grams [*Vigna radiate* (L.) Wilczek] and groundnuts [*Arachis hypogeae*] were produced in very low quantities.

With most households being engaged in agriculture, the largest number of crop species that were produced by the farmers was in Kaura (18), compared to 15 in Kogweno-Oriang. On the causes of food insufficiency, the result of this study showed that it was attributed to drought in Kaura (14.3%) and a shortage of land in Kogweno-Oriang (13.5%) (Table 4.2). This was followed by a lack of cash to purchase farm inputs, which was more prevalent in Kogweno-Oriang than in Kaura. In descending order, the lack of appropriate technology was ranked fourth as a constraint to agricultural production. Over all, insufficient funds and a shortage of land were the main constraints to food production in the two villages.

Table 4.1 Farmers crop priority ranking in Kaura (Homabay District) and Kogweno-Oriang (Rachuonyo District) in western Kenya‡

Crop	Kaura†		Kogweno-Oriang§	
	Male	Female	Male	Female
Beans	5	4	5	4
Cassava	7	–	3	5
Cotton	6	5	–	–
Finger millet	3	3	–	7
Ground nuts	–	–	6	–
Maize	2	1	2	2
Sorghum	1	2	1	1
Sweet potatoes	4	6	4	3

‡1= highest, †18 crops listed with rice ranked 7th by female, §15 crops listed, – crops not ranked. The ranking of the crops was by a selected group of farmers.

Farmers' perceptions of the importance of Striga

In this study, the farmers were asked to rank crops in their order of importance as a source of food. In Kaura, the four most important crops were maize, sorghum, finger millet, and beans, while in Kogweno-Oriang, sorghum, maize, sweet potato, and cassava topped the list

(Table 4.1). However, there were some differences within the sampled population in each village, as well as between male- and female-headed households. For instance, the men from Kaura considered finger millet as the third-most important crop, whereas it was only mentioned by the women from Kogweno-Oriang (who rated it seventh), while only the men from Kogweno-Oriang mentioned groundnuts (as the sixth crop in descending order of importance).

Table 4.2 Constraints to agricultural production in Kaura and Kogweno-Oriang villages in western Kenya

Agricultural production constraints	Kaura	Kogweno-Oriang	Mean
Disease and pest	9.2	10.0	9.6
Drought	14.3	8.6	11.7
Floods	12.7	9.9	11.4
Insufficient funds	11.5	12.7	12.1
Lack of agricultural technology	12.5	10.5	11.6
Lack of equipment	9.5	9.3	9.4
Lack of market	8.7	13.4	10.8
Shortage of land	10.9	13.5	12.1
Weed infestation	10.8	12.2	11.4

Values within each column are frequencies from individual farmers responses reflecting their perceptions.

In Kaura (sorghum, maize, and finger millet) and Kogweno-Oriang (maize and sorghum), the most important food crops were attacked by *S. hermonthica*. Another parasitic plant growing on leguminous crops (*Alectra vogelii*) was mentioned and was referred to as "*Kayongo*", the local name for *Striga*. Among the constraints to agriculture, weed infestation by *Striga* was highly ranked (Table 4.2). The level of *Striga* infestation in the farmers' fields ranged from mild to severe. The survey revealed that 71.4% of the farmers had *Striga* in their fields. They reported that *Striga* reduced the crops' (maize and sorghum) yield by about 70%. Some of the farmers predicted that, if the *Striga* menace remains unchecked, hunger will remain as a persistent problem because some of them have abandoned growing staple crops on heavily infected fields and have changed to growing legumes, such as groundnuts and beans.

Farmers' perceptions of the factors that aggravate the incidence of Striga

The farmers from the two villages had different views on the factors that were responsible for the increase in the magnitude and severity of *Striga*. In Kogweno-Oriang, the farmers attested that, in the colonial era, they uprooted *Striga* before flowering from their fields and deposited it on the roadside. Uprooted *Striga* plants were collected later for burning. This practice of uprooting *Striga* has been going on to date without upholding the set standards of colonial times. The disposal of *Striga* on the roadside has enhanced its dispersal to new areas by water.

The escalating price of certified seeds is another factor that has increased the incidence of *Striga* as farmers cannot afford them due to high poverty levels. Therefore, the farmers share seeds from the previous harvest for planting, which are contaminated with *Striga* seeds. Another farmer's school of thought contended that *Striga* began to spring out when researchers started on-farm testing to ascertain which crops were resistant and which were susceptible to the weed. This introduced more seeds into their fields without providing a remedy.

Other farmers in Kaura considered a lack of capital, soil fertility, and poor farming methods, such as mono-cropping, caused the increase in the incidence of *Striga*. However, the farmers in both villages acknowledged that the movement of animals, especially cattle, in search of grass after harvesting aggravates the *Striga* problem by disseminating the seeds on their hooves and dung to new areas. In addition, the farmers were willing to try new technologies that do not require additional capital.

Sources of information on modern farming and the control technologies for Striga

The study revealed that the farmers got most of their information on modern farming methods and *Striga* from their neighbors (contact farmers), radio and television programs, and chief or district officers' barazas (gatherings that are held to raise awareness and share collective information) (Fig. 4.2). Most (78.8%) of the farmers indicated that they did not seek or get technical advice from extension services. However, this lack of information was made worse by the international organizations and non-government organizations through their technical officers. Even though government extension services were available, the attitude of farmers had not changed to conform to the current practice, where farmers are supposed to demand services, rather than wait for the services to be provided on a top-down basis. As much as the extension staff is willing to maintain more frequent contact with the farmers, this might not be possible due to infrastructure limitations and budgetary constraints. The research institutions that are mandated to play a vital role in technology dissemination have not lived up to the task, as they were poorly rated by the farmers.

Farmers' perceptions of the effectiveness of the control strategies for Striga

The farmers had varied perceptions on the mechanisms to control *Striga*. However, the majority (86%) admitted that they usually applied the technologies that are used to manage common weeds, such as *Commelina benghalensis*, *Mitracarpus villosus, Digitaria horizontalis, Brachiaria lata*, and *Cyperus esculentus*, in order to control *Striga*. These weed management practices are less effective in controlling parasitic weeds. In assessing the popularity of the control options, the farmers ranked hand-pulling as the best technology (Fig. 4.3).

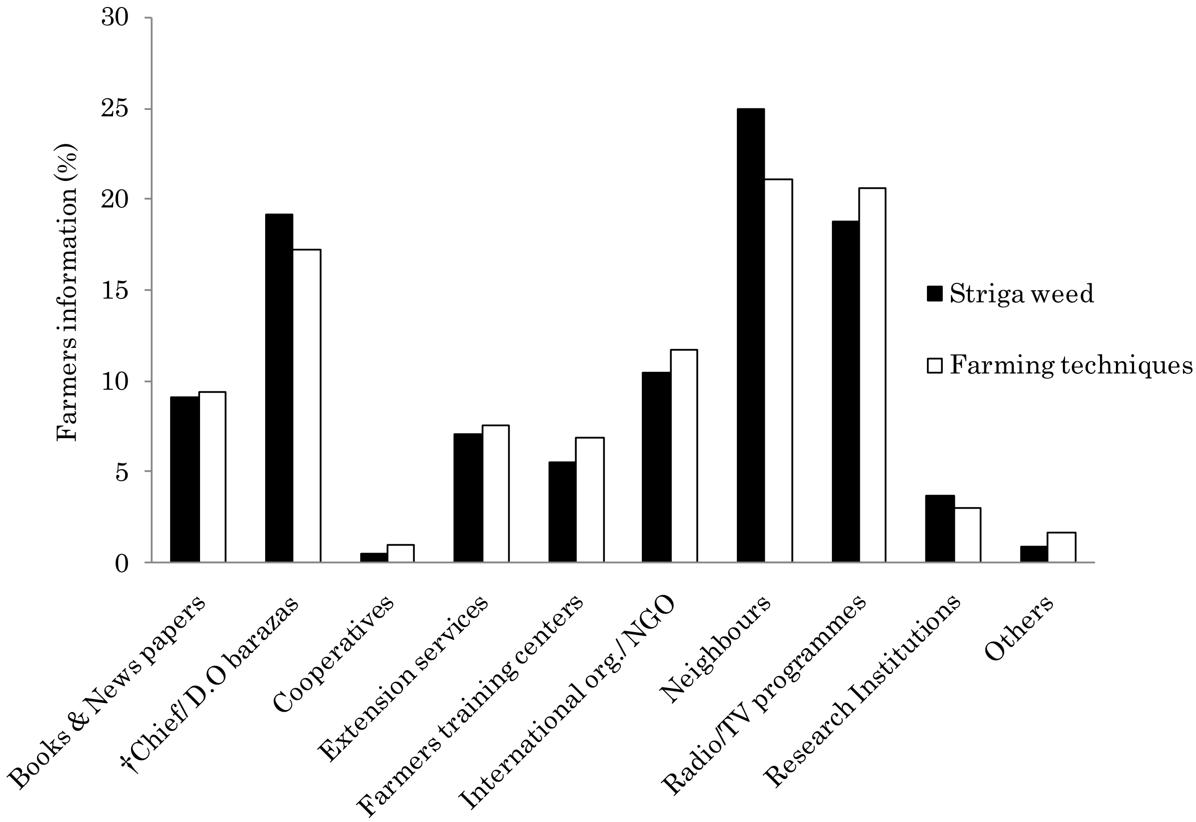

Fig. 4.2 Farmers sources of information on farming techniques and Striga weed. † Chief/District Officer Barazas - gathering held to raise awareness and share collective information.

Crop rotation was ranked second, while intercropping was ranked third by the farmers for controlling *Striga* (Fig. 4.3). The farmers reported that, other than having an extra food crop in the field, the crops tended to differ in their response to physical and environmental stresses. The resources that became available through the failure of one crop species could be used by the surviving crop (Table 4.3). In all cases, the use of herbicide-coated seeds, such as imazapyr-resistant (IR) maize, was perceived as a potentially good mechanism to control *Striga*. However, it is unlikely to be adopted widely as the farmers cannot afford the seed (Table 4.3). Fertilizer application as a method to control *Striga* was poorly ranked (Fig. 4.3). When the farmers were asked why they did not use fertilizer as a control mechanism, they overwhelmingly replied that they would use fertilizer but have no money to purchase it.

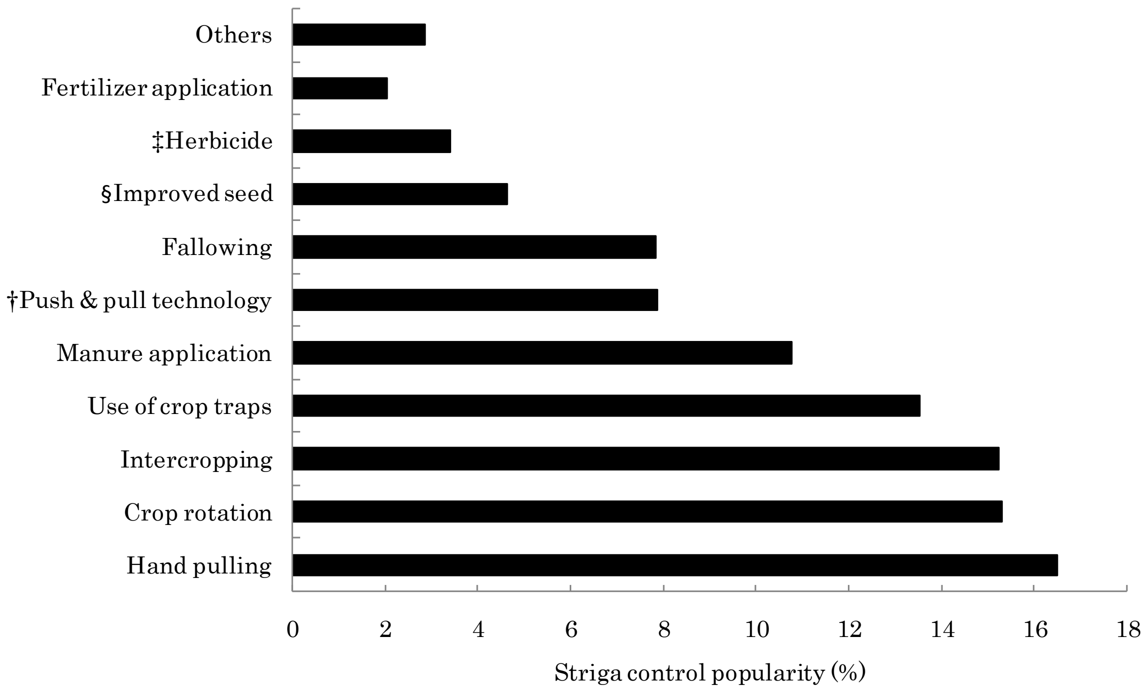

Fig. 4.3 Farmers perception on Striga control mechanisms popularity (n =78) in Kenya. † Integrated management of stem borers, Striga weed and soil fertility, § Striga tolerant varieties, ‡Imazapyr resistant herbicide-coated maize seed that forms protective zone around the roots of maize under the name of StrigAway™.

Rationale for the non-adoption of the control mechanisms for Striga

The reasons for the non-adoption of the control technologies for *Striga* by the farmers were related to a fear of investing (money and time) in control methods in *Striga*-prone fields. The results revealed that, in both Kaura (25.5%) and Kogweno-Oriang (31.6%), the technologies were considered to be too risky to adopt as there is no guarantee of a direct pay-off in returns, while 22.6% and 29.9% of the farmers in Kaura and Kogweno-Oriang, respectively, pointed out that they lacked the cash to purchase inputs (Table 4.4). More than 14% of the respondents in Kogweno-Oriang indicated that traditional methods are better in controlling *Striga*, while 7.8% were still gathering more information on the technologies. The results also revealed that 18.6% of the respondents from Kaura village were still gathering information on *Striga* control methods.

Table 4.3 Farmers perception on the advantages and disadvantages of *Striga* control mechanisms

Control method	Advantages	Disadvantages	Adorption potential†
Hand pulling and burning	Reduction of seed bank and increase yield if done before flowering	Increase of seed back due to inappropriate disposal	High
Weeding	Reduction of Seed bank and high crop yield	Costly due to the requirement of labor and money	Moderate to high
Crop rotation	Increase in soil fertility and reduction of damage by *Striga*	Difficult to adhere to the per family food requirement	Low to moderate
Intercropping	Increase soil fertility especially with legumes, reduction of damage by *Striga*, additional income and easy weed control	Labor intensive and attraction of rodents	Moderate to high
Fertilizer application	Reduction of incidence *Striga*	Expensive and unavailable increase in soil pests if inappropriate application	Low
Compost application	Reduction of damage by *Striga*, increase in soil fertility and high crop yield	Increase soil pests if not appropriately applied	High
Herbicide seed dressing	Suppression of incidence of *Striga*	Expensive to purchase dressed seeds	Low

† indicates the farmers willingness level of adoption

Discussion

Almost all the farmers viewed *Striga* as a challenge to crop production. Diversified techniques have been developed by agriculturists to limit *Striga* damage, but farmers have not been convinced of their efficacy (Aliyu *et al.*, 2004). The problem is whether or not the developed technologies are economically viable and whether or not they fit into the farming systems and the reality of farmers. Perhaps, most of the available control measures fall short of being practical in the labor-intensive subsistence agriculture of poor farmers with little investment capacity. A potential viable technology should be of low-cost and within reach of small-scale, poor farmers and address their interrelated problems of low soil fertility and *Striga*. Owing to the diversity of African farming systems, it is unlikely that a single control method will be universally acceptable. It is widely recognized that the most likely method to control *Striga* is the development of an integrated strategy that combines a range of technologies (Berner *et al.*, 1996; Emechebe *et al.*, 2004). The control program should be aimed at reducing the *Striga* soil seed bank and maximizing productivity and profitability while being flexible and sustainable.

Table 4.4 Farmers reasons for non-adoption of Striga control mechanisms in Kaura and Kogweno-Oriang in western Kenya

Rationale for non adoption of the control measures	Kaura	Kogweno-Oriang	Mean
Too risky to adopt	25.8	31.6	28.7
Lack improved seeds	17.2	10.3	13.8
Lack of cash to purchase inputs	22.6	29.9	26.2
Traditional methods are better	6.5	14.3	10.7
Gathering more information	18.6	7.8	13.2
Cultural factors	5.4	0.6	3.2
Others	4.0	5.6	4.8

Values within each column are frequencies from individual farmers responses reflecting their perceptions.

It is interesting that the farmers attributed the increased incidence of *Striga* to grazing animals (through seed dissemination by the hooves and dung) and the planting of crop seeds that are contaminated by *Striga* seeds. These results corroborate the findings of Emechebe *et al.* (2004) that *Striga* seeds often are disseminated by cattle and contaminated crop seeds. An integrated *Striga* management program recommends that animals should be restricted to fields that are uninfected with *Striga* in order to prevent any further seed dispersal and that farmers should plant uncontaminated seeds (Berner *et al.*, 1996). The amount of crop yield losses in the farmers' fields due to parasitic infections was about 70%, especially in maize and sorghum. Similar losses have been reported in maize and sorghum under field experiments (Clark *et al.*, 1994; Adetimiri *et al.*, 2000; Kim *et al.*, 2002; Merkir & Kling, 2007).

Among the ten control technologies that were assessed, the highly ranked and preferred were hand-pulling, crop rotation, and intercropping. The farmers viewed hand-pulling (16.9%) as the most effective way to control *Striga* (Fig. 4.3). This result agrees with the findings of Smaling *et al.* (1991) in western Kenya that hand-pulling reduced the incidence of *Striga* and increased the grain yield in the following season. In addition, Emechebe *et al.* (2004) stated that hand-pulling was one of the most popular techniques to control *Striga* with some communities in West Africa. However, as much as it seems to be an easy-to-practice and straightforward approach to interrupt the life cycle of the parasite, it has some serious drawbacks. The *Striga* weed emerges 5–6 weeks after planting and it takes another 3 weeks for the *Striga* plants to be big enough to be uprooted (Oswald, 2005). By this time, the farmers already have carried out their normal weeding of their crops, meaning that the farmers have to go back to uproot *Striga*, not only once but several times, as *Striga* continues to emerge until a few days before harvesting. This requires considerable investment in terms of time and labor. Also, even if *Striga* is uprooted, the damage already has been caused because it exerts phytotoxic effects on the host plants (Gurney *et al*., 2006). However, this control mechanism still has a major impact because few mature plants can replenish the seed bank in the soil.

Technologies that fit farming communities, as mentioned earlier, easily can be adopted by farmers, unlike those that demand a significant modification of their farming practices (Hearne, 2009). Crop rotation and intercropping were perceived to be among the best approaches to control *Striga* in the two villages of Kaura and Kagweno-Oriang (Fig. 4.3). These views are probably related to reports by Oswald and Ransom (2001) and Oswald *et al*. (2002), who showed that crop rotation and intercropping were more robust ways to reduce *Striga* infestations, considering the limited resource base of small-scale subsistence farmers in SSA. The use of legume crops, such as soy beans, as rotational crops with cereals to reduce the *Striga* seed bank through suicidal germination can be one of the components of the integrated management of *Striga* (Khan *et al*., 2007). In addition, soy beans that are grown as an intercrop with cereals will have the advantages of added product to the farmer and improved performance of the cereal crops. However, the demand and market for soy beans that are produced at the household level must be available if they are to be suitable as a mechanism for *Striga* control. Subsequently, some technologies (such as the use of the fodder crop, *Desmodium* spp., as an intercrop in Kenya) reduce *Striga* infections to appreciable levels through suicidal germination (Khan *et al*., 2008; Hooper *et al*., 2009), but farmers without dairy animals will not easily adopt the technology unless there is a market for the fodder. Crop rotation and intercropping technologies also require several years of repeated and continued application before realizing a significant rise in annual grain yield. These technologies need to be re-evaluated and repackaged to ensure that they fit the local knowledge and economic circumstances of farmers in order to enhance their adoption.

In this survey, 24.1% of the farmers stated that they had not adopted control mechanisms due to a lack of cash to purchase the inputs (seeds and fertilizers). This finding is partially consistent with the two reasons for the low adoption of fertilizer use in Kenya: a lack of information and savings difficulties (Duflo *et al.,* 2008). Fertilizers are expensive and unavailable to many farmers who live in rural areas (Morris *et al.*, 2007). Unless governments subsidize fertilizers, as in the case of Malawi (MoAIFS, 2005), it will be difficult for farmers to access and adopt fertilizer use as a control mechanism. In fact, a recent survey showed that only 37% of the farmers in western Kenya reported ever using fertilizers (Duflo *et al.,* 2008).

Although the use of *Striga*-resistant crops is an ideal mechanism to control the parasite, with no additional cost to the farmer, it was poorly rated by the two communities. Crops, such as sorghum (Framida, SRN 6496, SRN 39, and N13), possess the characteristic of lowered germination stimulant production and offer attachment resistance to *Striga* (Haussmann *et al.*, 2001). Similarly, herbicide-coated IR maize, which has been introduced in Kenya under the name of StrigaAway™, is effective in controlling *Striga* as it inhibits the activity of acetolactate synthase and forms a protective zone around the roots of maize (AATF, 2007). However, the major problem regarding the non-adoption of all seed-based technologies is that they are cost-prohibitive and are not easily accessible to farmers. If farmers have access to resistant varieties and have cash to purchase the initial seed, then the adoption of these varieties is possible, as this fits well within their existing farming systems.

Conclusion

Based on these results, the potential obstacles that limit the adoption of the control mechanisms for *Striga* need to be identified and strategies need to be formulated in order to mediate them before the control mechanisms are released to farmers. This calls for the ability of researchers to assess farmers' priorities, which will enhance the generation of suitable improved *Striga* control programs. In most cases, researchers do not understand or lack ideas on farming systems in *Striga*-prone areas and the technologies that have been developed are in themselves barriers to farmers' adoption. In order to enhance adoption, the use of the participatory approach for farmers is recommended as it ensures that the farmers receive programs that match their requirements. In addition, the approach facilitates collaborative research that can identify the strengths and weaknesses of technologies and create a platform for dialogue. The key issue is the achievement of qualitative interaction between the stakeholders in the agricultural sector, such as extension workers, the private sector, research workers, and farmers. This kind of approach, if adopted, can produce reliable technologies that are practical and available to farmers. These technologies will have a greater chance to create an impact in the fight against *Striga* in sub-Saharan Africa.

Farmers' Perception and Constraints to the Adoption of Weed Control Options: the Case of *Striga asiatica* in Malawi

Abstract

Studies were conducted to determine farmers' perception on *Striga* control options and their potential for adoption in two Extension Planning Areas (EPAs) in Central Malawi. Individual interviews were conducted in Mpingu (Lilongwe District) and Mponela (Dowa District) EPAs in 2010 in a sample of 247 respondents. The study revealed that crop production was the main source of livelihood for most households. Farmers identified *Striga* as a constraint to maize production and attributed its increasing incidence to insufficient funds to purchase inputs, soil fertility and grazing animals. On *Striga* control mechanisms, manure application was perceived to be the best by farmers, followed by crop rotation, fertilizer application and hand pulling. Even though *Striga* infestation is increasing in farmers fields, they have not adopted the control options. The low adoption of the options has been justified as "too risky" as farmers do not trust them. Emphasis should be laid on undertaking on-farm trials and development of technologies should involve farmers if they are to gain wide acceptability.

Key words: *Striga asiatica*, farmers, perception, control mechanisms, Malawi

Introduction

The parasitic angiosperm, *Striga* spp., is obligate root parasite endemic in sub-Saharan Africa causing severe constraint to cereals. It is a growing pandemic, undermining the struggle to attain food security of the continent. Approximately 40% of the cereal producing area is infected and 300 million people affected (Ejeta, 2007). The most affected are subsistence farmers losing about 20–80% of their crop yield (Atera *et al*., 2011). In Malawi, the recorded species are *S. asiatica, S. aspera, S. gesneriodes* and *S. forbesii*. Among these, *S. asiatica* is said to be widespread and the most noxious to cereal crops such as maize, sorghum, millet and rice (Kabambe *et al*., 2008).

The parasite is estimated to be infecting 268,000 ha of farm land in Malawi (AAFT, 2006). A survey carried out in the country showed that 63% of the maize is infested (Kroschel *et al*., 1999). The figure has since risen to 80%, an indication that *Striga* problem is not declining (Parker, 2009). Total crop yield loss occurs under heavy infestation. Other losses as result of *Striga* depend on land use system, soil fertility, crop species and genotype, and rainfall patterns (Atera *et al*., 2011). The parasite is difficult to control because it has the capacity to produce large number of tiny dust like seeds which can survive in the soil for more than 10 years (Hearne, 2009). These seeds do not germinate unless they are stimulated by root exudates of their hosts.

The life cycle of the parasite is closely interlinked to that of its host and largely depends on chemical signals. This is a challenge to researchers particularly in understanding host-parasite biology. Several germination stimulants have been recorded that trigger *Striga* germination; however, strigolactones are the most common root exudates from many cereals (Scholes & Press, 2008). Knowledge of the biosysthetic pathways is required so that production of germination stimulants can be manipulated to identify genes involved in the synthesis and regulation of strigolactones. This might probably lead into designing a novel control strategy. Contrary to normal weeds, most of the damage to the host is done before the parasite emerges above the soil (Kiwia *et al*., 2009; Atera *et al*., 2012a). Therefore, control methods should focus on reducing soil seed bank and interfere with the parasite's early developmental stages.

Various *Striga* control options such as use of resistant crop varieties, cereal-legume intercropping, trap crops that stimulate suicidal germination and nitrogen fertilizer application have been suggested (Frankie *et al*., 2006; Hooper *et al*., 2009). A combination of a wide range of technologies into an integrated *Striga* control (ISC) program has been identified as a feasible approach to contain the parasite. The adoption and successful implementation of this technology largely depend on farmers' perception and reaction towards it. The objective of this research was to determine farmers' knowledge and, perceptions of *Striga* and its control options in Malawi to serve as basis for development, assessment and adaptation of the options by farmers.

Methodology

The study was conducted in January to March 2010 in two districts (Dowa and Lilongwe) in the central region of Malawi, where S*triga* has been a problem. With the help of Ministry of Agriculture (MoA) extension staff, one Extension Planning Area (EPA) (Mponela, Dowa District and Mpingu, Lilongwe District) was selected in each district (Fig. 5.1). Six villages within the locations of these EPAs were selected. Farmers' from each village were selected randomly from the list in the office of agricultural extension staff. Within the six villages from each EPA, a sample of 118 and 129 households in Mpingu and Mponela EPA were selected for data collection and the response was 96%. Forty three (43) open structured household level questionnaires were administered.

The survey captured the farmer's characteristics such as sex, age, educational level, farming experience and access to information on farming. It also covered farming technologies, constraints to agriculture and *Striga* and its control strategies. This information was meant to collate the perceptions of farmers to production constraints. Data were collected through a field survey by face-to-face interviews with the farmers by trained enumerators and agricultural extension staff. Farmers were invited to be part of the survey through agricultural extension agents and opinion leaders.

Crops of preference were ranked and simple scores used to reflect the farmers' perception on constraints to agricultural technologies and *Striga* management approach. The simple scores were developed to show how well certain farming and *Striga* control strategies met farmers' preferences. In each technology, ordinary numbers were used as bench marks to rank and score its importance. Farmers' perception was judged on a scale and determined by following equation:

$$W = \frac{\sum_{n=1}^{N} \sum_{i=1}^{x} a_{in}}{x}$$

Where W = weight of factor, i = 1…x, n = 1……N, x = Number of factors, N = Number of sample, a = Value of factor i for the sample number n.

Through the interviews, farmers provided primary information on their opinion and challenges on both agriculture and *Striga*. Reviews were conducted before interviews to ascertain the available farming technologies, farmers' constraints and if the proposed technologies fit within their farming systems. We adapted sections of Manyong *et al.* (2008) survey in identifying the rationale for non-adoption of *Striga* control mechanisms. Data from the questionnaire were analyzed using the statistical package for social scientists (SPSS) software. The results presented in this chapter are perceptions of farmers about *Striga asiatica* and its control options.

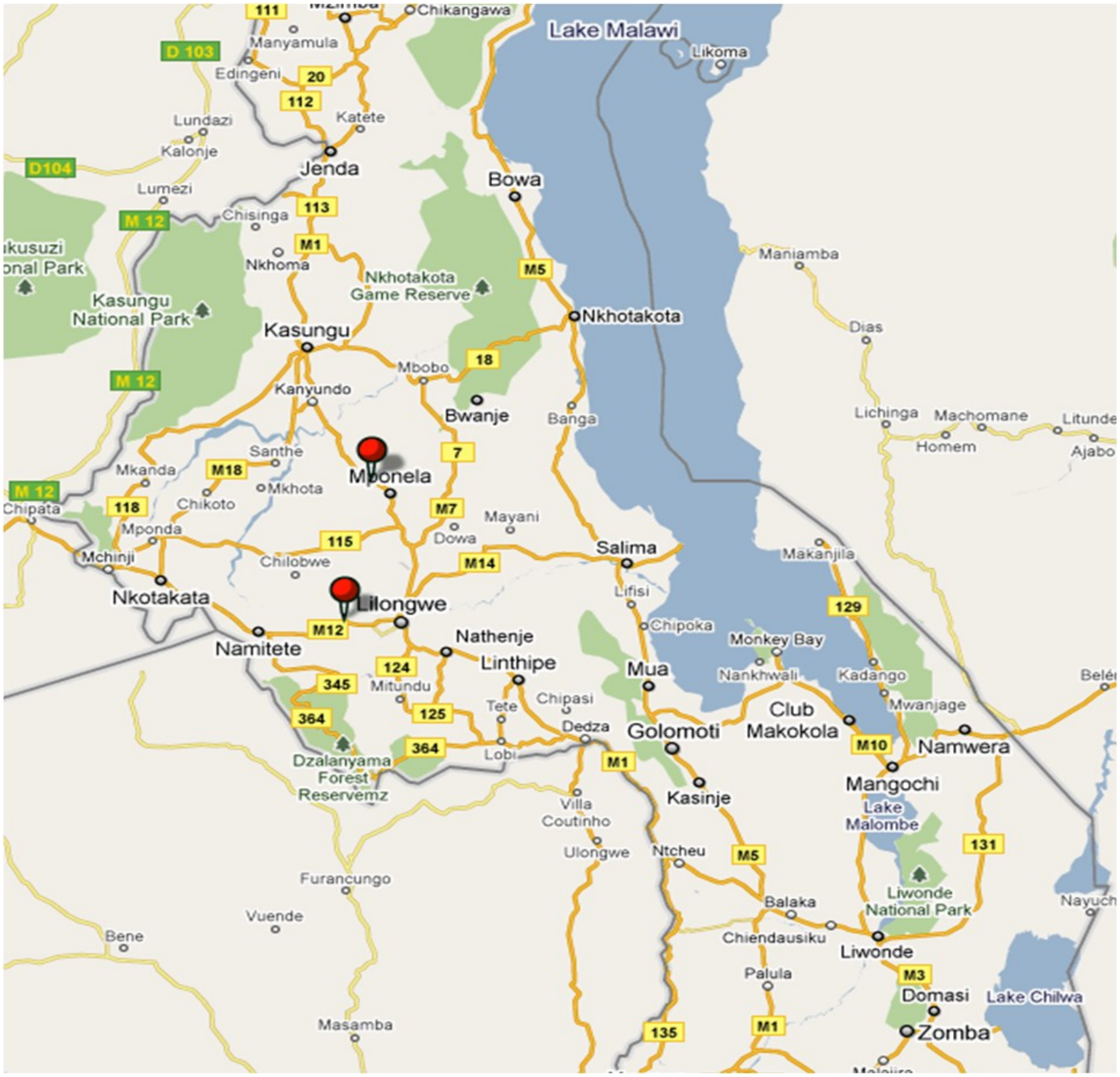

Fig. 5.1 Map of Central Malawi, showing the locations of Mponela (Dowa District) and Mpingu (Lilongwe District) EPA where households were sampled in 2010.

Results and Discussion

Household characteristics

In this study, most of the sampled households (76.3%) were headed by males. This represented typical household headship in African societies, where women can assume headship after becoming widows. The study revealed that 85.6% and 76% of the household heads received formal education in Mpingu EPA and Mponela EPA, respectively. Mpingu EPA also had more (4.3%) respondents trained in vocational and short-term training on farming skills. This may be as result of proximity to Lilongwe City and Chitedze Research Station which offers opportunities for urban based training on agriculture. There were several Non Governmental Organizations (NGOs) involved in offering training to rural poor farmers in Lilongwe District compared to Dowa District. The study showed that educational level is one of the most important attributes that indicates a household capacity to adopt technology. In both EPAs, the average household heads were in their economically active age of about 45 years. There were more household heads working off the farm in Mpingu EPA (17.3%) than Mponela EPA (8%). Of the sampled population, most households owned about 0.9 ha of land.

Importance of crop production to the local communities' livelihood

The study revealed that agriculture is the livelihood source for the communities in the two EPAs, Mpingu and Mponela. Maize [*Zea mays* L.] is regarded as source of food (Table 5.1) and it is produced by almost every farmer. It is also considered by some farmers as source of income. Maize is life "*chimanga ndi moyo*" to many farmers in Malawi for its famous use to prepare the stable dish *nsima*. Our result is related to Kabambe *et al.* (2008) who reported that maize constituted a major component in the diet of Malawian people. Theu (2008) revealed that 55-60% of the maize grown in Malawi comes from the central districts, and the area is most affected by *S. asiatica*. This indicates the importance of maize in the study area and the need to address constraints that reduce its productivity.

Maize-legume intercropping was generally practiced among farming households to reduce *Striga*. This agrees with the findings of Mbwaga *et al.* (2001) that intercropping cereals with legumes reduced *Striga* infections and increased yield in Cameroon and Ethiopia. The cropping system not only increases yield but soil fertility is improved by nitrogen fixation and soil erosion reduced. Odhiambo and Ariga (2001) reported that maize-bean intercropped in the same hole increased maize yield by 78.6% above the pure stand in heavy *Striga* infected area. Intercropping maize with desmodium has also been shown to reduce *Striga* incidence in Kenya through allelopathic effect (Khan *et al.*, 2007) and the same to sesame intercropped with sorghum and pearl millet in Eritrea (ICRISAT, 2002). These findings clearly testify that inclusion of legumes in cereal-based systems has beneficial effects in reducing *Striga* incidence resulting to enhanced cereal yield.

Table 5.1 Farmers crop priority ranking in Mpingu (Dowa District) and Mponela (Lilongwe District) EPA in Central Malawi‡

Crop	Mpingu§		Mponela‡	
	Male	Female	Male	Female
Beans	–	6	7	5
Cassava	5	4	5	6
Groundnuts	3	2	3	2
Irish potato	–	–	6	–
Maize	1	1	1	1
Soya beans	6	5	4	4
Sweet potato	2	3	2	3
Vegetables	4	–	–	–

‡1= highest, §11 crops listed, ‡14 crops listed with ground beans ranked 8th by male, – crops not ranked

Traditional non tradable crops such soybeans [*Glycine max* (L.) Merr.], groundnuts [*Arachis hypogaea* L.], sweet potatoes [*Ipomea batatas* (L.) Lam.] and cassava [*Manihot esculenta* Crantz] were widely grown in the study sites. The study revealed that groundnuts and sweet potatoes were the second most important crops and production was fairly well spread between the study sites (Table 5.1). With most households engaged in crop production, the largest number of crop species was produced by farmers from Mpingu compared to Mponela. According to Moyo (2010) legumes are important components of Malawi's maize based farming system. Despite the benefits which can be accrued from legumes, the sub-sector is characterized by low productivity due to the fact that farmers experience serious problems of accessing seeds at planting time. The focus of the agricultural sector is to use innovative systems of approach to increase farmers' access to seed and use research to address production and marketing bottlenecks in the legume value chain.

Farmers' perception on Striga as a cause to food insufficiency

In this study, farmers were asked to rank the crops in order of priority as a source of food and cash. The four most important crops in the study area were maize, sweet potatoes, groundnuts and cassava (Table 5.1). However, there were some differences within the sampled population in each EPA as well as within males and females. For instance, farmers in Mponela considered Bambara beans as the eighth important crop while only males rated irish potato as the sixth in descending order of importance. In both EPAs, the most important crop (maize) was infected with *Striga asiatica*. A leguminous parasitic plant *Alectra vogelii* which most farmers referred as "*Kaufiti*" a local name for *Striga* infected groundnuts, bambara beans, common beans and soybeans, which are farmers preferred legumes crops.

Striga infestation in the farmer fields ranged from mild to severe infestation. The survey revealed that 67% of farmers in the study area have *Striga* in their fields. Almost all farmers (91.3%) viewed *Striga* as a challenge to crop production. Lack of funds to purchase inputs (20.4%) and farm tools (13.7%) in the study sites were recorded as the major causes of insufficient food (Table 5.2). About 10.5% of the respondents stated weed infestation was responsible for low productivity in the agricultural sector. AAFT (2009) identified lack of inputs and *Striga* infestation as the major constraint to crop productivity which is consistent with our findings. In order to improve on food sufficiency, the Government of

Malawi introduced farm input subsidy program (FISP) known as “starter pack” (SP) which provided farmers with packs of fertilizer, maize and beans or ground nuts to rural households. The inclusion of legumes in FISP was undertaken to improve on the soils and yield as well as to reduce *Striga* infections (MoAIFS, 2005). As much as the government subsidized the price of fertilizer, the targeted farmers still cannot afford it in sufficient quantities because they are capital constrained when the planting season sets in.

Table 5.2 Constraints to agricultural production in Mpingu and Mponela EPA in Malawi

Agricultural production constraints	Mpingu		Mponela		Mean
	Male	Female	Male	Female	
Disease and pest	0.484	0.5	0.462	0.683	0.532
Drought	0.529	0.602	0.436	0.54	0.527
Floods	0.078	0.102	0.12	0.143	0.111
Insufficient funds	0.837	0.833	0.812	0.714	0.799
Lack of agricultural technology	0.333	0.269	0.427	0.476	0.376
Lack of equipment	0.497	0.63	0.556	0.46	0.536
Lack of Market	0.458	0.259	0.376	0.46	0.388
Shortage of land	0.373	0.333	0.684	0.574	0.491
Weed infestation	0.412	0.472	0.282	0.603	0.442

Values within each column are weight transformed calculated according to the equation in the methodology reflecting farmers' perceptions.

Perception of farmers on Striga increase in their fields

The majority of farmers from the two EPAs attributed lack of capital to purchase inputs as the major problem that has aggravated increase of *Striga*. In addition, farmers in Mponela EPA considered low soil fertility and poor land preparation due to mono-cropping increased *Striga* incidence in their fields. However, Mpingu farmers claimed that sharing of seeds for planting from previous harvest for planting aggravated *Striga* incidence. Respondents from both EPAs acknowledged that movement of animals especially cattle after harvesting aggravated the *Striga* problem by disseminating the seeds on their hooves and dung. They viewed the grazing animals and wind as the major agents of *Striga* dissemination to new areas. These findings are similar to those of Emechebe *et al.* (2004) that *Striga* seeds are often disseminated by cattle and contaminated seeds in northern Nigeria. Farmers were willing to try new technologies which do not require additional capital. They felt that there was need to reduce the *Striga* seed banks and prevent further seed dissemination to new areas.

Farmers' knowledge on farming methods and Striga control technologies

The study showed that farmers major source of information on modern farming methods and *Striga* control technologies are from government extension staff (Fig. 5.2). Approximately 26% of the respondents viewed International Organizations/NGOs as playing a significant role in providing farmers with knowledge on farming techniques. Most farmers gained access to knowledge on *Striga* from the extension services (33%) and neighbors (23%). The view is probably related to Oswald (2005) who showed that even extension staff in Kenya did not have enough knowledge on *Striga* and only 34% of farmers received training on *Striga* from them, while the rest depended on their neighbors.

Interestingly, the media service (TV and radio) was ranked third as the source of information for farmers on *Striga*. Radio as media of information in particular, is very popular as it reaches a wide audience and is readily accessible and affordable. The government has ensured that there are live programs and forums making it possible for presenters to interact with farmers. Nevertheless, the study revealed that research institutions are not instrumental in technology dissemination even though they are prominent in the generation.

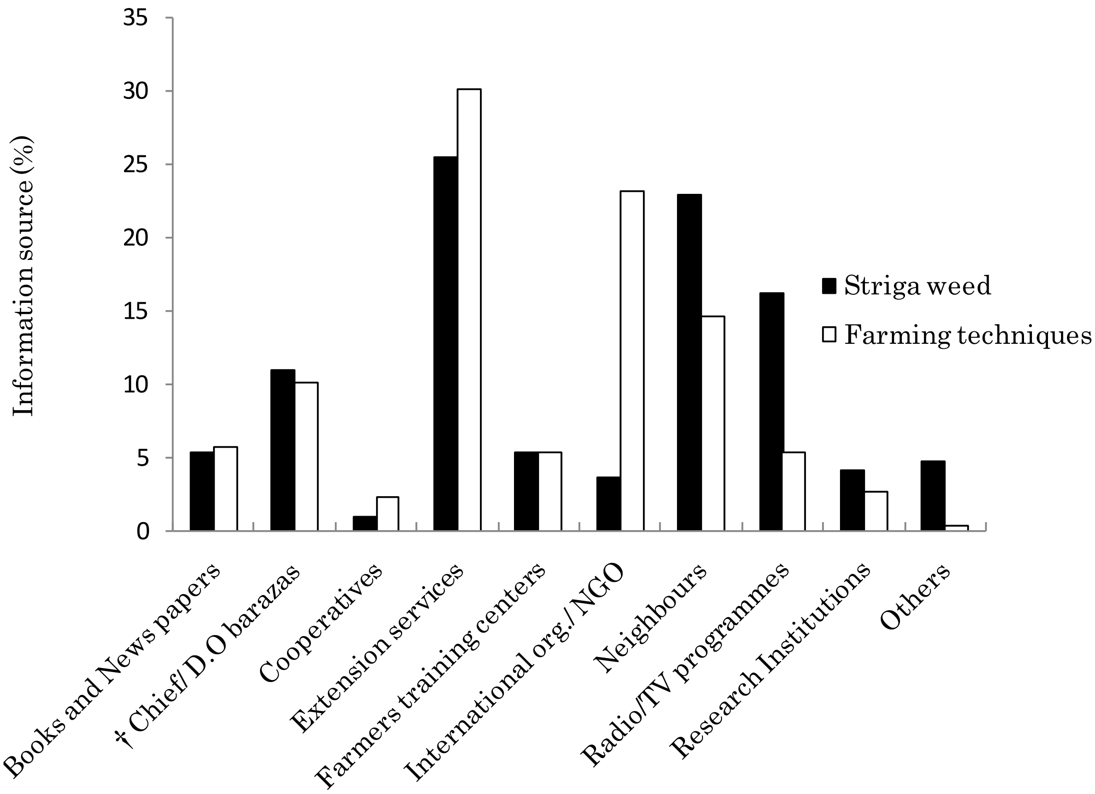

Fig. 5.2 Farmers sources of information on farming techniques and Striga weed. †Chief/District Officer Barazas-means gathering held to raise awareness and share collective information.

Farmers perception on effectiveness of Striga control mechanisms

Majority of the respondents (74.2%) admitted that they usually applied the technologies used to manage normal weeds (*Conyza stricta, Solanum incanum, Oxalis latifolia* etc.) to control *Striga*. The management practices of these weeds are ineffective in controlling parasitic weeds. Farmers in both EPAs ranked manure application as the most popular and best option in *Striga* control (Fig. 5.3). This implies that consistent manure application is perceived to reduce *Striga* populations. However, Smaling *et al.* (1991) reported that effects of N, P, S and farmyard manure were disappointing as none of them suppressed *Striga* significantly. In addition, Manyong *et al.* (2008) stated that manure increases nutrients in the soil for crops to grow well, but it does not reduce *Striga* seed bank.

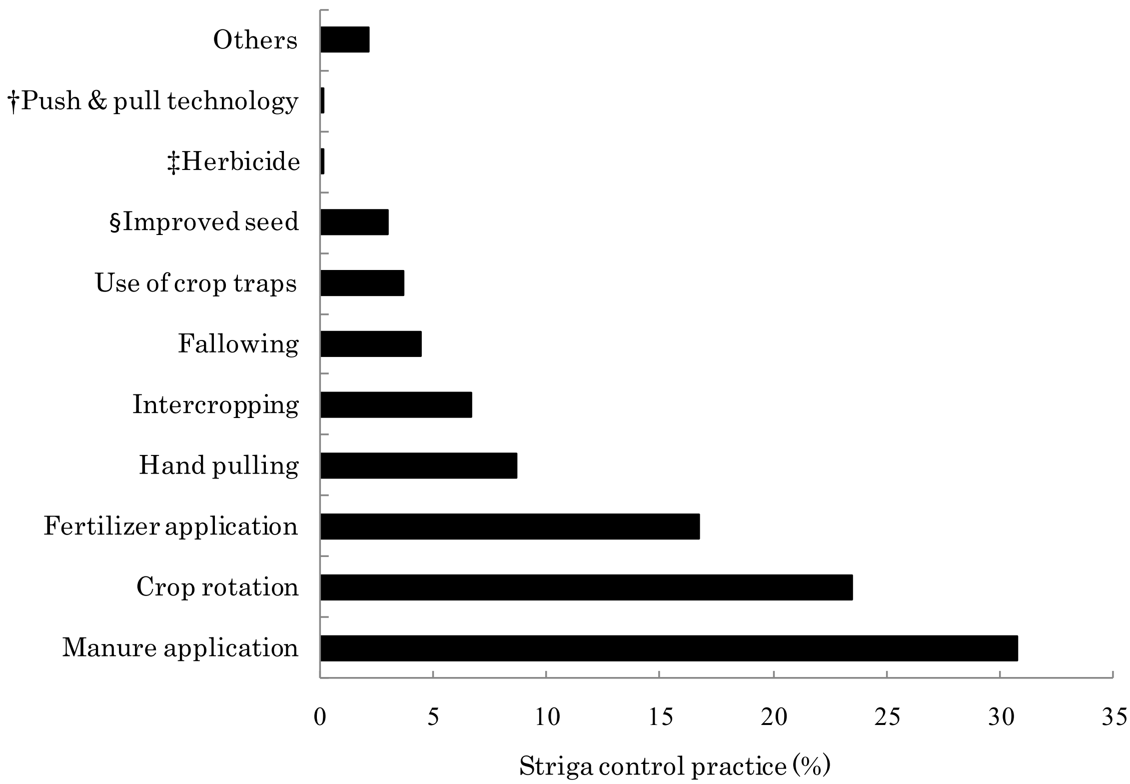

Fig. 5.3 Farmers perception on the control mechanisms popularity (n=58). †Integrated management of stem borers, S*triga* weed and soil fertility, §*Striga* tolerant varieties, ‡Imazapy resistant herbicide-coated maize seed (IR maize) that forms protective zone around the roots of maize under the name of StrigAway™.

Crop rotation and fertilizer application were ranked highly while intercropping was among the best mechanism with the farmers. According to the farmers, crop rotation and intercropping provided additional benefits. They reported that other than having extra food crop in the field, the methods appear to be creating crop sequences with varying patterns of resource competition, allelopathic interference and soil disturbance, thus providing unstable environment that prevents proliferation of particular weed species. In addition, the resources that become available through failure of one crop species can be used by the surviving crop. This view is probably related to Ransom (2000) and Oswald and Ransom

(2001), who showed crop rotation as a farming system that can reduce *Striga* infestation and fits the small scale subsistence farmers with their limited resources. However, the average Malawian farmer has a land holding of about 0.9 ha. Practicing crop rotation as a farming system is not viable considering the small land ratio. Several farmers may be forced into nomadic life of searching for hired labor to feed their families because the land may not produce their food requirement.

The use of herbicide coated seeds such as imazapyr-resistant maize (IR maize) which has been perceived by researchers (De Groote *et al.*, 2008) as the best option to contain the *Striga* menace was ranked poorly (Fig. 5.3). The farmers felt that purchasing of seeds every planting season is not affordable due to poverty. That notwithstanding, Oswald (2005) reported that the IR maize has serious drawback as resistance of herbicide is based on a single recessive gene. Therefore, any crossing of this maize will result to plants that are no longer resistance.

Non-adoption of Striga control mechanisms

Farmers in the study sites had varied reasons on non-adoption of control mechanisms. They expressed fears of investing in the *Striga* prone areas as the losses incurred were huge. The result revealed that 30.8% of the respondents perceived the technologies as too risky to adopt and have no guarantee of direct payoff in crop yield increase, while 20.8% of the respondents pointed out that they lacked cash to purchase inputs (Fig. 5.4). More than 15.1% of respondents in Mpingu EPA indicated that improved crop varieties were better in *Striga* control while 20.6% in Mponela EPA were still gathering more information on the technologies. The respondents openly disclosed that they feared some of the technologies as they did not have enough information on them.

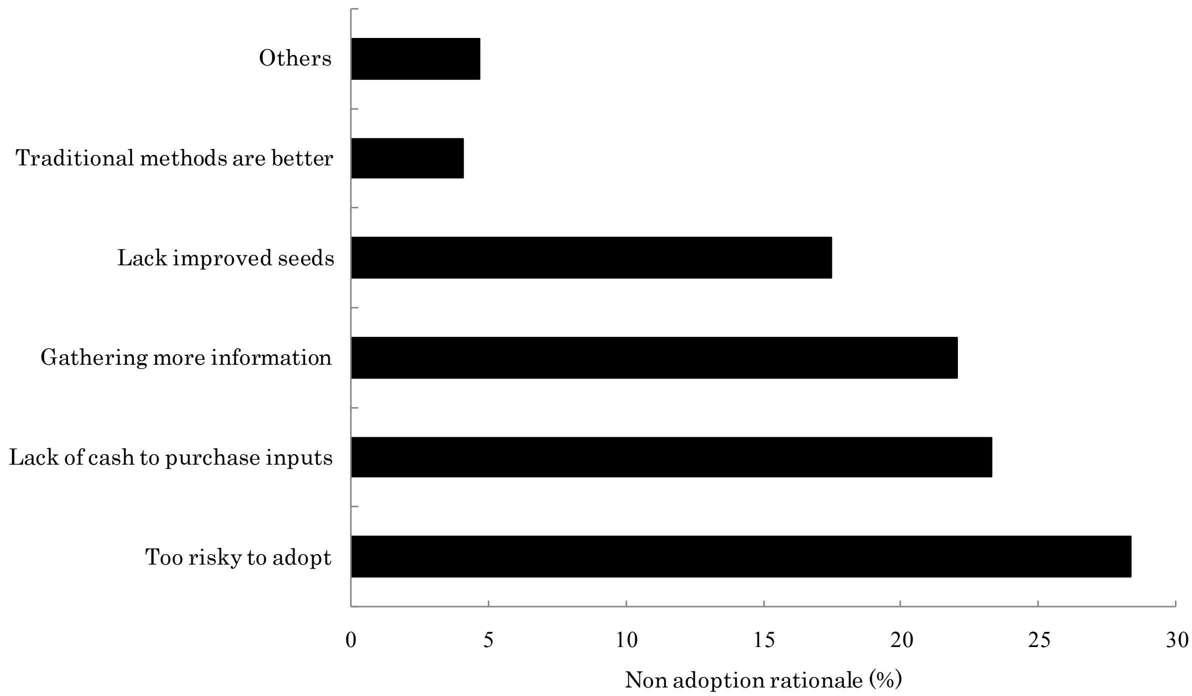

Fig. 5.4 Farmers' reasons for non adoption of the control mechanisms in Mpingu and Mponela EPA .

From these results, it was evident that most farmers (48%) do not know on how to handle witchweeds despite the availability of the recommended options. Some of the options are beyond the farmers reach in terms of their resources. This result corroborate the views of Oswald (2005) in a survey of 198 randomly selected farming households in western Kenya, where 11% of the farmers knew that *Striga* propagate by seed while 51% did not how it propagates. A similar study conducted in Ghana showed that 36% of farmers knew *Striga* produce seed and 56% thought it produced stolons (Ransom, 2000). These results are indications that farmers need knowledge and training. Furthermore, Hearne (2009) reported that non adoption of *Striga* control options may be as result of reliability of technologies, poor access and cost of technologies, limited practicality of the methods, and poor information.

Conclusion

Significant investment in research has been directed towards the study of *Striga* in the last 30 years, resulting to increased understanding of the witchweed life cycle and biology as well as development of control options. Lack of sufficient knowledge on *Striga* has been a setback to farmers in adoption of control mechanisms in most developing countries. It is necessary to establish whether research findings on *Striga* control options are imbedded in books and journals which make it difficult for farmers to access them. Participatory approach in *Striga* research involving farmers, scientists and extension personnel at all stages will promote knowledge sharing and acquisition. This approach may accelerate the process in which farmers participate in testing the options and subsequently adaptation.

Response of NERICA Cultivars to Purple Witchweed (*Striga hermonthica*) Parasitism

Abstract

Striga hermonthica (Del.) Benth. (hereafter referred to as Striga), an obligate root hemiparasite, poses a serious threat to cereal production in sub-Saharan Africa. Field experiments were conducted in two years at Alupe farm, western Kenya, to investigate the effect of Striga on growth and yield parameters of New Rice for Africa (NERICA) cultivars. A randomized complete block design replicated three times and rice cultivars NERICA 1, NERICA 4, NERICA 10, NERICA 11 and Dourado precoce, a local landrace were used. Striga significantly reduced grain yield and the yield components. Reduction in grain yield and its components were more severe under moisture stress period in 2008. Grain yield loss ranged between 33-90%. NERICA 1 gave the highest yield in the two seasons both in Striga infected and control plants. This was followed by NERICA 10, which was also the most economically viable when infected with Striga. Result showed that both NERICA 1 and NERICA 10 are resistant to *S. hermonthica* while NERICA 4 is highly susceptible.

Key words: *Striga hermonthica*, resistance, NERICA, yield, Kenya

Introduction

Striga weed, a root parasitic flowering plant, is common in sub-Saharan Africa (SSA) causing severe constraints to crop production. It survives by diverting essential nutrients which are otherwise taken up by cereal crops such as sorghum [*Sorghum bicolor* (L.) Moench], pearl millet [*Pennisetum glaucum* (L.) R. Br.], finger millet [*Eleusine coracana*

(L.) Gaertn], maize [*Zea mays* L.] and upland rice [both *Oryza glaberrima* (Steud.) and *O. sativa* L.] (Rodenburg *et al*., 2006; Atera *et al*., 2011). These cereals are of utmost significance to African farmers for their home consumption. Underground the weed siphons water and nutrients for its growth while above the ground, the crop withers and grain yield is reduced (Khan *et al*., 2007). However, most farmers are not aware of the threat *Striga* poses to their land quality and food security as the weed continues to increase its soil seed bank and spreading to new areas.

It has been estimated that the parasite infects some 21.9 million ha (40% of the cereal-producing areas) (Gressel *et al*., 2004) of SSA where farmers lose about 20–80% of their yield estimated at US$7 billion annually, and affecting livelihood of approximately 300 million people (Scholes & Press, 2008). In Kenya, Striga infects approximately 210,000 ha [of which Western Kenya accounts for 80%] (AATF, 2006) causing annual crop losses of US$ 40.8 million (Gethi *et al*., 2005). The most affected are resource poor subsistence farmers with infertile fields (Gurney *et al*., 2006).

According to Oswald (2005), Striga has been on existence in farmers' fields in Western Kenya since 1936. Poverty level of small scale farmers has enhanced the spread of the parasite through sharing of seeds collected from the previous crop harvest. In addition, Striga pandemic has increased in size and severity as a result of mono cropping and seed dormancy (of more than 10 years in the soil). The parasite produces several seeds which are incorporated into the soil during tillage. Through the tools used by man for land preparation and weeding, seeds are spread to new areas over time. They are also spread by animals moving from one field to another in search of pasture. This has made it easier for the noxious weed to spread to new areas affecting crop yield.

Research on Striga control has been carried for a long time and a wide range of technologies have been developed (Atera *et al.*, 2011). Despite efforts made to control the Striga problem, it has persisted and increased in magnitude. Although research on the parasitic weed has a long history, adoption of the control options is limited (Emechebe *et al.*, 2004). This is one of the greatest tests to be addressed by researchers as to why farmers are not embracing the control mechanisms.

The development and integration of more tolerant and resistant crops to Striga into upland production systems (UPS) may be a viable option for attaining optimum yields. Whereas some studies report resistance, attachment and effect of Striga weed on upland rice growth and yield (Swarbrick *et al.*, 2009; Gurney *et al.*, 2006; Harahap *et al.*, 1993; Johnson *et al.*, 1997), only a limited number of cultivars have been evaluated. For instance, the interspecific hybrids known as NERICA have not been evaluated for Striga resistance/tolerance since introduction in the farmers' fields. NERICA rice is slowly becoming an alternative cereal crop in the moist savanna areas of sub-Saharan Africa where Striga problem has been most severe. In Kenya, four NERICA cultivars (NERICA 1, NERICA 4, NERICA 10 and NERICA 11) were released to farmers. Adoption of NERICA by smallholder farmers may depend in part if they can withstand the Striga scourge as well as maintain high yield potential. Therefore, the NERICAs should be evaluated in different Striga infected agro-ecosystems to determine any level of exhibition of resistance. Some studies have shown high level of variation existing within and between the Striga populations from Kenya, Mali and Nigeria (Gethi *et al.*, 2005). This study assessed the performance of NERICA rice cultivars infected with *S. hermonthica* from Alupe, Kenya and the cultivars displayed different levels of tolerance.

Materials and methods

Site description

Field studies were conducted in the long rains of March to August and short rains of September to January in 2008 and 2009 at Alupe farm of Lake Basin Development Authority, near Busia town (0°29´N, 34°07´E) in western Kenya, where *Striga hermonthica* is a serious limitation to cereal crop production. The experimental site receives approximately 1148mm of rainfall per annum, has mean annual temperature of 29°C and is located at an altitude of 1189 meters above sea level. The soil characteristics at the beginning of the experiment were 4.22 mg g^{-1} of soil organic content, 4.29 mg kg^{-1} Olsen P, 0.099% of N, 0.007% of P and pH of 5.9. The proportions of sand, silt and clay in the soil were 68%, 19% and 13% respectively. Prior to the trials, the site was under cultivation of local rice varieties.

Experimental design

A completely randomized block design was used with three replications in two sites of the farm. Striga infected cultivars were planted on one block which had been under continuous cultivation of cereals while controls plants were planted in another block, a recently opened field for cultivation. Five cultivars namely NERICA 1, NERICA 4, NERICA 10, NERICA 11 and Dourado precoce, a local landrace were sub-plots. The characteristics of the cultivars are as shown in Table 6.1. Plots were 2.5 m x 5 m in size. Natural conditions were relied upon at each site. Five seeds were sown by hill at spacing of 30 x 12.5cm and later thinned to three. To allow Striga to thrive, minimum fertilizer was applied at rate of 60 kg N ha^{-1} (30 kg ha^{-1} at basal and the rest after the first weeding). The infected fields were weeded once with a hoe, after which the weeds were pulled by hand other than Striga to avoid damaging young Striga seedlings. Control fields were weeded three times. The rice seeds were treated with murtano fungicide/insecticide before planting according to label instructions.

Table 6.1 Characteristics of upland rice cultivars used for the trials in 2008 and 2009

Cultivars	Stature	Maturity days
DOURADO PRECOCE	Tall	95-110
NERICA 1	Semi dwarf	95-100
NERICA 4	Tall	95-100
NERICA 10	Tall	90-100
NERICA 11	Semi dwarf	75-85

Striga infections

For purposes of Striga infestation uniformity, the plots were artificially inoculated with Striga seeds. The seeds were obtained from Kenya Agricultural Research Institute, Alupe, harvested from rice field in 2004. Tetrazolium red was used to test seed viability as described by Berner *et al.* (1997). The seeds were mixed with sand sieved through a screen of pore diameter of 250µm at a ratio of 1:39 by weight to obtain germination of about 3000 seeds per station. The Striga seeds in the mixture were uniformly sprinkled in rows trenches which were half buried with soil. Rice seeds were planted in hills along the rows as recommended in Kenya.

Economic yield loss

Crop yield loss can be defined as the difference between potential yield and actual yield. In this study the actual yield was obtained from the Striga infected area while the potential yield was from uninfected Striga area (control plants). To estimate the economic value of Striga infection losses, the actual loss was measured. Striga economic evaluation (SEE) was determined when crop loss due to the weed was multiplied by the area and the price.

Crop yield loss in the study was presented as the potential yield denoted as Y_p and actual yield as Y_s. The crop loss difference was expressed as potential yield proportion represented by Y_r, which can easily be used to estimate loss in yield in *Striga* infected areas if actual yield is known.

$$Y_r = \frac{Y_p - Y_s}{Y_p}$$

The ratio "s" was determined from the representative sample in the field. If the ratio "s" is known, then losses due Striga can be derived using the following formula.

$$Y_p - Y_s = Y_s \frac{s}{1 - s}$$

Similarly, crop loss for a region or country can be determined by using the same formula when potential yield is known. However, Striga in the field is not uniformly distributed and therefore, there are prone to be error margins in the estimates. It is possible to obtain a function that can estimate crop loss within the error margins. In our study, we estimated the economic losses due to Striga using the formula above.

Data collection and statistical analysis

Striga emergence counts were done at 8 weeks after seeding. Due to high variability of emerged Striga plants both within and among the treatments, data was transformed using natural logarithms, log (x + 1) to stabilize the variance for the analysis (Johnson *et al.*, 1997). Rice plant height and tiller number were estimated from 10 plants per plot at every 14 DASE. The grains were harvested when 80% turned golden brown. Yield was estimated from 20 hills in each plot and corrected to 14% moisture content. All data were subjected to analysis of variance (ANOVA). Whenever significance differences were detected ($\alpha = 0.05$), the means were compared using the Tukey's HSD test at 5% levels of significance.

Results

Striga growth and dry matter accumulation

There were significant effects of Striga infections on growth and yield parameters of cultivars. The first Striga plant emerged 42 days after rice seed emergence. The minimum time taken by Striga to complete the life cycle from emergence was 56 days. Striga plants emerged even after harvesting of the plants. More Striga plants were sighted on plots that were planted with Dourado Precoce and NERICA 4 compared to NERICA 1 and NERICA 10.

Dry matter (DM) accumulation at 30, 60 and 90 days after sowing (DAS) of infected rice cultivars is as shown in Fig. 6.1. NERICA 10 had higher DM accumulation at 30 and 60 DAS and NERICA 1 at 90 DAS. Our results showed effects on reduction in plant height (Table 6.3) and biomass of the cultivars. Striga influenced dry matter between different parts (allometry) thereby modifying the architecture of infected plants. The parasite significantly reduced the growth of Dourado precoce and NERICA 11 after 60 DAS. Infected plants produced 42% of the total biomass of uninfected plants.

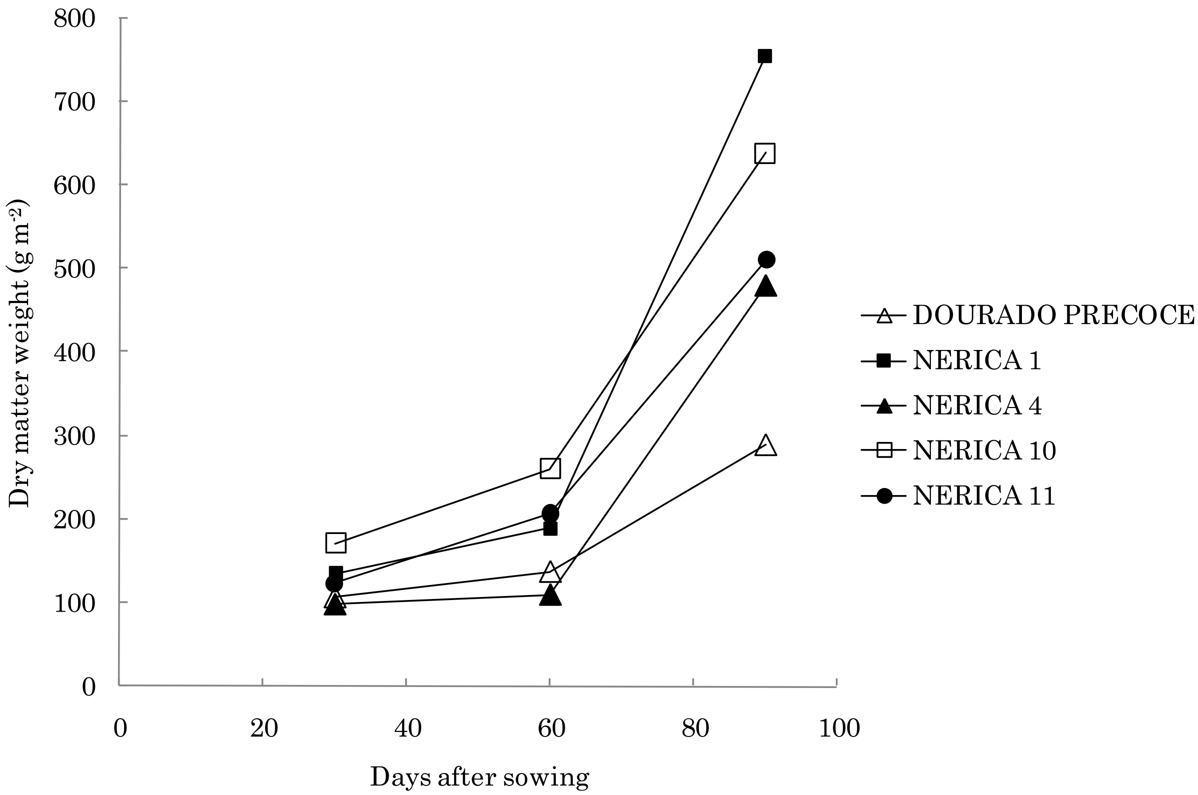

Fig. 6.1 Trends of shoot dry matter weight of infected plants in 2009. Each data point is the mean of three replications of each cultivar.

Yield components of Striga infected cultivars

The main effects of the year, interaction of Striga and cultivar significantly influenced panicle production. Average panicles were 213 m^{-2} in 2008 and the corresponding value in 2009 was 202 m^{-2} of Striga infected cultivars (Table 6.4) compared to 280 m^{-2} of the control plants (Table 6.2). Over the years, NERICA 1 produced more number of panicles (262 m^{-2}) and the least were recorded for Dourado precoce among the infected plants. Results showed that the simple effects of the treatment factors were significant ($P \leq 0.02$) in 2009. NERICA 10 was ranked lowest in grain size as determined by 1000-grain weight (24.8g 1000^{-1}) (Table 6.4). Grain size is ranked highest (29.5–31.1 g) in Dourado both in infected and control plants. There were no significant differences in the grain filling ratio among the cultivars. However, the ratio was lower in NERICA 4 compared to other cultivars.

Table 6.2 Yield parameters of control rice plants in 2008 and 2009

Cultivar	Panicles m^{-2}	Spikelets $panicle^{-1}$	Grain filling (%)	1000 grain weight (g)	Panicle length (cm)
DOURADO PRECOCE	274.3 ± 18.3	41.7 ± 6.7	83.8 ± 0.9	31.1 ± 1.5	21.4 ± 1.4
NERICA 1	287.9 ± 33.6	60.3 ± 4.5	84.7 ± 2.6	29.8 ± 0.5	20.3 ± 1.1
NERICA 4	282.4 ± 32.5	58.7 ± 6.1	84.5 ± 1.9	28.7 ± 0.4	20.9 ± 0.7
NERICA 10	273.4 ± 27.4	51.4 ± 2.5	88.3 ± 1.2	25.9 ± 0.8	20.2 ± 0.9
NERICA 11	281.6 ± 26.9	50.7 ± 5.9	82.5 ± 0.3	30.3 ± 0.8	19.3 ± 0.3

All values are mean ± SE for two years.

Table 6.3 Relative plant height and yield loss (%) of rice cultivars due to Striga infection

Cultivars	LY†	LPH§
DOURADO PRECOCE	86.2	52.5
NERICA 1	46.3	12.3
NERICA 4	90.2	48.8
NERICA 10	33.4	16.4
NERICA 11	72.8	21.7

†- Loss in yield, §- Loss in plant height. Values used represent average of two years.

Grain yield and economic analysis

In Striga infected cultivars, there was a significant difference in grain yield. Seasonal difference in paddy yield was noted in response to infections among the cultivars. The mean paddy yield was highest in the infected plots in 2009 compared to 2008 by 24.3%. This was attributed possibly due to the amount of rainfall received in the two seasons. The average yield of NERICA 1 for the two seasons was 2243.9 kg ha^{-1} while NERICA 4 was 373.4 kg ha^{-1} in the infected fields (Fig. 6.2). Relative grain yield loss as result of infections ranged between 33-90% (Table 6.3). The losses were highest in NERICA 4 and Dourado precoce. Grain yield was highly correlated (R=0.763) with dry matter accumulation in infected plants (Fig. 6.3).

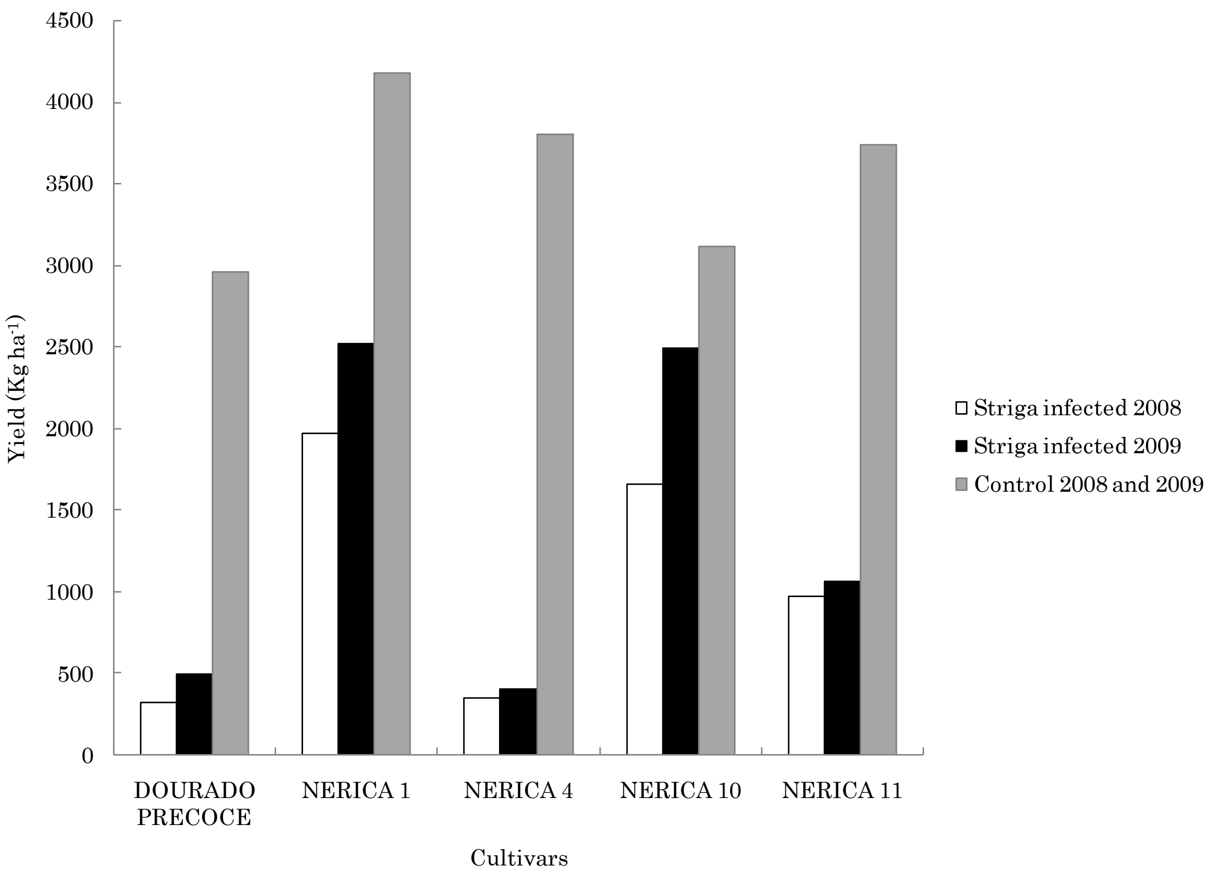

Fig. 6.2 Grain yield of *Striga* infected and control rice plants at LBDA-Alupe in 2008 and 2009.

Economic yield loss due to infections was highest in NERICA 4 in the two years (Fig. 6.4). NERICA 10 (US$ 351.7 ha^{-1}) was the most economically profitable with the least yield loss followed by NERICA 1 (US$ 652.8 ha^{-1}). Dourado precoce, the local landrace known to be susceptible to Striga, performed better than NERICA 4 and NERICA 11. It is important to note that the market prices for the different cultivars used for estimation in Fig. 6.4 were the same, thus, differences in losses were largely due to variations in yield levels of the cultivars.

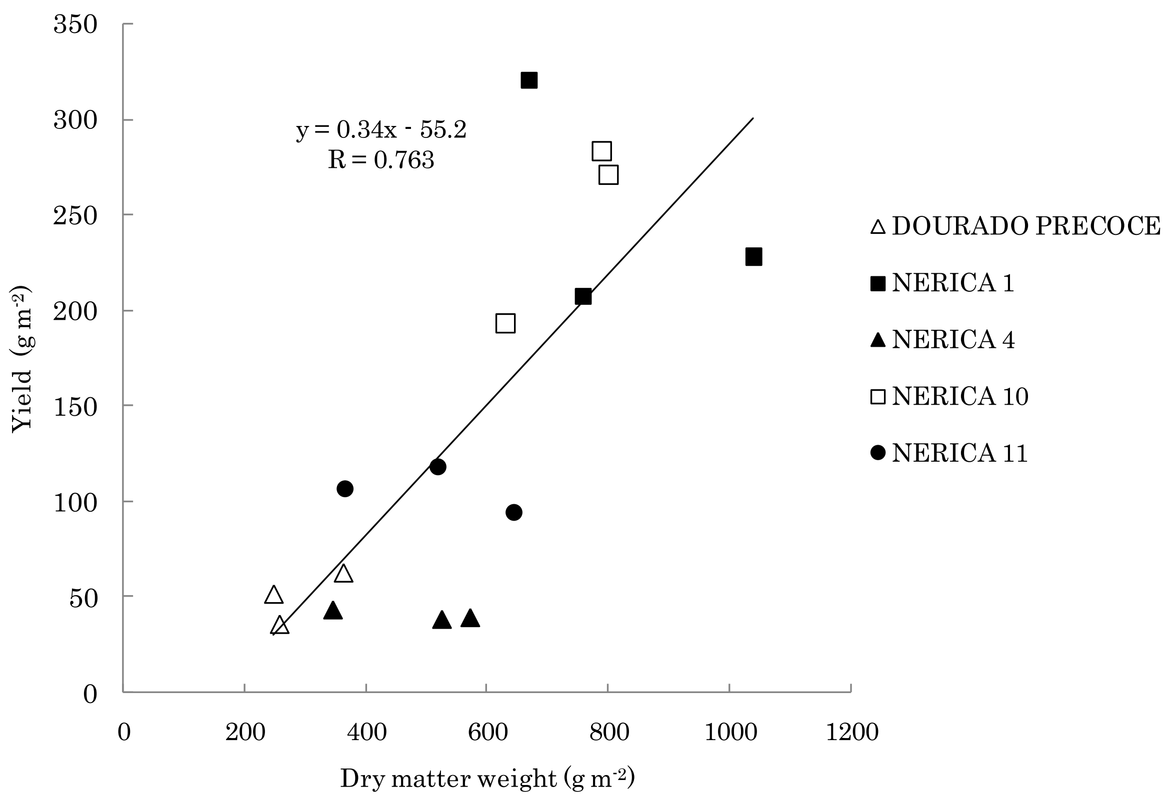

Fig. 6.3 Relationship of grain yield with biomass accumulation at maturity of infected rice plants in 2009. Each data point is the mean of three replications for each cultivar.

Table 6.4 Yield parameters in 2008 and 2009 of Striga infected rice cultivars

Cultivar	Panicle m^{-2}	Spikelets $panicle^{-1}$	Grain filling (%)	1000 grain weight (g)	Panicle length (cm)
2008					
DOURADO PRECOCE	160.5	13.9	59.2	30.3	17.7
NERICA 1	259.6	34.0	61.1	27.6	19.0
NERICA 4	197.8	16.8	58.7	26.6	19.3
NERICA 10	234.9	35.8	62.7	23.8	17.1
NERICA 11	210.0	26.5	62.6	26.9	17.4
Mean†	212.6a	25.4a	60.9a	27.0a	18.1a
LSD (0.05)‡	36.9	4.5	9.6	1.2	1.1
P - Value	0.041	0.004	0.290	0.003	0.029
2009					
DOURADO PRECOCE	148.2	21.5	57.1	29.5	17.1
NERICA 1	264.7	46.2	69.9	28.3	18.7
NERICA 4	161.4	17.7	50.0	25.3	18.5
NERICA 10	230.3	41.2	61.6	25.9	19.2
NERICA 11	205.8	27.3	53.7	27.5	19.4
Mean†	202.1a	30.8b	58.4a	27.3a	18.6a
LSD (0.05)‡	27.3	7.1	11.0	2.2	1.2
P - Value	0.002	0.021	0.214	0.033	0.008

† Means of cropping year with the same letters are not significantly different according to LSD at P=0.005. ‡ LSD values are for comparison of cultivars for each parameter in each year.

Discussion

Mono-cropping has led to continuous mining of nitrogen from the soil resulting into poor soil which favors Striga infestation. This has played role in the increase of Striga seed densities calling for an innovative and more proactive measures aimed at reducing seed banks. African smallholder farmers depend on cereals as their main source of food which is readily infected by Striga. Dugje *et al.* (2006) studied the effect of Striga infections on maize, sorghum, rice and pearl millet in the savannas of Northern Nigeria and reported that losses resulting from Striga ranged from slight to total crop failure in heavily infested areas. These results corroborate with our findings which showed 33-90% of yield loss as a result of infections on the NERICAs. Research conducted in western Kenya to evaluate the tolerance and resistance of rice cultivars also revealed that severe Striga infestation led to complete crop failure (Kouko *et al.*, 1992).

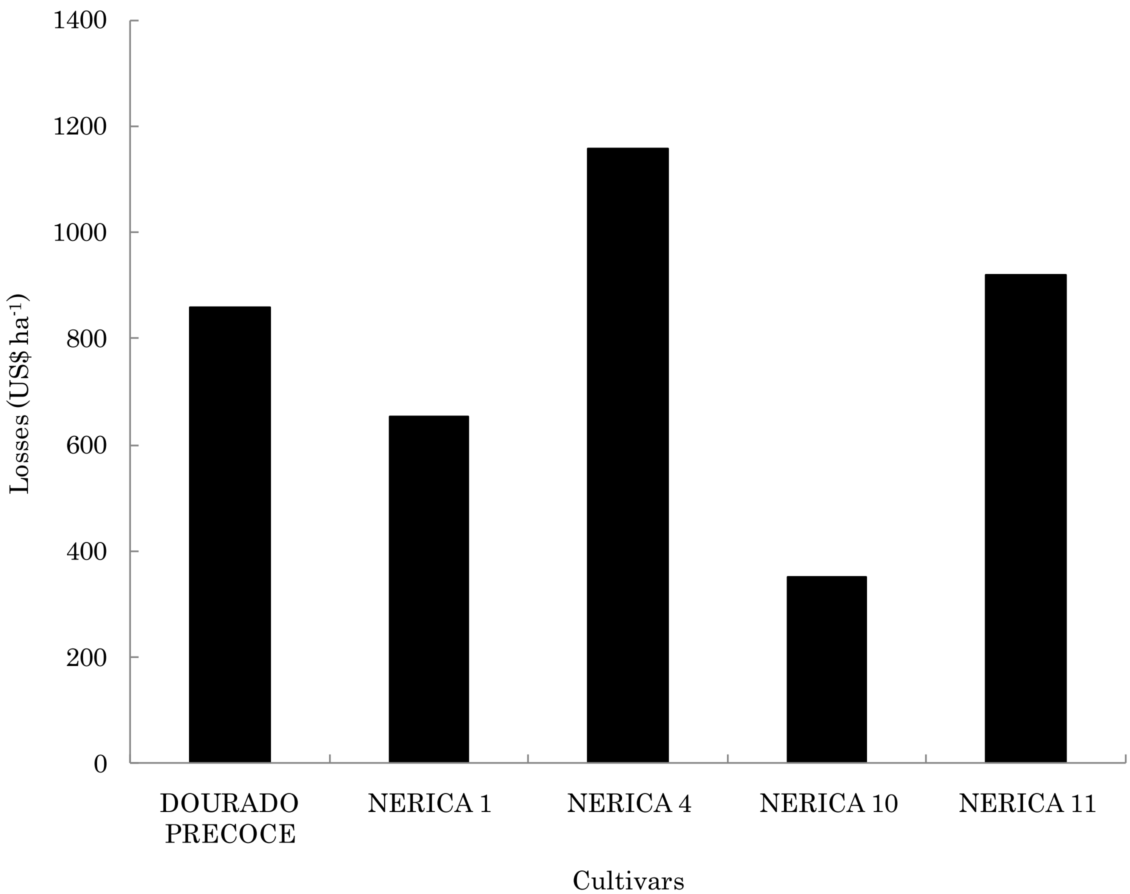

Fig. 6.4 Economic losses due to Striga at LBDA –Alupe. Values used represent mean of 2 years. Kenyan Shilling was converted to US dollars by using exchange rate of Ksh .81 to US$ 1.00

Striga infections affect dry matter weight. The Striga reaction on the biomass of the NERICAs expressed as percentage of susceptible Dourado precoce ranged between 40-66%. Dry matter of infected plots was lower compared to uninfected. Similar results have been reported in infected sorghum's biomass (CSH-1 and Ochuti) being lower that of uninfected plants (Frost *et al.*, 1997). In addition, Aflakpui *et al.* (2002) showed that shoot biomass of infected maize before any Striga had emerged above ground (at four-leaf stage) was about 93% that of uninfected maize but by the 18-leaf stage it was only 37% that of uninfected maize. NERICAs infected with *Striga* exhibited changes in growth and allometry when compared with uninfected plants. These included severe stunting of the host lower leaves and stem biomass. The changes in plant hormonal imbalances may be responsible for the differences in allometry observed (Taylor *et al.*, 1996). The cultivars supported different levels of Striga densities and tolerance. This variability not only depended on their genetic makeup but also to some extent to the prevailing climatic conditions.

NERICA 1 and NERICA 10 exhibited resistance to *Striga hermonthica* infections. The cultivars supported few number of Striga plants in the field. A pot experiment conducted by Kaewchumnong and Price (2008) showed that CG14 had no Striga emergence and is considered highly resistant to *Striga hermonthica*. Furthermore, Johnson *et al.* (1997) reported that *O. glaberrima* was less affected by Striga as compared to susceptible *O. sativa* cultivars. NERICA 1 and NERICA 10 being the progenies of CG14 might have inherited resistant genes. However, it has been shown that heritability of traits for Striga infected plants (61-70%) is higher compared to control (37-45%) (Kaewchumnong & Price, 2008). Gurney *et al.* (2006) reported robust resistance in Nipponbare rice cultivar to *S. hermonthica* in post-attachment experiment. In this cultivar, the parasite failed to form xylem to xylem connection to the host plant root. Studies have shown Nipponbare having low numbers of *Striga* and emerging late (if at all) thus concluding that the variety is resistant (Swarbrick *et al.*, 2009). However, it was significantly affected by *Striga* as revealed in several traits at harvest (stem dry weight, flower + grain dry weight, and plant dry weight) (Kaewchumnong & Price, 2008). These are in agreement with our results as Striga reduced harvest traits of infected NERICAs (Table 6.4). The results clearly indicated that *Striga* can impose effects on the hosts even in its early and underground stage of development, which might be attributed to the production of toxins by the parasite affecting growth and physiology of the hosts (Press *et al.*, 1999).

NERICA rice cultivars evaluated in the present study apparently shared the same parents but they supported different levels of tolerance. Further studies will be carried to investigate the rationale of their variability through genetic mapping and identify genomic regions for Striga tolerance especially in NERICA 1 and NERICA 10. Similar studies are desirable in different environments to assess Striga reaction with the NERICAs in an array of soil types under different Striga densities and moistures levels.

Identification of QTL for *Striga hermonthica* resistance using backcross population derived from a cross between *Oryza sativa* (cv. Nipponbare) and *O. rufipogon*

Abstract

The obligate root hemiparasite, *Striga hermonthica* (Del.) Benth., native to sub-Saharan Africa causes serious economic constraint to cereal production. Studies on *Striga* spp. interactions with rice are desirable as it is a model monocot with high density molecular linkage maps. In this study, quantitative trait locus (QTL) analysis for *S. hermonthica* resistance was carried out using 141 backcross recombinant inbreed lines (BRILs) derived from a cross between *Oryza sativa* (cv. Nipponbare) and *O. rufipogon* W630. The population was grown in the field at Lake Basin Development Authority, Alupe farm in 2013 and infected with *S. hermonthica* from Alupe, Kenya. Putative QTL for *S. hermonthica* resistance was assumed using single-point analysis (qGene program) at $p<0.01$ significance level. As a result, a single QTL explaining 6.6% of total phenotypic variance was detected near RM242 marker locus on chromosome 9, and the Nipponbare allele was found to have *S. hermonthica* resistance. The QTL chromosomal region can also be further studied to promote better understanding on the nature of resistance.

Key words: quantitative trait loci (QTLs), rice, *Striga hermonthica*, resistance

Introduction

Rice is the most economically important food crop in sub-Saharan Africa (SSA). It is consumed widely in all countries and sub-regions of the continent and is mostly cultivated by resource-poor farmers under diverse ecosystems (Balasubramanian *et al*., 2007). Both cultivated rice species, *Oryza sativa* (L.) and *O. glaberrima* (Steud.), are grown in Africa. For the last 30 years, the harvested area has risen by 105% while production is by 170% (Rodenburg and Demont, 2009). However, the average rice production per unit is still low which is as a result of several production constraints, of which weed competition is regarded as the most severe. Weeds such as *Striga* spp. are the most problematic in upland conditions of SSA (Jamil *et al*., 2011). There are four *Striga* spp. considered to be serious pests to rice: *Striga hermonthica* (Del.) Benth., *S. asiatica* (L.) Kuntze, *S. aspera* (Willd.) Benth. and *S. forbesii* Benth. (Rodenburg *et al*., 2010; Atera *et al*., 2011). Among these species *S. hermonthica* is the most destructive, leading to severe yield losses of over 50% thereby affecting livelihoods of millions of farmers (Franke *et al*., 2006).

Cereal cultivars that offer resistance can post a major impact on limiting *Striga* infections and would dramatically improve yield (Rodenburg and Bastiaans, 2011). This would boost the morale of farmers in SSA as they view resistance as a desirable characteristic in cultivars. Several reports of resistance to *S. hermonthica* have been documented in rice (Harahap *et al*., 1993; Gurney *et al*., 2006; Jamil *et al*., 2011), sorghum [*Sorghum bicolor* (L.) Moench] (Vogler *et al*., 1996; Ezeaku & Gupta, 2004, Noubissie *et al*., 2012), pearl millet [*Pennisetum glaucum* (L.) R. Br.] (Kountche *et al*., 2013) and maize [*Zea mays* L.] (Amusan *et al*., 2008, Karaya *et al*., 2012). However, this information has not found its way to the hands of farmers as it is imbedded in books and journals which make it difficult for farmers to access.

In many studies, African rice species appears to offer better sources of resistance to *Striga* parasitism than Asian rice species (Johnson *et al*., 2000; Kaewchumnong & Price, 2008). Harahap *et al.* (1993) and Johnson *et al.* (2000) reported resistance to *S. hermonthica* observed in African rice cultivars in CG14, IG10, Makassa and ACC102196, and in Asian rice cultivars IR49255-B-B-5-2 and IR47255-B-B-5-4. The inter-specific New Rice for Africa (NERICA) cultivars offers a potentially interesting gene pool of resistant rice cultivars. NERICA 1 and NERICA 10 are said to be resistant to *S. hermonthica* infections (Cissoko *et al.*, 2011; Atera *et al.*, 2012a).

A resistant phenotype is characterized by lack of ability of the parasite to penetrate through the endodermis and therefore the parasite cannot make xylem-xylem connections to establish a vascular for continuity after attachment to the host. This has been demonstrated by Gurney *et al.* (2006) with Nipponbare, *O. sativa* Japonica lowland rice cultivar containing sources of resistance of post-attachment to *S. hermonthica*. Advanced backcross inbred lines (BILs) from a cross of Nipponbare and Kasalath (*O. sativa*, indica cultivar) were screened for resistance to *S. hermonthica* from Kibos, Kenya. Seven QTLs were detected on chromosomes 1, 4, 5, 6, 7, 8 and 12. Interestingly, Nipponbare conferred greater resistance allele in six out of the seven QTLs. The two largest QTLs (an indication where phenotypic variance in a population is greatest) were on chromosome 4 associated with Kasalath allele and chromosome 12 of Nipponbare.

In the study of Swarbrick *et al* (2008) of Koshihikari-Kasalath BILs, three *Striga* resistance QTLs were detected, two of which were from Kasalath alleles with the largest located on chromosome 4. In addition, Kaewchumnong and Price (2008) identified two other QTLs on chromosomes 1 and 8 from the population derived from a cross between cultivars Bala and Azucena which coincided with the QTLs found by Gurney *et al.* (2006) for post-attachment resistance to *S. hermonthica* in Nipponbare and Kasalath population. The impact of *Striga* spp. infestation in farmer's cereal crop fields must be reduced at all cost. This can be done through rice as it has played a central role in human nutrition and culture for the past 10,000 years. In addition, rice has a small genome (*c.* 389Mb) which can easily be used for QTL mapping (International Rice Genome Sequencing Project, 2005). In this study, we detected *S. hermonthica* resistance QTL in rice using BRILs derived from a cross between *O. sativa* cv. Nipponbare and *O. rufipogon* W630.

Materials and Methods

Site description

The field study was conducted in the long rains of March to August 2013 at Alupe farm of Lake Basin Development Authority (LBDA), near Busia town (0°29´N, 34°07´E) in western Kenya, where *S. hermonthica* is a serious limitation to cereal crop production. The site is located at 1189m above sea level and normally receiving a mean annual rain and temperature of 1148mm and 29°C (even though 2013 was drier than the normal year), respectively. Prior to the trial, the site was under cultivation of maize.

Plant materials

In this study, *O. sativa* Japonica cultivar Nipponbare and a wild annual accession *O. rufipogon* W630 from Myanmar were used. *O. rufipogon* W630 is quite susceptible to *S. hermonthica* (although not as susceptible as other cultivars such as Dourado precoce) collected from Alupe, Kenya in a pre-test pot experiment conducted at Maseno University (Fig. 7.1). Nipponbare had previously been classified previously as a resistant cultivar to *S. hermonthica* from Kibos, Kenya (Gurney *et al.*, 2006). The segregating population for QTL analysis consisted of 141 backcross recombinant inbred lines (BRILs) between Nipponbare (a recurrent parent) and *O. rufipogon* W630 (a donor parent) at BC_2F_{10} generation. BRILs were obtained from Kobe University, Japan. The *S. hermonthica* seeds used in this study were collected from maize host in 2011 at Kenya Agricultural Research Institute (KARI) Alupe, Kenya.

A B

Fig. 7.1 *S. hermonthica* infecting rice in a pot experiment at Maseno University, Kenya in 2012: (A) *O. rufipogon* W630; (B) Dourado precoce, a highly susceptible cultivar

Genome composition and phenotypic recording of BRILs

Estimation of wild chromosomal segments in each of the 159 BRILs at BC_2F_8 generation ranged between 0.0 to 23.6% (Thanh *et al*., 2011). The estimation was done using 180 microsatellite loci covering 1,362 cM of the 12 rice chromosomes. The BRILs have about 11.3% of wild genome on average in the genetic background of Nipponbare and between three (3) to thirty nine (39) lines of the BRILs were identified to have wild homozygous alleles at these marker loci.

In this study, the 141 BRILs were each inoculated with 0.5g of *S. hermonthica* seed per row as described by Berner *et al.* (1997). This weight of *Striga* seeds contained about 3000 germinable seeds per hill. Before inoculation, the *Striga* seeds were thoroughly mixed with fine soil which was sieved through a screen of pore diameter of 250μm to serve as carry since *Striga* seeds are very small. Each hill was 30cm by 30cm of which soil of about 10cm diameter and depth of 5cm was dug, and sprinkled with a scoop full of *Striga*-soil mixture. Three rice seeds of each BRIL were planted per hill in ten hills (already artificially inoculated with *Striga*) per row. After germination, seedlings were thinned to one per hill. Fertilizer was applied at rate of 60kg N ha^{-1}. The infected field was weeded once with a hoe, after which the weeds were pulled by hand other than *Striga* to avoid damaging young *Striga* seedlings. Field data on the number of *S. hermonthica*, survived BRILs and infected hills per row were recorded.

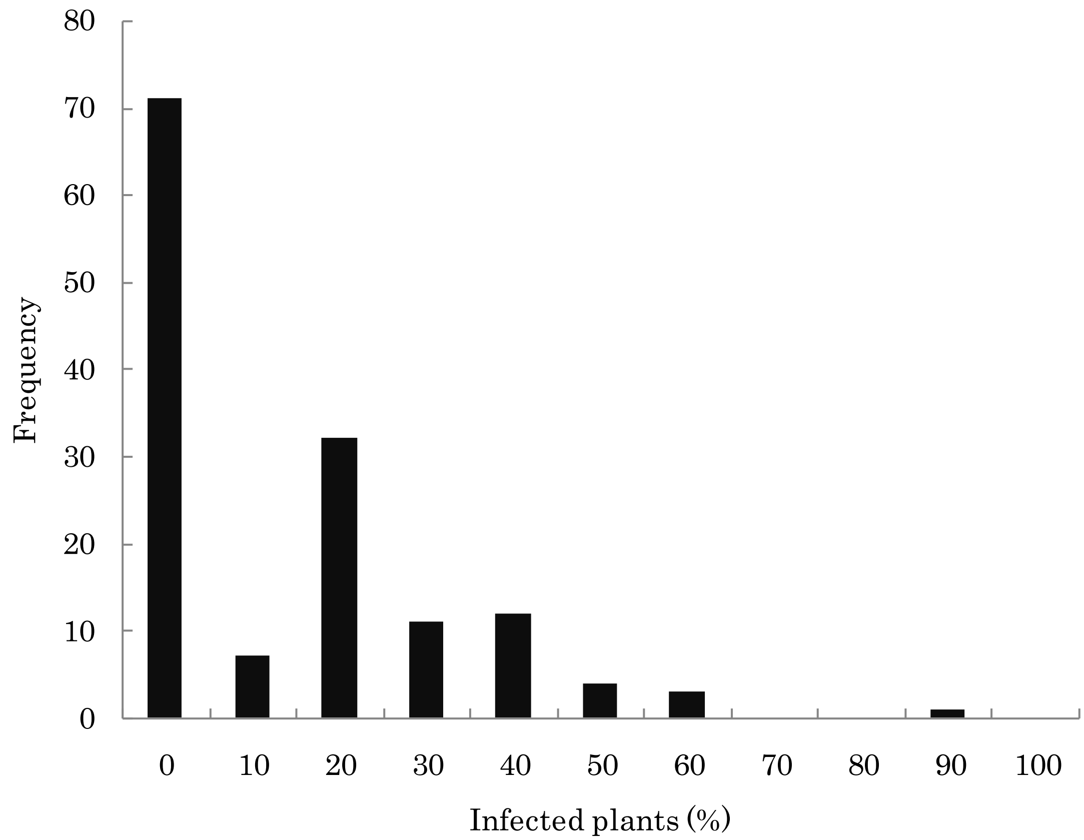

Fig. 7.2 Frequency distribution of infected plants by *S. hermonthica* of the backcross recombinant inbred lines a cross between *O. sativa* Nipponbare and *O. rufipogon* W630. Frequency scores were calculated as the proportion of the lines in which *Striga* failed to attach to the BRILs.

QTL analysis

Based on the infected rates (no. infected plants / total no. plants examined) by *Striga* in the BRILs (giving more than five plants examined), QTL analysis was carried out. Single marker analysis (SMA) was used to estimate QTLs for *Striga hermonthica* resistance by qGene software (Nelson, 1997). The significance threshold for SMA was set at $p<0.01$ level. The proportion of phenotypic variation explained by significant marker was estimated as a coefficient of determination (R^2) for the single locus model.

Results and Discussion

Evaluation of *Strig*a resistance in parents and BRILs

O. sativa Japonica cv. Nipponbare is resistance while wild accession *O. rufipogon* W630 was susceptible to *S. hermonthica* from Alupe, Kenya infections. From the pre-test pot experiment at Maseno University, Nipponbare had no *Striga* plants while *O. rufipogon* had at least two to four *Striga* per pot (Atera and Itoh, communication). In the field at Alupe, Nipponbare was attacked by very few *Striga* plants compared with the other cultivars. This confirmed the classification of Nipponbare as a resistant cultivar as described by several authors (Kaewchumnong and Price, 2008; Swarbrick *et al*., 2008). Unfortunately *O. rufipogon* being an aquatic species, it could not grow in upland conditions as germination was very poor. Field observations showed that 50.4% (71 out of 141) of the BRILs had no *Striga* infections based on the number of *Striga* attached to rice plants above the ground. The frequency distribution of infected plants by *S. hermonthica* is as shown in Fig. 7.2. This result suggested that the resistance for *S. hermonthica* was under polygenic control.

Detection and analysis of QTL

The threshold to declare a QTL was at the significance level of $p < 0.01$ as revealed by the genome scan (Fig. 7.3). The QTL for *S. hermonthica* resistance was detected on chromosome 9 with a P value of 0.0022 and a PV value (percentage of phenotypic variance explained by the QTL) of 6.6% (Table 7.1). At $p<0.05$ significance level, other loci having weak effects were detected on chromosomes 2, 3, 7 and 12 but they may not be considered biologically significant unless they are validated (Fig. 7.3).

Table 7.1 Putative QTL for *S. hermonthica* resistance detected in the back cross recombinant inbred lines derived from a cross between *O. sativa* Nipponbare *and O. rufipogon* W630

Chromosome	Marker	Source	P Value	[a]PV(%)	[b]Additive effect (%)
9	RM242	*O. rufipogon* W630	0.0022	6.6	7.6

[a]Percentage phenotypic variance in the mapping population explained by the QTL, [b]Additive effect on mean resistance (arcsine transformed) of an allelic substitution from *O. rufipogon* W630 to Nipponbare allele. Significance level at $p<0.001$.

The result showed that *O. rufipogon* W630 allele at QTL on chromosome 9 increased the infection rate in the genetic background of Nipponbare. The Nipponbare-derived allele conferred resistance at this QTL as expected. In our QTL detection, the BRILs were subjected to *Striga* infections in its natural condition with several environmental interferences. Previous QTL detections for *S. hermonthica* resistance were post-attachment in cultivated rice and in a controlled environment (Gurney *et al*., 2006; Kaewchumnong and Price, 2008; Swarbrick *et al*., 2008). In field experiments crop varieties interactions between *Striga* and its host determine the reproductive success of the parasite. For incidence, *Striga* seeds only germinate when exposed to moisture, a favorable temperature and germination stimulant is required which is the host plant root exudates. These interactions sometimes provide opportunities to the host to resist the parasite.

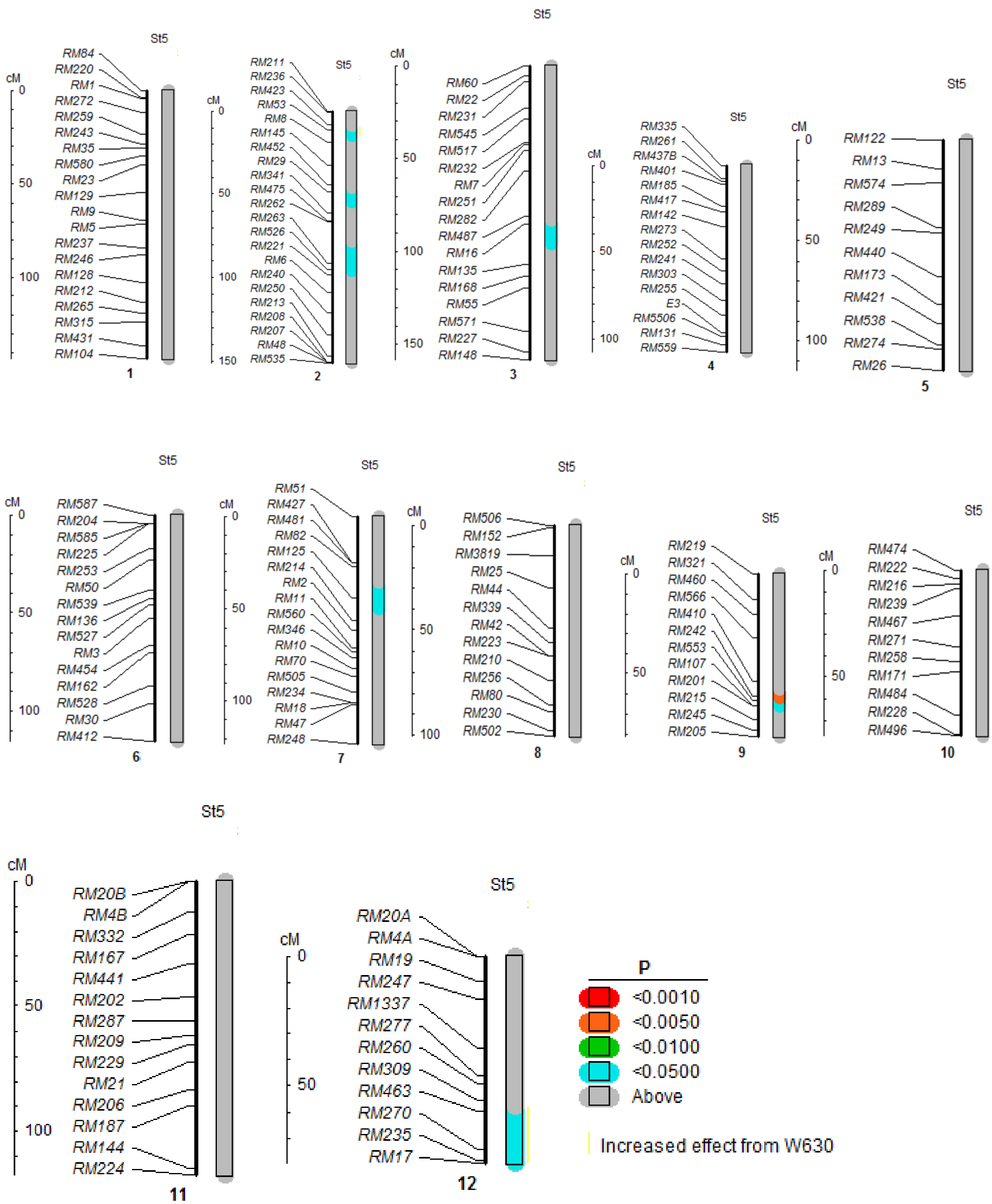

Fig. 7.3 Genome scan of quantitative trait loci (QTL) for *Striga* resistance in *O. sativa* Nipponbare and *O. rufipogon* W630 population. The marker orders and the genomic regions associated with QTL scored at significance level at P < 0.001 and P<0.05.

The detected major QTL can be further studied to see if there is a possibility of identifying candidates for resistance through fine mapping. It has been reported that genes that are expressed in infected plants tissues of two contrasting parents and able to map closely to a QTL are most likely to be appropriate candidates for host-resistance genes (Holloway *et al.*, 2011). According to Swarbrick *et al.* (2008) resistance genes can be identified near the major QTL associated with resistance. If resistance genes can be identified in rice, orthologous genes may be estimated in other cereal crops such as maize and sorghum though the synteny of chromosomal gene order.

CHAPTER 8

GENERAL DISCUSSION

Introduction

This chapter provides a summary of the research findings in the entire study period. The chapter presents an overview of the research objectives in each aspect of the study as well as highlighting the limitations in each thematic area of study, challenges and outlook for future research.

The broad research objectives for the study were:-

- To examine the incidence of *Striga hermonthica*, research achievements and its control in Kenya
- To elucidate farmers' perception on *Striga* spp. control methods and gauge their knowledge on production constraints in Kenya and Malawi
- To assess tolerance level of NERICA cultivars to *S. hermonthica* and determine the economic losses
- To analyze the quantitative trait loci (QTL) for *S. hermonthica* resistance of *O. sativa* Nipponbare and *O. rufipogon* W630 backcross recombinant inbred lines (BRILs) at BC_2F_{10} generation

Conclusions on the study findings

Based on the literature review findings, four broad study objectives were set as presented in the introduction (chapter 1). The objectives were addressed under independent studies. The literature review in chapter 2 describes insights on ecology, infections and, conditions that favor *Striga* existence and its agents of seed distribution in SSA. The chapter also highlights the severity of *Striga* infection on cereals and presents resistant cultivars to *Striga*. It was revealed that *Striga* poses the greatest threat to agriculture in the sub-Saharan Africa. The parasite infects major cereal crops [maize, rice, millet and sorghum] (Ejeta, 2007) which Africans depend on as food. The agents aggravating *Striga* incidence are infertile soils, wind, animals and activities of man (Hearne, 2009).

Striga existence and distribution in Kenya is discussed in chapter 3. There are 9 *Striga* species found in the country. It was noted that more than 70% of farm land in western Kenya is infected with *Striga* causing a loss of about 30-100%. In Africa, *Striga* infestation causes a loss of about 40% of its economy. Research on *Striga* control has been carried for a long time and a wide range of technologies developed including: - use of chemical herbicides, hand pulling, appropriate fertilizer applications, crop rotation, intercropping, resistant crops and bio-control (Ahmed *et al*., 2001; Hearne, 2009). Despite the efforts made to control *Striga*, farmers have not adopted the control options developed (Emechebe *et al*., 2004; Oswald, 2005). The study also showed that there are several factors that play a role in genetic diversity of *Striga* which include: seed bank persistent for many generations, hybridization, geographic distribution, dispersal and locally adapted host races. According to Aigbokhan *et al*., 2000 geographical distribution appears to have a major role in determining the genetic differences of species. Studies conducted at Kobe University on genetic differences of *S. hermonthica* strains from Kenya showed that they have great diversity among and within its population.

In Kenya, the staple crops are maize, sorghum and finger millet are readily infected by *S. hermonthica* (chapter 4). Yield losses reported in the farmers field (maize and sorghum) were more than 70% on heavily infected fields. Among the ten *Striga* control technologies assessed in Kenya, the highly ranked were hand pulling, crop rotation and intercropping. These findings were in agreement with Emechebe *et al.* (2004) that crop rotation, intercropping, hand pulling and use of manure were among the most popular technologies used in West Africa in *Striga* control. On the rationale why farmers have not adopted the control mechanisms, there were all indications that farmers feared to invest as a result of no guarantee on pay off in yield.

Striga asiatica is estimated to be infecting 268,000 ha of farm land in Malawi (AAFT, 2006). Maize is the staple food crop in the country and is heavily infected by *S. asiatica* (chapter 5). According to Park (2009), approximately 80% of the maize crop is infected. The parasite is also infecting a wide spectrum of grasses along the road sides and open fields, pointing at how difficult it is to control the parasite. A new leguminous parasitic weed *Alectra vogelii* infects soybean, cowpea, bambara nuts and groundnut which are the most popular legume crops. Unfortunately, the farmers and extension staff are not aware of the parasite and this needs urgent research on its control. In chapter 5, it was revealed that manure application was perceived to be the most popular by farmers. This was followed by crop rotation, fertilizer application and hand pulling. Despite the development of the control options, *Striga* has increased in size and magnitude in the farmers fields. The farmers have as well not adopted the options which they described as too risky as they cannot trust them.

A newly infected rice experimental field at LBDA Alupe showed that number of *Striga* plants ranging from 3,500 to 420,000 in 2012 and 2013 cropping years (Table 8.1). However, it also known that *S. hermonthica* can produce massive amounts of seed estimated between 58,000 and 200,000 per plant (Parker & Riches, 1993). According to Rodenburg *et al.* (2006) *Striga* seed production normally continues beyond harvest especially to crops such as rice. The magnitude of the additional seed production after harvest depended on seed bank density. Continued *Striga* reproduction beyond harvest contributed significantly (39%) to the final reproduction under low infestation, whereas under high infestation only 8% was produced after harvest.

Table 8.1 Number of *Striga* plants in the rice field at LBDA Alupe 2012 and 2013

Cultivar	*Striga* number ha^{-1}	
	2012	2013
NERICA 1	3,571	-
NERICA 4	75,000	89,286
NERICA 10	17,857	28,571
NERICA 11	53,571	71,429
WAB 56-104	7,144	10,714
Nipponbare	-	10,714
CG14	100,000	117,857
Dourado Precoce	346,429	421,429

CG14 is *Oryza glaberrima* rice , - Data was not collected

NERICA rice is grown in the moist savanna area of sub-Saharan Africa where *Striga* problem has been most severe. The study on the response of NERICA cultivars to *S. hermonthica* infections (chapter 6) showed NERICA 1 and NERICA 10 are resistant in the two years experiment. The first *Striga* emerged 42 days after rice seed emergence in the susceptible rice varieties. The minimum time taken by *Striga* to complete the life cycle from emergence was 56 days. Grain yield losses ranged from 33 to 90%. The order of *Striga* tolerance (resistance to susceptibility) of the cultivars was NERICA 1, NERICA 10, NERICA 11, Dourado precoce and NERICA 4. However, the most economically viable cultivar was NERICA 10 when infected with *Striga*. Our result corroborate that of Cissoko *et al.* (2011), who demonstrated pronounced differences in post-attachment resistance to two parasitic species in NERICA cultivars and their ancestors, with some (NERICA 1 and 10) showing substantial resistance effects. Cissoko (2012) also showed that there are different responses to NERICAs both in the laboratory and field studies. Cultivars were identified that exhibited superior resistance responses to *S. hermonthica* from Mbita, Kenya (CG14, NERICAs 1, 10 and 17) and *S. asiatica* from Kyela, Tanzania (NERICAs 10 and 17) and while other cultivars were moderately to highly susceptible to *S. hermonthica* from Mbita, Kenya (IAC165, WAB56-104, WAB56-50, NERICAs 7 and 9) and *S. asiatica* from Kyela, Tanzania (WAB56-104, NERICAs 7 and 9).

Rice has a small genome (*c.* 389 Mb) and a complete genome sequence is available as well the physical maps (International Rice Genome Sequencing Project, 2005). As a model plant, it is therefore important that QTL for *Striga* resistance be estimated. This will be of great benefit as genes for resistance may be identified and transferred to other cereals. In our study of QTL for *S. hermonthica* resistance to rice, we used *O. sativa* cv. Nipponbare and *O. rufipogon* W630 backcross recombinant inbred lines (BRILs) (chapter 7). The QTL was detected near RM242 marker on chromosome 9 at a significance level of $P<0.01$. The Lod score for the QTL was 2.1 and the source for resistance was Nipponbare allele. There were other weak QTLs detected on chromosomes 2, 3, 7 and 12. However, these QTLs are not considered biologically significant unless they are validated. In the studies of Cissoko (2012), QTL for *Striga* resistance was detected near RM101 marker on chromosome 12 in CG14.

Future directions for research outlook

There is no "quick fix" to the *Striga* problem in SSA. The magnitude level of the parasite and its persistent infections not only to cereals crops but also wild grasses make the parasite a serious biological constraint. The genetic diversity and soil seed bank of *Striga* as well as root exudates of host plants need to be studied. This will facilitate understanding *Striga* races or biotypes and how it copes with environmental variability.

Despite calls for a better understanding of the genetic structure of *Striga* (Mohamed *et al.* 2007), practically, for the deployment of resistant cultivars, it seems that the most important requirement is plant breeders should understand that different *Striga* populations may differ in virulence, and that this requires a precautionary approach to cultivar deployment, as well as comprehensive monitoring for host resistance breakdown. For a long time, presence of biotypes of *Striga* has been thought to be responsible for the breakdown of resistance in crops.

In the absence of detailed historical information about different populations of *Striga* and their hosts that has expanded over time, host plants grown in different places at different times, and knowledge on the impacts caused by *Striga* on the environment based on its interactions, studies that seek to illustrate the effects of different hosts and environments on *Striga* virulence in field trials and supporting lab analysis, will definitely seem to be the best way forward. In a recent study, Huang *et al.*, (2013) underscores that breeders should pay attention on the genetics of the root parasitic plants.

Research on stages of *Striga* between germination and emergence at the field is required in order to understand the steps of the life cycle and intervention options that can be put in place for its control. This management strategy will involve the use of control measures that can cause a reduction in seed production, viability of newly produced seed and its survival in the soil. This implies that intervention in the early parasite life cycle is necessary for a successful outcome to suppress *Striga*.

Possibility should be explored on the use of quantitative trait loci (QTL) to identify genes in rice that are resistant to *Striga*. In this case, NERICA need to be further studied to identify genomic regions containing resistant traits for *Striga*. The mapped QTL of NERICAs will promote understanding on the nature of tolerance. Already there is an attempt by Cissoko (2012) who showed that *Striga* resistance QTL is located near RM101 marker on chromosome 12 in CG14. However, an analysis of the 18 NERICA cultivars carried using marker RM101 showed monomorphic amplification. It is my considered opinion that RM101 marker was not suitable for analyzing differences of chromosome 12 among the NERICA cultivars. Nipponbare, the Japonica rice cultivar and *O. rufipogon* W630, the wild accession from Myanmar used in our study in QTL analysis need to be studied further with an aim of identifying resistant genes. In order to understand *S. hermonthica* resistance QTL of *O. rufipogon* W630, it will be probably appropriate to determine the underlying genetic determinants by analyzing changes in gene expression in *Striga* infected roots of host. This can be carried out using affymetrix of the whole genome rice oligonucleotide array. Identification of resistant genes can go a long way in enhancing yield and boosting the morale of farmers. These genes can be transferred to other cereals such as maize, millet and sorghum by marker-assisted selection through the use of synteny (chromosomal gene order similarity).

Development of genetically modified (GM) crops with *Striga* resistance is certainly feasible. But political opposition on dissemination of GM technology may impede the speed of adoption of the technology. The cost of seed also poses a challenge as farmers may not have the resources to purchase seeds in every planting season. It will be unrealistic to assume that the major cereal crops can be replaced by other food crops unless governments are willing to subsidize the cost of seeds and adopt the GM technology.

Whole genome sequencing is a valuable approach to understand an organism. The genome sequences of the growing numbers of model and crop plant species have been published in recent years, providing new insights in plant biology. The development of new generation sequencing technologies has dramatically accelerated the speed of large-scale sequencing.

The molecular and genomic resources currently available for the study of *S. hermonthica* are limited. These studies on molecular resources will be in tandem in understanding the parasitic processes of this obligate parasite. However, it is also known that sequencing the whole genome of a non-model plant is still challenging and laborious task. The persistence of purple witchweed infecting and increasing its host base in sub-Saharan Africa, calls for nothing less other than understanding the consequences of adaptation and its parasitic life style. Therefore, the study of the genome of this parasite is necessary to provide insight on evolution of the species and facilitate identification of genes important for plant parasitism. It will also lead to identification of genes which will eventually assist in answering the questions on plant-parasite interactions. As it is currently, it is unknown which *Strig*a genes are required to successfully infect susceptible host plants. More importantly, the study of genetic variability will help in targeting the areas of breeding for resistance.

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