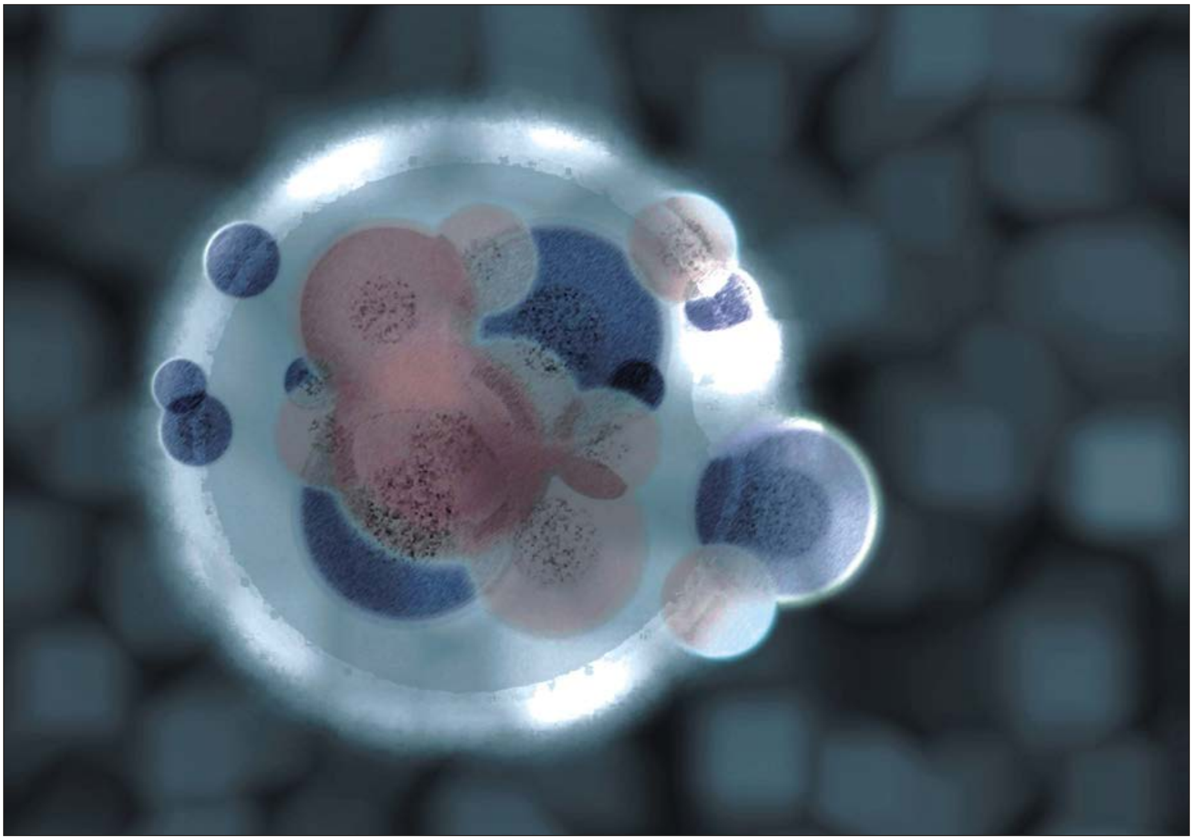

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Perspective Article
Predictions of the *Striga* Scourge under New Climate in Southern Africa: A Perspective

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Abstract
Striga is a major parasitic weedy species in Southern Africa and is an impediment to attainment of household food security for poorly resourced communal farmers. The objective of this study was to use future niche descriptions and the life stages of *Striga* to predict the *Striga* epidemic in the future. Climate change projections through time scale analysis, general circulation models (GCM) down scaling and dynamical down scaling were used to predict the likely scenario in relation to the *Striga* epidemic. Agricultural systems are expected to face an increasing risk of erosion, runoff and soil degradation. Alternating high temperatures and rainfall may assist breaking of dormancy in *Striga* whilst severe winds greatly aid dispersal of the weed seeds. Generally production of strigolactones, haustorial initiation factors, attachments, seed production and dispersal were expected to increase as temperature rises like other biological processes. From this study it can be concluded that the *Striga* epidemic is going to increase under the new climate. The parasitic weed is likely going to become a more serious threat to crop production.

Key words: Climate change, *Striga* asiatica, epidemic, niche descriptions, food security

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Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Striga is the major biological constraint to increased cereal production in the smallholder sector of Southern Africa. *Striga* species are a major parasitic weedy pest throughout the semi-arid sub Saharan Africa and many parts of Asia[1]. Many African countries including Tanzania, Kenya, Malawi, Madagascar, Botswana, Zimbabwe, Gabon, Nigeria, Ethiopia, Niger, Togo, Benin and Burkina Faso are highly infested with *Striga* causing serious yield losses that are as high as 100% at some sites[2]. In particular, the major crops that supply the bulk of the energy and protein needs of the poor in the African savannah, namely maize, sorghum, millets, upland rice and cowpeas have been severely vulnerable[3].

Losses from *Striga* are compounded because of the tendency of crops grown under severe moisture and poor fertility conditions to show significant predisposition to *Striga*. According to Scholes and Press[4] and Ejeta[5] over 50 million hectares of arable farmland under cultivation with cereals and legumes in sub Saharan Africa are infested with one or more *Striga* species. In many of these places the *Striga* has reached epidemic proportions presenting a desperate situation in subsistence agriculture[6]. The weed causes annual losses of yield estimated to be in excess of US$10 billion[5]. The *Striga* spp. affects the welfare and livelihoods of over 100 million people in Africa[1]. According to Parker[7] the weed has impacted on the sub region's economy.

Over the years, many promising *Striga* control methods have been suggested in various formats, some suggestions appearing in multiple incarnations[8]. Despite this valuable work, adoption and utility of these control methods are limited, yield loss attributable to *Striga* is acute, perhaps even exacerbated ranging from 35-72% in some studies[9]. It is becoming very apparent that there is no silver bullet for *Striga* control. Despite its status as a serious parasitic weed work on the status of *Striga* under climate change is limited. Prior weed predictions done have not included *Striga* as a threat to food security under climate change. The objective of this paper is to use future niche descriptions to predict the *Striga* epidemic under the future climate. The authors speculate that the *Striga* epidemic is going to increase under the new climate.

Genus *Striga*: *Striga* is a latin word for 'witch' presumably because plants diseased by *Striga* display stunted growth and an overall drought like phenotype long before the weed appears. The genus was previously grouped within the family *Scrophulariaceae* but more recent analysis have placed the *Striga* under the family *Orobanchaceae*[5,10]. *Striga* possibly originates from a region between Semien Mountains of Ethiopia and the Nubian Hills of Sudan[11]. The same is the birth place of cultivated sorghum which is the major host species for several *Striga* spp.[10]. The main agriculturally important *Striga* spp. are *Striga hermonthica* (Del) benth and *S. asiatica* (L.) Kuntze in cereal crops and *Striga gesnerioides* (Willd) Vatke in cow peas. *Striga aspera* (Willd) Benth and *Striga forbesii* are also significant problems in cereals in limited locations[7]. The spread of various *Striga* spp. across the African continent is shown on Table 1.

Extent of the *Striga* problem in Southern Africa: Parasitic weeds are fast becoming a major constraint to many crops in Southern Africa and yet the efficacy of available means to control them are minimal. It has become one of the greatest biological constraints to food production in the drier parts of Africa, probably a more serious problem than insects, birds or plant diseases. The C_4 cereal maize, sorghum, rice and millet are the preferred hosts and the infection of these plants by *Striga* spp. can result in severe grain losses. According to Rubiales *et al.*[1], typical yield losses vary from 15-20% at a regional level but can be much more severe at local scales, sometimes resulting in total crop failure. The losses largely depend on the level of infection, crop variety, soil fertility and rainfall[12].

It has been estimated that yield losses attributed to the weed exceed US$7 billion in value without accounting for the adverse effect on the welfare and livelihoods of over 100 million people in Africa[1]. The most affected are the resource poor, small scale subsistence farmers and severe infestations cause serious food shortages in Southern Africa. There are variable statistics on the extent of the *Striga* infestations by individual species but generally, 40% of arable land in sub Saharan Africa and 67% of the 73 million hectares in cereal zones is infested by *Striga*. Harsh conditions mean that few alternative crops are available and the use of high cost inputs such as herbicides are generally not feasible for resource poor farmers. The small scale famers' cash investments in crop production are low. According to Ronald *et al.*[13] inputs are low, rainfall is erratic and soils are poor and these conditions are the most suitable for *Striga* spp. to thrive.

In other areas the weed has reached epidemic proportions presenting a desperate scenario to small scale farmers. Where the scenario has worsened to these proportions the farmers are left with one option which is to abandon the land. According to Atera *et al.*[14], demographic pressure has led to monocropping, thus increasing the frequency of *Striga* spp host crops in the cropping system, an ideal condition for *Striga* to thrive.

Table 1: Distribution and occurrence of *Striga* spp. in sub Saharan Africa

Striga spp.	Host plants	Distributions
Striga asiatica	Rice, sorghum and maize	Angola, Lesotho, Malawi, Mozambique, Namibia, Tanzania, Madagascar, South Africa, Zanzibar, Zambia, Botswana, Burundi and Democratic Republic of Congo and Zimbabwe
Striga aspera	Rice, maize, sorghum, finger millet, wild grasses and sugarcane	Burkina Faso, Cameroun, Central African republic, Ethiopia, Gambia, Guinea, Cote'divoire, Nigeria, Niger, Mali, Ghana, Senegal and Sudan
Striga forbesii	Sorghum, sugarcane, maize and rice	Angola, Botswana, Democratic Republic of Congo, Ethiopia, Kenya, Malawi, Mozambique, South Africa, Sudan, Swaziland, Tanzania, Uganda, Zambia and Zimbabwe
Striga gesnerioides	Cowpeas and legumes	Angola, Botswana, Burkina Faso, Cameroun, Central Africa Republic, Democratic Republic of Congo, Ethiopia, Sierra Leone, Senegal, South Africa, Tanzania, Zimbabwe, Gambia, Ghana, Kenya, Malawi, Mali, Mozambique, Somalia, Nigeria, Rwanda, Uganda and Zambia
Striga hermonthica	Maize, millet, rice, sorghum, Pearl millet, Finger millet and sugarcane	Angola, Cameroun, Central Africa Republic, Djibouti, Eritrea, Gambia, Guinnea Bissau and Ethiopia

Managing *Striga* in Southern Africa: Despite the concerted efforts to come up with a sustainable method of *Striga asiatica* control, there is no sustainable control method available for managing the parasite. It remains as the number one biological constraint limiting the production of cereal grains in Southern Africa. Several methods have been studied but accompanied by minimum success. 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 of the weed both prior and after attachment to the host. The numerous methods that have been suggested or developed together with their technical limitation are shown in Table 2.

Prediction method: Niche based model: The niche based model is based on the knowledge for suitable habitat beyond the species' current distribution or severity. It is a pattern based indicator[30]. The first task is to use the current data on distribution to predict the severity of spread under current conditions then use niche descriptions to predict the level of spread under future climate.

The second task according to Crossman *et al.*[30] is to use expert opinion to quantify dispersibility and identify the level of the epidemic expected. For *Striga* spp. the life cycle is a multistage ranging from dormancy breaking, strigolactones release, stimulation of germination, haustorial formation and attachment, its life under ground and life outside after emergence then seed production and dispersal. The objective is to try and predict the level of occurrence of each stage under the current climate and under future climate. Whilst *Striga* is a threat now predictions have to be made to check the level of spread under future climate. The current climate may be suboptimal preventing the weed from reaching epidemic levels or they may be optimal conditions and when climate changes the weed may deteriorate in status or infections.

Current climate and expected future climate in Southern Africa: Southern Africa is predominantly a semi-arid region with high rainfall variability, characterized by frequent drought and floods. According to Davis[31] there is a high degree of spatial variation in rainfall across southern Africa and the average for the region is just less than 1000 mm/year. The highest amount is 3100 mm and the lowest is less than 100 mm/year. The majority of the region is between 500-1500 mm/year. Southern African rainfall shows a clear seasonal characteristics with a large part of the subcontinent experiencing a summer rainfall season, usually commencing in October/November and tapering off in February and march[32]. The Southern African region exhibits a largely warm climate, with warm average temperature mostly above 17°C with exceptions of high altitudes and coastal areas. Given bellow is a summary of the climate change projections using various techniques for predictions according to Tedross *et al.*[33] (Table 3).

The future conditions may make niches for the *Striga* spp. When temperatures rise, they may provide a suitable habitat for the *Striga* parasite to increase or decrease its abundance. The implications of the niche to changes in climate are given in Table 4. When temperature increases other crops like wheat which are currently not under attack by the *Striga* because it is planted in winter may be susceptible. Vasey *et al.*[34] found wheat to be susceptible to *Striga hermonthica* and questions the implications of this to wheat production areas under climate change in Africa. A summary of the niche descriptions for the future are shown in Table 4.

Striga epidemic under climate change

Seed dormancy and after ripening: *Striga* seeds have an after-ripening requirement and do not germinate in the season in which they are produced. Rich and Ejeta[26] asserts that this requirement prevents newly matured seed from germinating too late in the season when host plants capable of supporting the parasitic plants to maturity are scarce. *Striga* seeds must go through a phase of conditioning[10]. Peak germination of *Striga* seeds occur *in vitro* after 10-15 days of soaking in water at a temperature of 28°C. Sun *et al.*[35] reported that pre-conditioning at a suitable temperature releases the dormancy within 2-3 weeks and increases the sensitivity of *Striga* seed to strigolactones by several orders of magnitude. If no strigolactone is received during this time, the *Striga* seeds will eventually fall into secondary dormancy.

Germination is linked to the presence of the host that is nearby as the endosperm of *Striga* can not sustain growth for only 3-7 days. *Striga* seeds generally are dormant and the dormancy is broken down by alternating wet periods and high temperature exposure. Under climate change the alternating wet and hot conditions are predicted to be a norm hence dormancy will easily be broken and germination rates will be increased.

Strigolactone biosynthesis and exudation: Nutrient deficiencies have profound effects on strigolactones biosynthesis and exudation. According to Yoneyama *et al.*[36], roots of host plants grown in phosphorus deficient soils

Table 2: *Striga* control strategies, mechanisms and causes of reduced adoption

Control strategy	Mechanism	Reduced adoption	References
Increased soil fertility	Shortage of nitrogen and phosphorus leads to more active production of strigolactone to attract mychorhizal fungi for increased nutrient absorption	Most of the affected farmers can not afford the levels of fertilizer required to reduce production of strigolactones	Mabasa[15], Jamil *et al.*[16], Lopez-Raez *et al.*[17] and Yoneyama *et al.*[18]
Intercropping with legumes	The mechanism according to Fernandez-Aparicio involves smothering by cover crops and increase in soil moisture and fertility for legumes and decrease soil temperature		Jasi and Mabasa[19], Khan *et al.*[20], Midega *et al.*[21], Picket *et al.*[22], Hooper *et al.*[23] and Tsanuo *et al.*[24]
Trap crops	These crops stimulate germination of the parasitic weed but is not compatible with subsequent infection process	Trap crops can not exhaust the seed banks	
Catch crops	These are true hosts that promote *Striga* germination but will be burnt down as soon as *Striga* germinates	Not economic for the farmer	
Host resistance or tolerance	Low strigolactone production, low haustorial initiation factors, plugging of xylem-xylem connection between host and parasite and antibiosis	This is a sustainable approach but not even a single variety has shown complete resistance	Jamil *et al.*[16], Gurney *et al.*[25], Rich and Ejeta[26] and Chitagu *et al.*[27]
Herbicide seed dressing	Herbicide coated seed maize uses germplasm resistant to Imidazolinone group of accetolactate synthase (ALS) inhibiting family of herbicides	Successful so far	Kanampiu *et al.*[28] and Manyong *et al.*[29]

Table 3: Climate change projections using various techniques for Southern Africa

Weather parameters	Timescale analysis	General circulation model statistical downscalings	Dynamical downscalings
Rainfall	Decrease in most parts of Southern Africa	Decreases in Zimbabwe and Zambia	Increases over Eastern Africa
Temperature	1-3°C	0.8-3.6°C	0.4-3.2°C
Extremes of weather	Increases in hot days and heat waves	Increases in very hot days and heat waves	More extreme rainfall events in eastern and Southern Africa, increases in hot days above 35°C

Table 4: Niche conditions under current and future climate

Niche conditions	Current conditions	Conditions under the future climate	Likely scenario in relation to *Striga*
Mean annual temperature	Moderate	High	Increased photosynthesis and fitness for C4 hosts and increased ability to support *Striga*
Mean annual precipitation	Moderate	Heavy and erratic	Increased dormancy breaking for *Striga* seed
Average soil pH	Low	Very low (acidic)	Increased strigolactones stability
Soil fertility level	Moderate	Low	Increased Strigolacone production
Wind speed	Moderate	High	Increased dispersal
Carbon dioxide level	Low	High	Increased temperature making more areas have a suitable habitat for Striga invasion

were found to produce more strigolactones. More root parasitic plants generally prevail on nutrient deficient soils and thus fertilizer application suppresses their emergence. Yoneyama *et al.*[36] reports of a 100 fold increase in germination stimulation activity of root exudates from plants grown under phosphate starvation. Yoneyama *et al.*[36] further confirms that in *Sorghum bicolor* suffering from phosphate deficiency enhances strigolactones production particularly the case of 5-deoxystrigol and sorghumol. The same was confirmed by several authors that nitrogen and phosphorus shortage enhances strigolactones biosynthesis[26].

With climate change serious land degradation is expected which can result in heavy leaching and degradation of soils. Plant growing under that environment would require strong cooperation with AM fungi for increased adsorption of these nutrients. Therefore, cereal crops growing under degraded soils are likely to produce more strigolactones. Soil degradation is expected to alter soil pH to more acidic levels. Although the effects of soil pH on *Striga* germination have not been studied adequately. The projected increases in soil degradation in Africa may therefore indirectly four *Striga* spp.[37,38]. Germination of *Striga* seeds in agar was obtained at a pH of 4. Loss of activity of synthetic germination stimulant (GR 7) was lost in alkaline soils. This may point to more strigolactones production under acidic conditions and the increased stability of strigolactones under the same environment which is a common feature under degraded soils.

Zwaneburg *et al.*[39] and Bouwmeester *et al.*[40] found that strigolactones are unstable in watery environments. With the alternating periods of very wet and dry conditions under climate change, germination may occur under dry conditions phase. Once germinated the *Striga* grows under ground for between 4-8 weeks and so the *Striga* may continue to grow once germinated.

Various authors have reported that maximum germination occurs at temperatures between 30-35°C. Currently the average temperature is bellow 28°C in Southern Africa and thus with increased carbon dioxide enrichment in the atmosphere, temperature changes are likely to lead to increased germination of *Striga* as long as they bellow 35°C. Hence the 2-3°C increase expected is likely going to increase germination of *Striga*.

Haustorial inducing factors: Haustoria are invasive structures that develop at the tip of *Striga* radicles in response to host root contact. The formation and penetration of host root by *Striga* is stimulated by haustorial inducing factors. These are compounds such as quinines, flavonoids and phenolics. The only haustorial inducing factor isolated in plants is 2-4 dimethoxybenzoquinone and it comes from the oxidative degradation of lignin and decarboxylation of phenolic acids. The quinines, flavonoids and phenolics are called allelochemicals and are produced under extreme conditions such as higher temperature and exposure to extreme radiation. With these expected to increase under climate change the production of haustorial inducing factors is expected to increase. This may lead to an increase in number of *Striga* plants successfully attaching to the host.

Seed production and dispersal: Hearne[8] reported that *Striga* has a high reproductive capacity producing between 10 000-200 000 seeds/plant. These seeds are small with dimensions of 0.3 and 0.15 mm. the seeds are very light weighing 4-7 µg and are easily dispersed by winds, water and animals. With strong winds expected under climate change long distance dispersal is expected to be more. The seed is likely going to be spread to new areas as a result of wing dispersal.

With increased temperatures and carbon dioxide expected most C4 host plants are expected to increase in productivity and *Striga* productivity depends on food availability. The large quantities of long lived seeds will ensure that the parasite adapt to changes in host availability, consequently making them more difficult to control[34].

Perspective: The current ecological drivers for *Striga* presently are temperature, degraded soils with acidic pH, winds that are prevalent for dispersal and precipitation. All these ecological attributes are predicted to change under the future climate therefore the *Striga* scourge may also change. Laboratory experiments done found that more acidic pH increases the stability of strigolactones, more prevalent winds increase dispersal. Extremes of temperature may limit the growing of temperature sensitive plants, farmers may concentrate on C4 plants (sorghum, millets and maize) which are hosts.

Although it is difficult to predict with certainty the level of *Striga* epidemic under the future climate, life stages of *Striga* may be promoted under the future climate. Whilst *Striga* is a problem in particular areas at the present moment it is likely that the width of its niche is likely to increase under the changed climate. For Southern Africa, a 4°C increase in the average temperature may move the average to 34°C for most areas. Most of the biological processes involved in *Striga* infection occur at their optimum at that temperature. Soil degradation that is predicted under the future climate may move soil pH to more acidic levels. Mohamed *et al*.[41] have predicted that *Striga* distribution might in the long run expand to moderate climate zones at the expense of tropical and sub-tropical areas. Due to the fact that the life cycle of the weed is multistage, it is very difficult to assume that all stages are going to be enhanced under the new climate. Detailed laboratory experiments may need to be done to determine the conditions with respect to water availability, temperature and wind speed that give optimum responses to particular life stages of the *Striga* life cycle.

CONCLUSION

It was concluded that under the new climate, the *Striga* epidemic may worsen. The various conditions under the new climate may worsen the *Striga* scourge as they seem to favor the various life stages of the parasite. *Striga* spp. may start to be a weed of economic importance in areas where it was not found.

SIGNIFICANCE STATEMENTS

This study predicts that *Striga* parasitism is going to worsen under the new climate. Such studies are limited in literature. That knowledge is beneficial in that the weed managers and the farming community have to be prepared to deal with the epidemic. This study will help the researcher to link every life stage of *Striga* to the expected future conditions that many researchers did not explore.

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