

Striga (Witchweed) Threats to Cereal Crops Production and Its Management: A Review

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Abstract

Striga (witchweed) is one of the most successful parasitic weeds of cereal crops in Africa. It is 'a poor farmer's problem' as there is a near perfect ecological overlap between areas of *Striga* infestation and where hunger prevails. It is originated in Semien hills of Ethiopia and the Nubian hills of Sudan and later expanded in about 42 African countries. *Striga hermonthica*, *Striga asiatica*, *Striga gesnerioides*, and *Striga aspera* constitute the greatest economic threat to cereal crops' yield losses. They are obligate root parasites causing growth inhibition and yield losses of 20-100% in maize, rice, sorghum, pearl millet, finger millet, sugar cane and cowpea. Cultural practices such as long-term rotational cultivation of cereal crops with legume crops unaffected by the parasite is effective in managing the weed. Besides, biological control by use of parasitic fungi (*Fusarium oxysporum* and Vesicular arbuscular mycorrhiza) play a role in managing the weed. In addition, chemical control with imidazolinone herbicide, ethylene gas, dicamba and 2,4-D are effective in managing striga in cereal crops in extreme cases. Integrated use of striga resistant crop varieties with water conservation practices, soil fertility amendment and use of parasitic fungi (*Fusarium oxysporum* and Vesicular arbuscular mycorrhiza) is effective in control, economically safe, socially acceptable and environmentally friendly than a single control measure. Therefore, the promising integrated striga management practices should be highly promoted. Moreover, host and *Striga* species specific integrated *Striga* management should be designed.

Keywords: Haustoria; Obligate parasite; Root parasite; Strigolactones; Witchweed

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1. Introduction

Parasitic weeds attack other plants by making networks and deriving portion or entire of their nourishment from their host. They are a major threat to native biodiversity, agricultural lands, range lands, national parks, road sides and urban green spaces with great economic and social consequences [1]. Up to a date about 4000 parasitic weeds are identified exploiting another plant vascular system to fulfill their nutrient requirements. Among these parasitic weed species 90% of them are hemiparasites retaining photosynthetic capacity while the rest, 10% of the species are holoparasites with obligate dependence on the host to obtain all their nutrients [2].

Some parasitic species have evolved to parasitize agricultural plants becoming weedy and posing a difficult-to-control threat to agriculture and cause serious problems for farmers in many parts of the world [3]. Root parasites (*Striga* spp. and *Orobanch* spp.) and shoot parasites (*Cuscuta* spp., *Viscum* spp. and *Arceuthobium* spp.) are the major threat to agriculture which cause the majority of yield losses [4]. If they are not timely managed, they can induce serious yield losses up to total failure of crop productivity [5].

Striga species from the family *Scrophulariaceae* [6] is one of the most important root parasites which causes serious threat to sorghum (*Sorghum bicolor*), maize (*Zea mays*), rice (*Oryza sativa*), pearl millet (*Pennisetum glaucum*), finger millet (*Eleusine coracana*), cowpea (*Vigna unguiculata*) and sugar cane (*Saccharum officinarum*) production in both tropical and sub-tropical countries in Africa [7]; [8]. *Striga hermonthica*, *Striga asiatica*, *Striga gesnerioides*, and *Striga aspera* constitute the greatest economic threat to cereal crops production and productivity [9]. The weeds are widespread with high rates of infestation across African countries. This is due to the fact that many farmers have limited knowledge about the weed and were therefore indifferent towards its control resulting in increasing weed infestation [10]; [11].

Continuous use of susceptible crop varieties without any protective measures causes disastrous levels of heavy infestation, crop failures and buildup of the *Striga* seed reserve in the soil. Considering the destructive effect of this weed infestation to cereal crops production, many studies have been conducted on its management [10]; [12]; [13]. It is also extremely difficult to achieve effective control of *Striga* spp. by a single control measure because of the nature of attachment and association between host and parasite requires a highly selective herbicide to destroy the parasite without crop damage. However, different management practices reducing the weed population and increasing crop yield are studied by different scholars. Therefore, the objective of this paper is to review the occurrences, distributions, economic importance and management practices of striga weed.

2. Body of the Text

2.1. Geographical Distribution, Species Diversity and Host Range of *Striga*

Striga spp. are considered as 'a poor farmer's problem' because of the fact that there is a near perfect ecological overlap between areas of *Striga* infestation and where the poor farm and where hunger prevails [10]. Semien hills of Ethiopia and the Nubian hills of Sudan is believed to be the center of origin for diversity of *Striga* species [14]. The *striga* species later expanded to about 42 countries in Africa [10]; [15]. These dispersal events are agricultural in origin with the transport of contaminated crop seed or via livestock.

African countries such as Ethiopia, Somalia, Kenya, Tanzania, South Sudan, Sudan, Eretria, Chad, Cameroon, Niger, Nigeria, Burkina Faso, Mali, Senegal, Gambia, Malawi, Mozambique and Botswana are heavily infested by *Striga* spp. Whereas moderate infestations by the *striga* spp. are reported in Benin, Burundi, Ghana, Uganda, Congo, Central African Republic, Liberia, Democratic republic of congo, Zambia, Sierra Leon, Gunnie, Gunnie Bissau and Mauritania. However, light weed infestations are reported from Western Sahara, Djibouti, Egypt, South Africa, Namibia, Angola, Congo Republic, Gabon, Equatorial Guinea, Swaziland and Lesotho (Figure 1) [10]; [15].

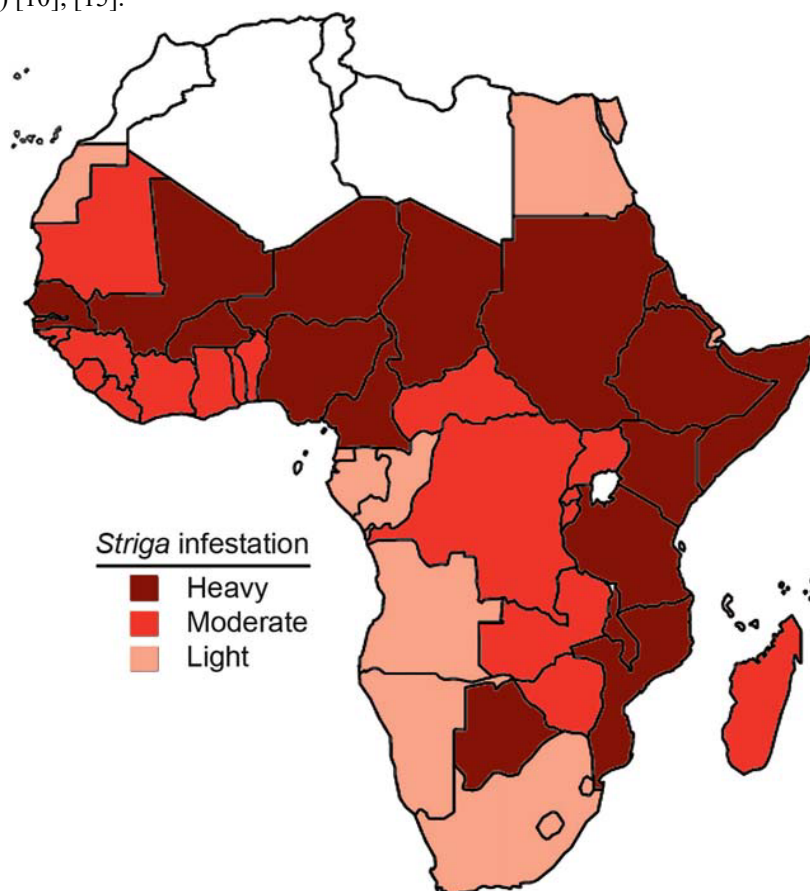


Figure 1. *Striga* distribution and infestation in African countries (Source: [10])

The genus *Striga* comprises more than 40 species, of which 11 species are considered parasitic on many cereals and few pulses [16]. Locally adapted *Striga* races have long been observed that specialize on particular crops [9]. Several factors contribute to genetic diversity in *Striga*: (i) seeds can persist in the soil for many generations; (ii) hybridization; (iii) wide geographic dispersals; and (iv) locally adapted host races.

Striga species are considered as a wide spreading and having wide hosts range, which are extremely difficult to control and result in significant economic losses [17]; [18]; [19]. They are reported by several workers occurring in mild to severe form on a variety of hosts. Cereal crops (Maize, rice, sorghum, pearl millet, finger millet, sugar cane) and pulse crop (cowpea) are generally the preferred hosts of this parasitic flowering species [18]; [19]; [20].

Striga hermonthica expanded throughout Eastern Africa in Kenya, Uganda, Tanzania, Ethiopia, Sudan, Rwanda, and Burundi as well as in West Africa in Niger, Nigeria, Libya, Chad, Western Sahara, Guinea, Burkina Faso, and Mali parasitizing maize, millet, sorghum, and upland rice (Figure 2). *Striga asiatica* occurs in both Southern and Eastern Africa, the Arabian Peninsula, India, and Pakistan parasitizing rice, sorghum, and millet. Whereas *Striga gesnerioides* infects dicotyledonous plants, greatly limiting cowpea production in the West African countries of Mali, Burkina Faso, Niger, and Benin. *Striga aspera* constrains maize and rice

production in Sudan, Malawi, Nigeria, Cameroon, Ivory Coast, and Senegal [21].

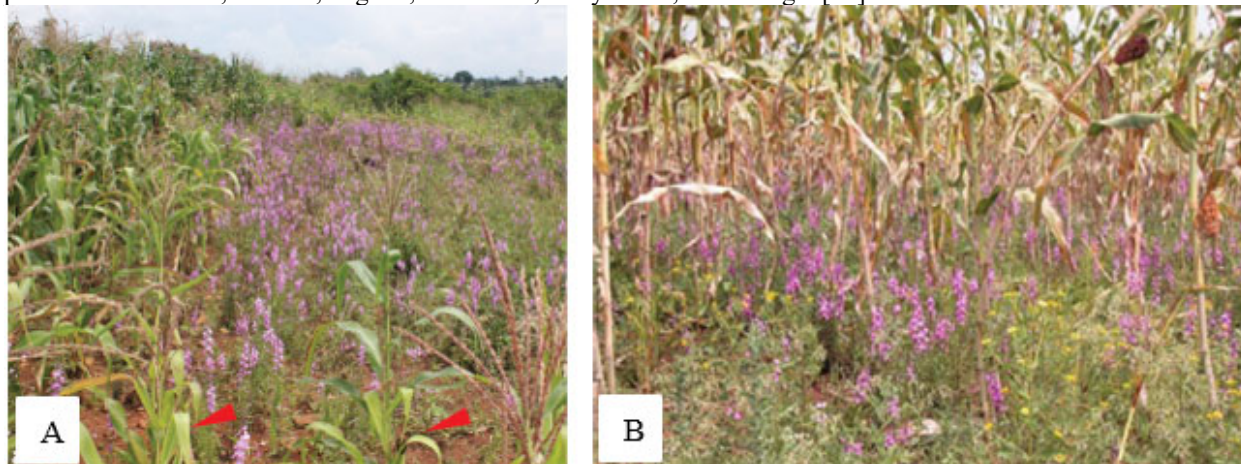


Figure 2. Destructive effect of *Striga hermonthica* on: A) Maize B) Sorghum

2.2. Unique Characteristics of *Striga*

Many unique characteristics of *Striga* are indicative of a successful parasitic weed whose control should take into account biological and chemical mechanisms underpinning *Striga*-host interaction. *Striga* reprograms the host in ways that are beneficial to its parasitism.

The unique characteristics of *striga* are; (i) the *striga* genus has many species that are widely distributed each with different host preferences, (ii) the ability to produce large number of seeds 50000 to 500000 per plant, (iii) its seed persistence in the soil for long period of time 15-20 years, (iv) seed dispersal mechanism, (v) *Striga* life cycle is highly synchronized with its host plants, (vi) its ability to alter levels of important hormone such as abscisic acid, cytokinins, and gibberellic acid during infection [22] (vii) it acquires genes from its host and modify them for parasite use [23], (viii) it is a sophisticated manipulator of host immunity [24], and (ix) it is able to subdue host defense by producing a series of effectors, just like bacterial and fungal pathogens.

2.3. Ways of *Striga* Mobility

Small sized *Striga* seed greatly enhances the parasite's dispersal by wind, water, and contaminated crop seeds. It also adheres to persons and animals, further aiding in seed spread and contamination of uninfected fields. However, a small *Striga* seed size means that the endosperm can only support growth for three to seven days [25]. Therefore, the seed germination must be rapid and synchronized with host localization.

2.4. Requirements for *Striga* Growth and Development

The growth and development of *striga* is highly associated to the host plant and physical environment. The *Striga* seeds germination is dependent the exudates released by host roots plants. *Striga spp.* thrive low soil fertility, light sandy soils, nutrient depleted soils with low organic matter content, low rainfall areas and temperature ranges of 18 to 40 °C [26].

2.5. Life Cycle of *Striga* and Mechanism of Host Infection

The life cycle of *Striga* is highly synchronized with its host. It encompasses three general phases (germination, haustorium formation, and penetration (Figure 3a-c and Figure 4). Seed germination initiated only in the presence of a susceptible host, which *Striga* locates using plant hormones called strigolactones. Following *Striga* seed germination, the *Striga* radicle attaches to the host and differentiates into a specialized organ called the haustorium (Figure 3b and c) [27]. The haustorium develops in response to chemical signals from the host, the haustorial inducing factors such as 2,6-dimethoxy-p-benzoquinone [28]. Finally, the haustorium of *Striga* penetrates the hosts root until it encounters the endodermis, where haustorial cells elongate and divide to establish vascular connections with the host plants (Figure 3b and c) [25]. Once the vascular systems of the host and parasite are connected, *Striga* uses this connection to siphon out nutrients[25].

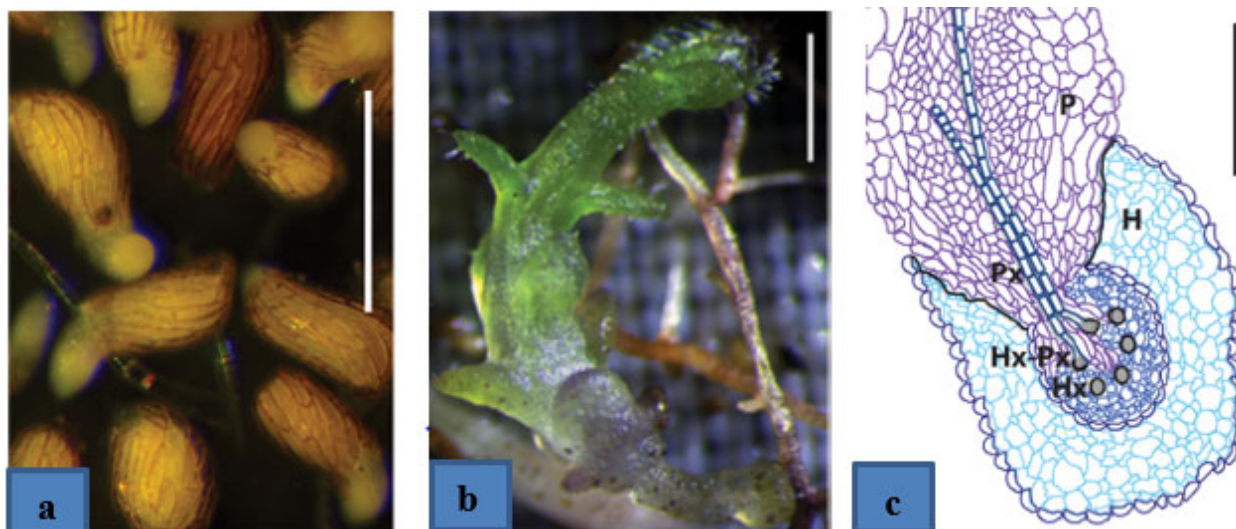


Figure 3. *Striga* at a glance. (a) *Striga* seedlings 12 hours after treating with a germination stimulant (GR24). Scale bar = 0.5 mm. (b) A 10-day old *Striga* seedling with a well-developed haustorium attached to a sorghum root. Scale bar = 0.2 mm. (c) A schematic of a section through a 10-day old *Striga* seedling showing the parasite (P) attached to a host (H). By this time, the parasite has developed fully. The parasite xylem (Px) has merged with the host xylem (Hx) to form a siphon (Hx-Px) that sucks out nutrients from the host. Scale bar = 0.05 mm. ICRISAT, International Crops Research Institute for the Semi-Arid Tropics

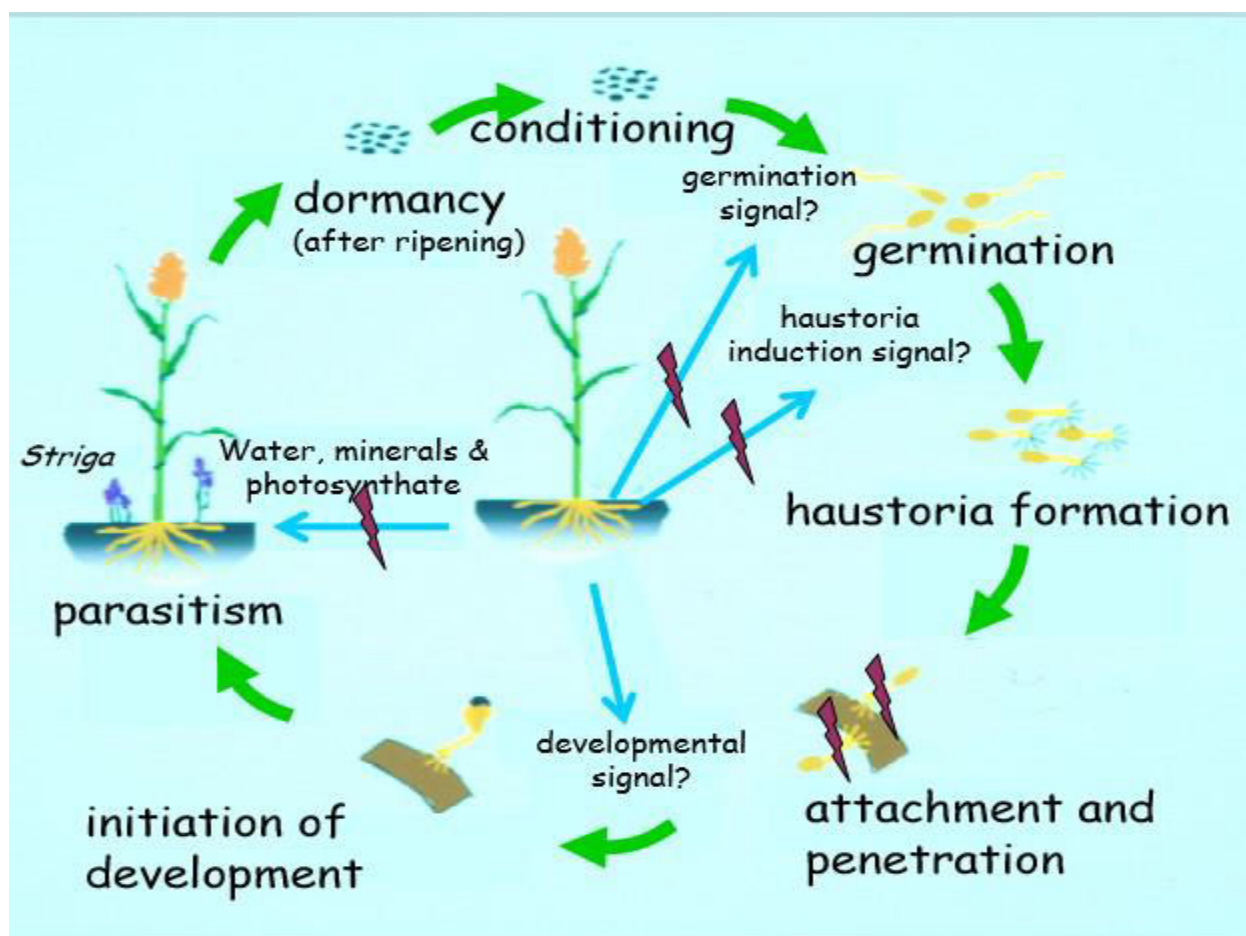


Figure 4: Illustrated *Striga* life cycle (Source:- [29])

2.6. Economic Importance of *Striga* species

Striga hermonthica, *S. asiatica*, *S. gesnerioides*, and *S. aspera* seriously affect cereals in many African countries.

They are obligate root parasites causing growth inhibition and yield losses of many cereal crops [13]; [18]; [19]; [30].

The wide host range of *striga* spp and their wide geographical distribution, make them amongst the most damaging parasitic weeds [30]. Studies indicated that *Striga hermonthica* infestation reduced Maize, rice, sorghum, pearl millet, finger millet, sugar cane yield by 30 to 90%; *Striga asiatica* and *Striga forbesii* reduced maize yield by 30-90% in Tanzania [30]. In Kenya, these species infestation reduced maize, rice, sorghum, pearl millet and finger millet yield by 15 to 100% [18, 31]. *Striga hermonthica* and *Striga asiatica* infestation reduced sorghum, millet and Maize yield by 60 to 100% in Uganda [18]. *Striga hermonthica* infestation reduced sorghum yield by 58 to 100% in Ethiopia and Sudan [13]; [19].

2.7. Managements of Striga

Striga has been known in many cereal crops in many African countries for many years [10]; [12]; [30] and many studies have been conducted on its management since the potential threat of the weed to cereal crops production [10]; [12]; [13]. The weed is widespread on many crops with high rates of infestation across African countries. This is due to the fact that many farmers have limited knowledge about the weed and were therefore indifferent towards its control resulting in increasing weed infestation [10]; [32]. It is also extremely difficult to achieve effective control of *Striga* by a single control measure because of the nature of attachment and association between host and parasite requires a highly selective herbicide to destroy the parasite without crop damage. However, different management practices reducing the weed population and increasing crop yield are studied by many intellectuals.

2.7.1. Host resistance

The use of host resistant varieties reduces the yield losses caused by *Striga* spp. by lowering the production of germination stimulant, being mechanical barriers between the parasite and host, inhibition of germ tube exoenzymes, phytoalexins synthesis, incompatibility, antibiosis, insensitivity to striga toxin and avoidance [10]; [13]; [17]. However, poor adoption for some resistant varieties, incompatibility of some genotypes and resistance break down observed in some host varieties are a big challenge in the control of striga by the use of host resistance [12].

2.7.2. Striga Seedbank Depletion

Application of simple chemical synthesis of strigolactones play a crucial role in significantly reducing *Striga* seeds in the soil. Chemical molecules that mimic the activity of strigolactones can cause the parasite to germinate in the absence of a host. This strategy is known as suicidal germination [21]. Even though this technology was previously not feasible due to the high cost of multistep chemical synthesis of strigolactones and its instability under field conditions, currently it is possible to synthesize simple strigolactone analogues that when treated with chemical formulations, retain activity and stability under field conditions [21].

2.7.3. Striga Management by Herbicides

The damage caused to the crops by root parasitic weeds can be reduced by using herbicides [33]; [34]. Seed coating of cowpea with an imidazolinone herbicide, imazaquin, is effective in reducing the populations of *S. gesnerioides* and *Alectra vogelii* attached to cowpea [34]. However, high-dose of imazaquin reduced the germination rate and delayed the flowering in cowpea [34]. Eplee [35] also concluded that ethylene gas used as a germination stimulant in the suicidal germination strategy successfully eradicated *S. asiatica*. Another study also indicated that dicamba and 2,4-D are used as feasible herbicides in controlling *S. asiatica* in the early program in United States and African countries [33]. However, the herbicides themselves can cause the problem by damaging a part or the whole plant parts since there is no selective herbicide for root parasitic weeds [34].

2.7.4. Striga Management by Cultural Practices

The best practice is long term rotational cultivation of cereal crops with legumes or other crops unaffected by the parasite. Cultural practices such as crop rotation, water management, early planting and use of early maturing varieties are effective in reducing *striga* seed banks in the soil, improving soil fertility, enhancing sorghum growth rate and retarding the parasites seed germination and seedling development [36]. However, their poor adoption, high cost of implementation, high labor requirement and inapplicability of them on large fields are limitation of cultural striga management practices [36].

2.7.5. Striga Management by Biological Control Agents

Biological control by using *Fusarium oxysporum* f.sp. strigae (FOS) is effective in controlling striga spp. The use of *Fusarium oxysporum* in controlling striga has many advantages: i) it has no residual effect, ii) it Reduces *Striga* population below its threshold level, iii) it improves sorghum yield and reduces days to maturity in sorghum. However, it not yet developed commercially for *Striga* management in most countries [13]; [17]; [37]. Vesicular arbuscular mycorrhizal (VAM) fungi are also reported to control *Striga* and enhance biomass production of compatible hosts when integrated with resistance genes [38].

2.7.6. Integrated Striga Management

No any single solution is likely to offer long-lasting solution to the serious problem of parasitic weeds.

Integration of striga resistant sorghum varieties (Gobiye, Abshir, Birhan, Hormat, and Gedo) with water conservation practices using tie-ridges and soil fertility amendment by optimum rates of inorganic fertilizers (UREA and DAP) plays a crucial role in striga management in sorghum [32]. Ejeta, [39] also concluded that integration of resistant cultivars with application of optimum rate of chemical fertilizer and soil moisture conservation using tied ridges significantly increased grain yield by reducing infestation by *Striga*. Also, the use of resistant sorghum genotypes that are compatible with FOS and VAM, biocontrol agents of *Striga*, together with host plant resistance could promote integrated *Striga* management (ISM). An ISM strategy that combines the use of *Striga* resistant crop varieties compatible with *FOS* is cost effective, environmentally friendly and can easily be adopted by smallholder farmers [36]; [40]. However, ISM is yet to be commercialized in many sorghum producing countries. Correspondingly the sequential application of pre-emergence herbicide (Dual gold) and post emergence herbicide (2, 4-D) is effective against *Striga* weed in sorghum in Ethiopia [41].

3. Conclusions

Striga spp. are among serious parasitic weeds of cereal and pulse crops in many countries of Africa. They are root holoparasites and rely on host plants to complete their life cycle. *Striga hermonthica*, *Striga asiatica*, *Striga gesnerioides*, and *Striga aspera* are the most wide spreading among 40 *Striga* species. Maize, rice, sorghum, pearl millet, finger millet, sugar cane and cowpea are hosts for *Striga* spp. They cause drastic crop yield losses. The *Striga* seed persistence in the soil for long period of time, the ability to produce large number of seeds per plant, ability to adapt to wide range of climatic conditions, its high synchronization with host plants, nature of attachment to the hosts and association between host and parasite made their management difficulty.

However, cultural practices such as long-term rotational cultivation of cereal crops with legumes or other crops unaffected by the parasite is effective in managing the weed. Besides, biological control by use of parasitic fungi (*Fusarium oxysporum* and Vesicular arbuscular mycorrhiza) play a role in managing the weed. In addition, chemical control with imidazolinone herbicide (imazaquin), ethylene gas dicamba and 2,4-D are effective to control striga in cereal crops in extreme cases. Integrated use of striga resistant host varieties with water conservation practices using tie-ridges and soil fertility amendment and use of parasitic fungi (*Fusarium oxysporum* and Vesicular arbuscular mycorrhiza) is effective in control, economically safe, socially acceptable and environmentally friendly than a single control measure.

4. The Way Forward

Since the current status of *Striga* is remarkably on increasing trend, it is recommended to: -

- 1) Create awareness in the community about the threat and management options of the weed.
- 2) Detect and monitor early since they are critical for the management of striga, as successful eradication is only possible when infestations are small.
- 3) Search for more improved or alternative approaches in managing the weed.
- 4) Promote Integrated Striga Managements such as;
 - a). Integration of striga resistant sorghum varieties (Gobiye, Abshir, Birhan, Hormat, and Gedo) with tie-ridges water conservation and soil fertility amendment
 - b). Integration of resistant host genotypes that are compatible with biocontrol agents (FOS and VAM)

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