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Susceptibility of Brazilian varieties of maize and upland rice to Striga (*Striga asiatica*)

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Foreword

This communication registers authors' impressions on the parasitism of Striga (Striga asiatica (L.) Kuntze) in Brazilian varieties of maize and dryland rice that were introduced in Mozambique. It was a rare opportunity to learn about this plant parasite in its native habitat, as it does not naturally occur in Brazil, although ecological conditions are favorable for its development. It is an important quarantine plant rigorously checked out of the country, because of the risks it poses to extensive Brazilian pasturelands and cereal cropland. We hope this report calls the due attention and helps to build up knowledge on the subject.

Alexandre Alonso Alves
Head of Embrapa Agroenergia

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Introduction

It is reported field observations regarding the interaction between the parasitic weed Striga (*Striga asiatica* (L.) Kuntze) and the Brazilian varieties of maize BRS 2022 e BRS 2043, and of upland rice BRS Sertaneja, BRS Primavera, BRS Pepita, BRS Serra Dourada e BRS Esmeralda. These varieties were introduced for the first time in a Striga infested area in the Province of Nampula, Northeast of Mozambique. Local climate is subtropical, with a concentrated rainy season (December to April), followed by a severe dry season. Predominant soil is a quartzarenic neossol, of low natural fertility. The occurrence of Striga was commonly observed in local native forage grasses, maize, sorghum and pearl millet. All Brazilian varieties introduced were susceptible to Striga infection, characterized by loss of vigor and growth, while the parasite thrives, firstly in the roots and later sprouting above-ground to flourish and seed production. A field experiment with maize BRS 2022 showed a negative correlation between grain productivity and Striga infection. As the Brazilian edaphoclimatic conditions are similar to those of Mozambique, it is important to be aware of the potential risks Striga poses if accidentally introduced into the country. These observations highlight the relevance of knowing about Striga biology and development.

First impressions

Brazil is still free of Striga and no one would recognize it at first glance. After almost 40 years of agronomic practice, we first learned about its parasitic potential without actually seeing the plant. Within a field experiment set up in Muriaze, near Nampula, Mozambique, with regular rains and enough soil moisture, amongst rows of well-developed maize plants there were two rows of maize plants with stunt growth and wilting symptoms (Figure 1). An experienced local Agronomist went straight to the point: it is the “pequeno-feiticeiro” (small-witch, or witchweed), as

Striga is locally known. He added that the Striga was feeding on the plant's roots and when strong enough it would sprout out of the ground to blossom.

Photo: Cesar Heraclides Behling Miranda

Figure 1. Maize plants in quartzarenic neosol in Nampula, Mozambique, with typical initial signs of Striga infection, with retarded development and water deficiency symptoms. Plants in the back are free of Striga and show a normal growth. First plant left holds a fully developed Striga, with stems covered with red flowers.

Surely, almost four weeks afterwards Striga was fully developed above ground, with stems covered with beautiful red flowers, which was later identified as *Striga asiatica* (L.) Kuntze (Figure 2). Meanwhile, the infected maize plants were so underdeveloped that they never reached the flowering stage. Many other plants in the adjacent rows became also infected and showed restrained growth, although not as bad as those infected on earlier stages.

Photo: Cesar Heraclides Behling Miranda

Figure 2. Typical flowers of *Striga asiatica* (L.) Kuntze infecting maiz and dry land rice.

Striga is a common plant in that area and large part of Africa, indistinctively infecting native grasses such as *Andropogon gayanus*, *Digitaria exilis* e *Hyparrhenia involucrate* (Jonhson et al., 1997), sugar cane (Mbogo; Osoro, 1992) and cereals such as sorghum, millet and both rice varieties of *Oriza sativa* and *O. glaberrima* (Figure 3). The damage to the plant´s development is worrisome (Figure 4), sometimes impairing the whole farmer’s crop (Figure 5).

Photos: Cesar Heraclides Behling Miranda

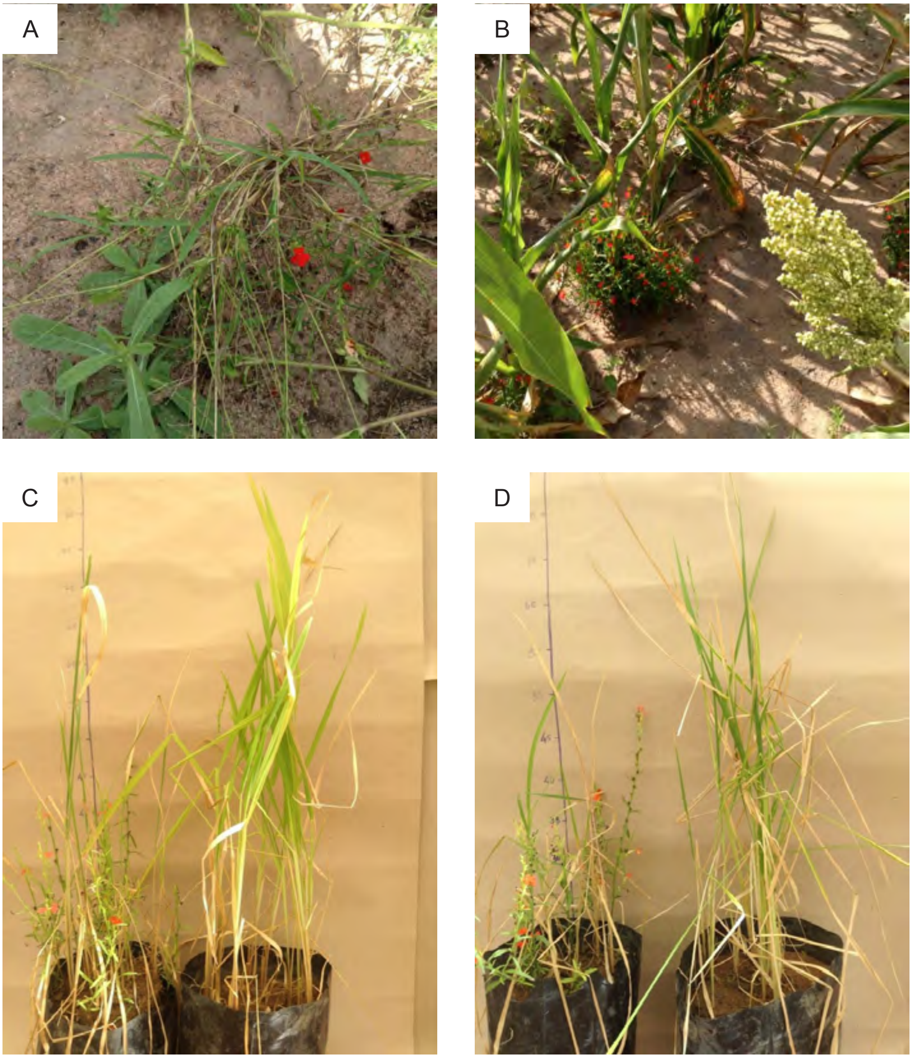

Figure 3. Striga infection of an unidentified local grass (A), a local sorghum variety (B) and two unidentified rice varieties from Cabo Delgado Province, North of Mozambique (C, D). Striga pods in (D) were harvested once they sprout out above-ground, thus most of the damage happened when the parasite was infecting the plant´s roots. Plants in (C) and (D) did not fulfil their growth cycles because of parasitism.

Photo: Cesar Heraclides Behling Miranda

Figure 4. Development of the Brazilian maize variety BRS 2022 free or infected with Striga (plants with red flowers in the soil level). Muriaze, Nampula, Mozambique, 2014.

Photo: Cesar Heraclides Behling Miranda

Figure 5. Smallholder field with a local maize variety highly infected with Striga.

General description of Striga

Striga is a plant native to Africa, Asia and Oceania, with preference of semi-arid, tropical areas, and soils of low fertility. It is an annual obligate root hemiparasite, without roots, which connects itself directly to the host xylem using haustoria (Figure 6), a specialized modified root for parasitic absorption of water, organic carbon and nutrients (Tesitel et al., 2010; Yoshida et al., 2016). It somewhat mimics Mistletoe, the well-known parasite of bushes and trees, although being far more aggressive to the host (Okubamichael et al., 2016). Such aggressivity may be assessed by the work of Parker (1984). He mentions that a single plant of *Striga hermonthica,* with less than 1 mg of dry weight, was responsible for a 400 mg of sorghum dry weight loss up to its fourth week of growth. Sorghum dry weight loss was 900 mg in the fifth week, while the parasite dry weight increased to 13.5 mg. He hypothesized that perhaps Striga inoculates in the host some compost that unbalances its hormonal system. Striga produces several toxic compounds (Rank et al., 2004), but it is not yet clear how they affect plant development out of draining their nutritional resources. For sure, hosts have their photosynthetic rate reduced, indicating a lesser fixation of radiant energy into organic carbon compounds, which could be related with carbon drained by the parasite. For instance, Gurney et al. (1999) measured a 29% reduction in the photosynthetic rate of *S. hermonthica* infected sorghum plants in comparison to striga-free plants. Also, Press et. al. (1987) reported a 62% reduction of *S. asiatica* infected sorghum plants.

Photo: Cesar Heraclides Behling Miranda

Figure 6. Above-ground biomass and roots of dryland rice variety BRS Pepita infected by *S. asiatica*. Biomass of Striga on the right, showing absence of roots.

There are between 30 and 35 species within the genus *Striga*. Number varies due to taxonomic uncertainties and multiple subespecies. However, the commonest are *S. asiatica* (L.) Kuntze, *S. gesnerioides* (Willd.) Vatke and *S. hermonthica* (Del.) Benth. Most Striga species parasites members of the poaceae (grass family), *S. gesnerioides* may also infect dicotyledons, especially Cowpea (*Vigna unguiculata*). *S. asiatica* shows a broader geographic dispersion (Cochrane; Press, 1997). Several studies present detailed descriptions of Striga's biology, infection mechanisms, reproduction and control alternatives (Musselman, 1980; Berner et al., 1995; Oswald, 2005; Rich; Ejeta, 2008; Scholes; Press, 2008; Atera et al., 2011; Spalek et al., 2013; Cardoso et al., 2014;; Kudra et al., 2014; Commonwealth Agricultural Bureaux International, 2017; Plantwise, 2017;).

Striga does not cause major disruptions in its natural habitat, as hosts co-evolved to tolerate it. On the other hand, it is aggressive to introduced cereals and grasses, often preventing their growth (Commonwealth Agricultural Bureaux International, 2017; Parker, 2012). Research in 12 West districts of Kenya, encompassing 1200 farms, showed 40% losses in Striga infected maize, an American native crop introduced to Africa (Ndwiga et al., 2013). Similar study in Nigeria shows losses between 0% and 100% (Amaza et al., 2014). Economic studies estimate maize production losses varying 20% to 100% in several African countries, with annual farmers revenue loss around one billion USD (Teka, 2014; Dawud, 2017). Infestations sometimes become too strong, causing farmers to abandon their land and move to other areas.

S. asiatica is a quarantine weed pest still not found in Brazil, classified under a high economical risk potential Fidelis et al., 2018; Brasil, 2020). Overall, any member of the Orobanche family, to which the *Striga* genus belongs, is considered a quarantine plant in the country. It is considered among the ten high potentially risky weed plants to Brazilian agriculture (Spadotto et al., 2014), especially to maize crops. As it may produce 25 to 200 thousand seeds, averaging between 0.1 and 0.3 millimeters, and weighing around 3.7 micrograms (Figure 7), that may subsist viable for over 20 years (Cochrane; Press, 1997), one can imagine the actual risks it poses if accidentally introduced into an area favorable to its growth and cropped with an suitable host . It was introduced accidentally in the USA in North and South Carolina in the years 1950, and was noticed when it already spread around 200 thousand hectares. It is considered now eradicated, due to adapted agricultural practices, but it costs around 250 million USD (Spalek et al., 2013), in a 10 years effort of a devoted team encompassing five universities, a specialized research station and a dedicated model farm (Eplee, 1992).

Photo: Cesar Heraclides Behling Miranda

Figure 7. Stems of *Striga asiatica* taken from dryland rice plants, with seeds.

Susceptibility of Brazilian maize and dryland rice varieties to Striga

Observations presented in this document were obtained on field experiments held as part of the Technical Component of the ProSavana Project, an international cooperation project between Mozambique, Japan and Brazil, aiming to develop the Nacala Corridor, in Mozambique. Research activities encompassed evaluation of local and Brazilian varieties of maize, dryland rice, cowpea, cotton, soybeans in Nampula Province, Northeast of Mozambique, plus varieties of wheat in the Niassa Province, at the Northwest. There were field experiments aiming to adapt best agronomic practices to upheld local production, including best time for planting, phosphorus, potassium and nitrogen fertilization, plant pests and diseases management in the cropping seasons 2012/2013, 2013/2014 and 2014/2015. General results are presented in Annals of two Workshops, held in 2014 and 2015

(Seminário de Divulgação de Resultados da Investigação Agrária no Corredor de Nacala, 2014, 2015).

Soils in Nampula Province are predominantly Quatzarenic Neosols, while in Niassa Latosols are predominant, especially Red Latosols. Experiments in Niassa were held in the surroundings of Lichinga City, located 1,000 m above the sea level. Striga is common in the surroundings, but it was not found in the experimental area. On the other hand, Muriaze area in Nampula, around 500 m above the sea level, showed a generalized infestation of Striga. Added to the slight temperature difference between the two areas, the main factor causing such difference seems to be the status of soil fertility, as Striga establishes better in soils of poor fertility.

It was found that Striga distinctively infected both introduced Brazilian maize varieties BRS 2022 and BRS 4103 (Figure 8) as well as two local varieties, Matuba e Changalane (Figure 9). Infestation was higher in areas where Striga was spotted in the previous year. There was a lower rate of infected plants in experiment with BRS 2022 planted in a closed bushy area turned into cropland. A *S. asiatica* variant with yellow flowers, which is rare, was found only in this area (Figure 10). On the other hand, in adjacent areas previously cropped with cereals or covered with grasses, infection of dry land rice was high. All introduced Brazilian dryland rice varieties, BRS Sertaneja (Figure 11), BRS Primavera (Figure 12), BRS Esmeralda (Figure 13), BRS Serra Dourada (Figure 14) and BRS Pepita (Figure 15) were naturally infected by Striga. Later, the damage caused by the infection was assessed in controlled experiments (data not shown), as can be seen in Figures 16, 17, 18, 19 and 20. General symptoms were similar to those observed in maize. At first, some plants did not grow at the same pace as others in the plant row, presenting permanent signs of water deficiency. Later, when the Striga stems were fully formed and blossoming, plants halted their growth and deteriorated rapidly. Some infected plants managed to reach the reproductive physiological stage, initiating panicles to flower, but all of them were dead before reaching the grain filling stage.

Fhoto: Cesar Heraclides Behling Miranda

Figure 8. Striga infecting the Brazilian maize variety BRS 2043. Field experiment, Muriaze, Nampula, Mozambique, 2014.

Fhoto: Cesar Heraclides Behling Miranda

Figure 9. Striga infecting the Mozambican maize variety Changalane. Field experiment, Muriaze, Nampula, Mozambique, 2014.

Photo: Cesar Heraclides Behling Miranda

Figure 10. Yellow flower variant of *Striga asiatica* infecting the Brazilian maize variety BRS 2022. Field experiment, Muriaze, Nampula, Mozambique, 2014.

Photo: Cesar Heraclides Behling Miranda

Figure 11. Striga infecting the Brazilian dryland rice variety BRS Sertaneja. Field experiment, Muriaze, Nampula, Mozambique, 2014.

Fhoto: Cesar Heraclides Behling Miranda

Figure 12. Striga infecting the Brazilian dryland rice variety BRS Primavera. Field experiment, Muriaze, Nampula, Mozambique, 2014.

Photo: Cesar Heraclides Behling Miranda

Figure 13. Striga infecting the Brazilian dryland rice variety BRS Esmeralda. Field experiment, Muriaze, Nampula, Mozambique, 2014.

Photo: Cesar Heraclides Behling Miranda

Figure 14. Striga infecting the Brazilian dryland rice variety BRS Serra Dourada. Field experiment, Muriaze, Nampula, Mozambique, 2014.

Photo: Cesar Heraclides Behling Miranda

Figure 15. Striga infecting the Brazilian dryland rice variety BRS Pepita. Field experiment, Muriaze, Nampula, Mozambique, 2014.

Photo: Cesar Heraclides Behling Miranda

Figure 16. Striga infecting the Brazilian dryland rice variety BRS Primavera. Greenhouse controlled experiment, Nampula City, Nampula, Mozambique, 2015.

Photo: Cesar Heraclides Behling Miranda

Figure 17. Striga infecting the Brazilian dryland rice variety BRS Serra Dourada. Greenhouse controlled experiment, Nampula City, Nampula, Mozambique, 2015.

Photo: Cesar Heraclides Behling Miranda

Figure 18. Striga infecting the Brazilian dryland rice variety BRS Esmeralda. Greenhouse controlled experiment, Nampula City, Nampula, Mozambique, 2015.

Photo: Cesar Heraclides Behling Miranda

Figure 19. Striga infecting the Brazilian dryland rice variety BRS Pepita. Greenhouse controlled experiment, Nampula City, Nampula, Mozambique, 2015.

Photo: Cesar Heraclides Behling Miranda

Figure 20. Striga infecting the Brazilian dryland rice variety BRS Sertaneja. Greenhouse controlled experiment, Nampula City, Nampula, Mozambique, 2015.

This is not the first reference to the susceptibility of Brazilian dryland rice varieties to Striga. Johnson et al. (1997) demonstrated that the variety IAC 165, the most used in Ivory Coast by then, was severely affected by *S. aspera*, *S. hermonthica* and *S. asiatica*. They found in a field study that around 17 stems of *S. aspera* per square meter, equivalent to three Striga plants, suffice to reduce 50% of the grain production. Rodenburg et al. (2017) in a study with several varieties of dryland rice in Tanzania, Kenya and Uganda, also confirmed this variety as highly susceptible to *S. asiatica* and *S. hermonthica*.

It is difficult to observe effects of Striga to individual rice plants, since rice planting in rows keeps a tight space between plants. It is easier with maize, which keeps at least 20 cm space among individual plants in the line. As such, it was observed that single plants in a spot or even several ones on the planting line were affected by Striga. This spacing allowed us to take some measurements to evaluate the possible correlation between the number of infected plants and maize development and productivity.

In the 2013/2014 cropping season such measurements were taken in a field experiment encompassing different rates and ways of phosphorus application to maize variety BRS 2022, that is:

1) Control (0 P_2O_5 soil fertility deficiency correction + 0 P_2O_5 maintenance (application after 45 days of plant emergence).

2) 0 P_2O_5 deficiency correction + 80 Kg/ha P_2O_5 maintenance spread all over the planting area.

3) 90 Kg/ha P_2O_5 incorporated into the planting area + 0 P_2O_5 maintenance.

4) 90 P_2O_5 correction incorporated into the soil + 80 P_2O_5 maintenance.

5) 90 Kg/ha P_2O_5 corrected spread + 0 P_2O_5 maintenance.

6) 90 Kg/ha P_2O_5 correction, spread + 80 Kg/ha P_2O_5 maintenance.

7) 22.5 Kg/ha P_2O_5 correction, in the planting line + 0 P_2O_5 maintenance.

8) 22.5 Kg/ha P_2O_5 correction, in the planting line + 80 Kg/ha P_2O_5 maintenance.

9) Soil was initially limed with 1 ton/ha calcitic lime and fertilized at planting with 15 kg/ha K_2O and 30 kg/ha N, as urea. Treatments were set in a randomized block design, with four replications. Every replication was a parcel with five rows 6 m each, spaced 0.90 m, totalizing 27 m^2. Space between blocks was1.5 m.

Twelve seeds of the variety BRS 2022 were planted per lineal meter, in 9/1/2014, leaving 2 seeds per spot, 20cm apart. Full emergency occurred 6 days later, when plants were thinned to one plant per spot.

A month later another 15 kg/ha K_2O and 30 kg/ha N were applied in the planting line. Plants blossomed around 3/3/2014, and were harvested when grains showed lower than 20% humidity on 27/5/2014.

On 27/3/2017 it was registered the number of all maize plants in the parcel as well as the number of those infected by Striga, estimated by at least one associated Striga blossomed stem. Data was used to establish the number of infected plants per block, which was later correlated to the total productivity of the block. The eventual effects of Treatments was not considered, allowing to correlate the results of 32 blocks altogether.

It is known that the number of emergent Striga plants associated to a host is highly variable and does not have a direct effect on the host stress (Musambasi et al., 2002), but it is the most consistent and discriminative characteristic to asses host tolerance or susceptibility, being commonly used as a breeding and selection parameter (Rodenburg et al., 2005).

Such indirect measure allowed estimating the potential damage caused by Striga to this maize variety. There was a negative and significant correlation (Pearson Correlation = -0,455, $P<0.05$, $n = 32$) between the number of infected plants and productivity (Figure 21). This results agrees with frequent reports of the deleterious effect of Striga on maize (Badu-Apraku et al., 2013; Dovala; Monteiro, 2014), as well as in sorghum (Gurney et al., 1999; Rodenburg et al., 2005) and rice (Cissoko et al., 2011; Rodenburg et al., 2017).

Similar and variable levels of infections were also observed in all others Brazilian maize and dryland varieties studied in these field experiments, despite of improved agronomic management, level of fertilizers applied or control of pests and diseases. Which is true with the nature of Striga infection, which happens before any major intervention can be made.

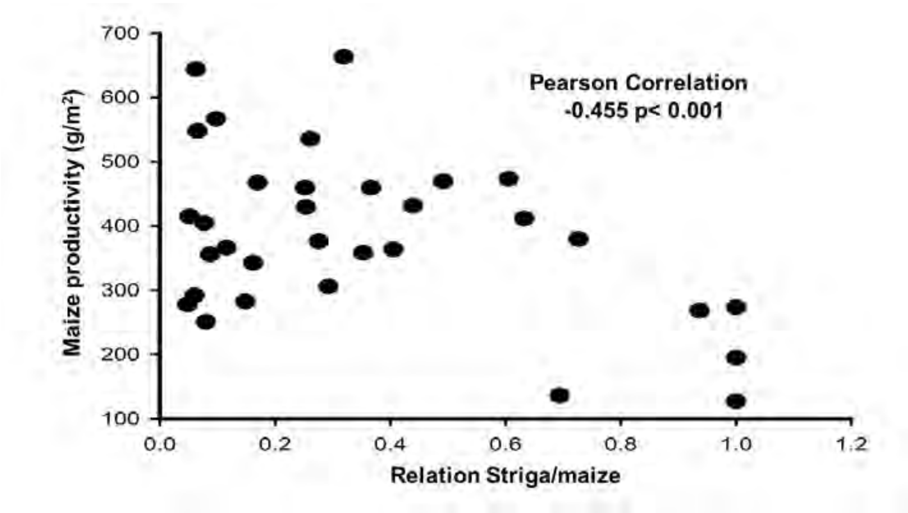

Figure 21. Relation between number of Striga per plant and productivity of the Brazilian maize variety BRS 2022.

These observations made in Africa suggests that indeed Striga poses a serious threat to Brazilian agriculture, which is strongly based in cereals cultivation and husbandry mostly with grasses introduced form Africa, such as *Panicum* spp. and *Urochloa* spp. We have observed Striga infecting both species in fields of Malawi (Figure 22).

Photo: Cesar Heraclides Behling Miranda

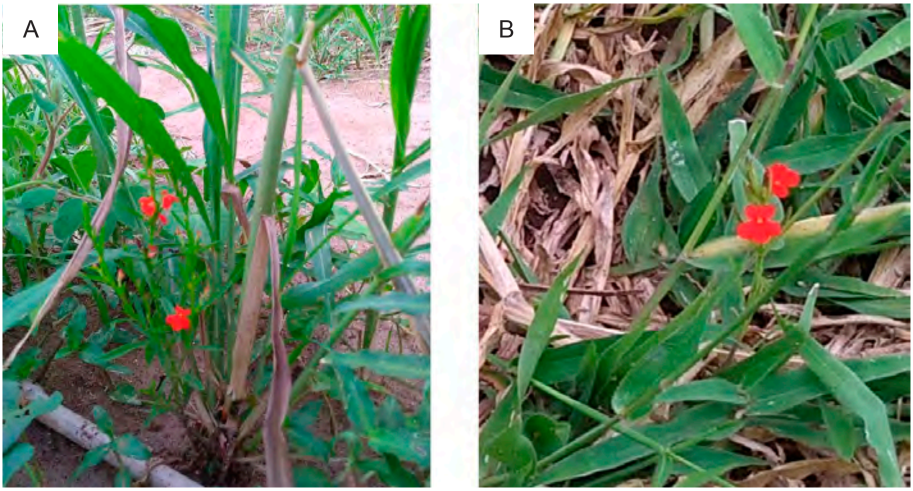

Figure 22. Striga asiatica infecting two *Urochola* spp. grasses, possibly *U. brizantha* (A) and *U. decumbens* (B), both commonly used in Brazilian pastures. Photo taken during a field trip to Mallawi, 2018.

As mapped by Nail et al. (2014), soil and climatic conditions in the country are suitable for the associated development of Striga. Thus, it is strongly recommended due sanitary measures and monitoring to avoid its introduction in Brazil.

At the same time, it is necessary to develop knowledge on this important parasite, aiming to deal effectively in its control if the need ever arise. As an example, the identification of the chemical route that opens the gates to the parasitism and its occurrence in Brazilian most used grasses and cereals varieties may be a way to prepare for a quick development of resistant varieties, without the need to actually work with this parasite and risk its introduction in the country.

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