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Drought-tolerant *Desmodium* species effectively suppress parasitic striga weed and improve cereal grain yields in western Kenya

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ABSTRACTS

The parasitic weed *Striga hermonthica* Benth. (Orobanchaceae), commonly known as striga, is an increasingly important constraint to cereal production in sub-Saharan Africa (SSA), often resulting in total yield losses in maize (*Zea mays* L.) and substantial losses in sorghum (*Sorghum bicolor* (L.) Moench). This is further aggravated by soil degradation and drought conditions that are gradually becoming widespread in SSA. Forage legumes in the genus *Desmodium* (Fabaceae), mainly *D. uncinatum* and *D. intortum*, effectively control striga and improve crop productivity in SSA. However, negative effects of climate change such as drought stress is affecting the functioning of these systems. There is thus a need to identify and characterize new plants possessing the required ecological chemistry to protect crops against the biotic stress of striga under such environmental conditions. 17 accessions comprising 10 species of *Desmodium* were screened for their drought stress tolerance and ability to suppress striga. *Desmodium incanum* and *D. ramosissimum* were selected as the most promising species as they retained their leaves and maintained leaf function for longer periods during their exposure to drought stress conditions. They also had desirable phenotypes with more above ground biomass. The two species suppressed striga infestation, both under controlled and field conditions, and resulted in significant grain yield increases, demonstrating the incremental capability of *Desmodium* species in striga suppression. These results demonstrate beneficial effects of *Desmodium* species in enhancing cereal productivity in dry areas.

1. Introduction

Production of cereal crops, principally of maize (*Zea mays* L.) and sorghum (*Sorghum bicolor* (L.) Moench) in many regions of Africa is constrained by a complex of biotic and abiotic factors, with parasitic weeds of the genus *Striga* being among the most serious. There are about 23 species of *Striga* in Africa, of which *Striga hermonthica* (Del.) Benth., commonly known as striga, is the most socio-economically important constraint in cereal cultivation in eastern Africa (Gressel et al., 2004; Gethi et al., 2005). Infestation by striga causes grain yield losses of up to 100%, amounting to estimated annual losses of $40.8 million (Kanampiu et al., 2002), and these effects are most severe in degraded environments with low soil fertility and low rainfall, and in subsistence farming systems with few options for use of external inputs (Gurney et al., 2006).

Striga germinates close to its hosts in response to specific chemical signals from the root exudates of the host or certain non-host plants (Hooper et al., 2009), indicating an ingenious adaptation and integration with the hosts (Bebawi and Metwali, 1991). Following germination, the radicle grows and, when approaching the host root cells, undergoes haustoriogenesis giving rise to the functional attachment organ through which parasitism is initiated (Hooper et al., 2009, 2015). The significant reductions in crop yields realized from striga infestations result from a series of physiological changes in the host plants following striga parasitism. These include weakening of the host, wounding of its outer root tissues and absorption of its supply of moisture, photosynthates and minerals (Tenebe and Kamara, 2002). There is also a “phytotoxic” effect expressed within days of attachment to its host whose underlying mechanism has not yet been established (Gurney et al., 2006).

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Control of striga has been complicated by the abundant seed production by striga plant, longevity of the seed bank, and a complicated mode of parasitism. Nonetheless, a number of control options, such as imidazolinone resistant maize varieties whose seed is coated with imidazolinone herbicides to control striga, have been developed (Kanampiu et al., 2003). One of the most effective ways of managing striga is the use of forage legumes in the genus *Desmodium* (Fabaceae) as an intercrop which provides the key chemical components for inhibiting development of striga in the field (Khan et al., 2008; Midega et al., 2014). *Desmodium* spp. suppress striga through a combination of mechanisms, including abortive germination of striga seeds that fail to develop and attach onto the hosts' roots (Khan et al., 2002; Tsanuo et al., 2003).

Climate variability has in the recent past become a serious threat to food production in SSA, largely due to the rainfed nature of much of the farming systems. Notably, there have been progressive increases in atmospheric temperatures, extended drought periods and reduced and erratic rainfall (Midega et al., 2015). Associated with these has been significant degradation and loss of arable land (Oldeman et al., 1990), cumulatively resulting in significant negative effects on food production, crop season length, and higher-order social impacts, including food insecurity (Sivakumar, 1993). There is thus a need to adapt effective cropping strategies such as the *Desmodium*-based system to climatic variabilities to ensure sustainable food production and environmental conservation (Midega et al., 2015). Our previous studies demonstrated effective control of the parasitic striga by the drought-tolerant *Desmodium intortum* (Mill.) Urb. Here, we report efforts to identify additional drought-tolerant *Desmodium* spp. to expand options available to smallholder farmers in agro-ecologies with varying degrees of drought and degraded soil conditions. Specifically, we sought to (i) establish drought tolerance in selected *Desmodium* spp., and (ii) evaluate their effectiveness in striga suppression, both under controlled and farmers' fields in western Kenya.

2. Materials and methods

2.1. Plants

Seeds of accessions of various *Desmodium* species were obtained from the International Livestock Research Institute (ILRI) forage plants gene bank (Ethiopia), Desert Legumes Program - University of Arizona (USA), and the USDA-ARS Plant Genetic Resources Conservation Unit (USA). The accessions were initially planted at *icipe*-Thomas Odhiambo campus (*icipe*-TOC), Mbita Point (0°25′S, 34°12′E; 1200 m above sea level), western Kenya, and examined for above-ground allometries to allow for a pre-selection of candidate accessions with desirable phenotypes: high biomass and low growth habit (for use as intercrops). From the initial observation trials, 17 accessions representing 10 *Desmodium* species with desirable phenotypes were selected for screening for drought tolerance. These were *D. dichotomum* (Willd.) D.C., *D. tortuosum* (Sw.) D.C., *D. uncinatum* (used as check), *D. ramosissimum* G. Don., *D. repandum* (Vahl.) D.C., *D. distortum* (Aubl.) J.F. Macbr., *D. incanum* D.C., *D. grahamii* A. Gray, *D. heterophyllum* (Willd.) D.C. and *D. psilocarpum* Gray.

2.2. Screening Desmodium species for drought tolerance

2.2.1. Growth environment and drought stress treatments

Single plants of the candidate accessions were grown in semi-restricted soil columns comprising white plastic bags measuring 60 cm deep and 26 cm wide filled with black cotton soils as the growth medium in a screen house at *icipe*-TOC. The soil columns were fitted with two 1-cm drainage holes at the base and mounted on 30 cm high wire mesh covered metallic benches to avoid direct contact with the ground. The minimum and maximum daily temperatures in the screenhouse during the period of the experiment averaged 17 °C and 35 °C, respectively. The plants were initially established and maintained under adequate soil moisture conditions for eight weeks and then subjected to 10 continuous weeks of exposure to three soil water regimes: severe drought stress (W3), moderate drought stress (W2) and a well-watered control (W1). In the severe water stress treatment, the plants were not watered for the 10 weeks. For the moderate drought stress treatment the plants received 125-mm of water uniformly distributed over the 10 weeks and delivered every two days through irrigation by hand. For the control treatment the plants were watered every two days to near field capacity for the duration of the trial.

Progression to wilting of above ground biomass of different *Desmodium* accessions exposed to 10 weeks of severe drought stress was visually monitored weekly and scored as either wilted or not. A plant was scored as wilted when signs of wilting were observed on leaves from the base of the plant to terminal whorl and shoots. At the end of the 10 weeks of trial the number of days an accession took to wilt was recorded.

2.2.2. Leaf water content

Plant leaf water status as affected by the drought treatments was evaluated using methodologies adapted from Abraham et al. (2004) and Bouchabke et al. (2008) using a smaller number of accessions that had shown ability to withstand extended periods of drought, and with useful growth habits as above. These were *D. repandum*, *D. incanum* and *D. ramosissimum*, with *D. uncinatum* being included as a control check. Recently fully expanded *Desmodium* leaves were sampled weekly at 12:00pm, noon when evapo-transpiration peaked, starting at the end of the sixth week after the drought stress treatments commenced. Four leaf samples were sampled from each of the three water treatments for each of the *Desmodium* species and their fresh weights were individually recorded. The leaves were then put in separate paper envelopes and oven-dried at 85 °C for 24 h, after which the final weights of the dried leaves were measured. Leaf water content (LWC) was determined using the equation:

$$LWC = ((FW - DW)/FW) \times 100$$

Where FW is leaf fresh weight and DW is dry weight of leaves after being oven-dried.

2.3. Leaf electrolyte conductance and cell membrane stability

Leaf electrolyte conductance was measured, using procedure adapted from Hirashima et al. (2009), to estimate ability of the four *Desmodium* spp. to accumulate leaf electrolytes in response to drought treatments, and to maintain integrity and stability of leaf cell membranes as a physiological indicator of drought stress tolerance. Leaf sampling and conductance measurements were carried out weekly for three consecutive weeks starting at the end of the sixth week after the drought tolerance treatments commenced. For each of the *Desmodium* species grown under the three water regimes, the uppermost fully expanded leaf trifoliate was selected and the three leaflets individually cut, excluding the petioles. Each set of the harvested leaflets were immediately placed and covered in 50-ml eppendorf plastic tubes to minimize water loss. Fresh weights of the sampled leaflet sets were recorded to enable expression of electrolyte measurements per unit of leaf biomass. Each of the three leaflets in a sample set was then cut into four leaf quarters and then placed back into the eppendorf tubes where they were rinsed three times with distilled deionized water