

Screening for Resistance to *Striga Hermonthica* in Mutagenized Sorghum and Upland Rice in Burkina Faso



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Abstract *Striga hermonthica* is a major production constraint to sorghum and upland rice in Burkina Faso due to poorly structured and nutrient deficient soils, unreliable rainfall and high temperatures that limit the cropping season. A mutation breeding project using gamma rays as the mutagen was undertaken to improve *Striga* resistance in these two cereal crops in farmer preferred varieties adapted to the unique challenges of Burkinabe agriculture. This chapter describes the screening protocols used to select sorghum and upland rice mutants with improved productivity over unmutagenized lines.

Keywords Mutation breeding • *Striga hermonthica* • Resistance • Tolerance • Sorghum • Upland rice • Burkina Faso

Introduction

Burkina Faso is a Sahelian country with a sub-tropical climate characterized by a transition zone between the Sahel in the North (average annual rainfall of 350 mm) and the Sudanian zone in the South (average annual rainfall 1000–1200 mm). Its rainy season lasts four to five months (May–September) which is the main agricultural production period (Burkina Faso MAWF 2011). Cereal production in Burkina Faso is primarily subsistence-based and rainfed and therefore vulnerable to climate change, especially in the North where higher temperatures limit the cropping cycle duration. More than 85% of the working population is involved in agriculture, which

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contributes nearly a third of gross domestic product as well as accounting for more than 85% of export earnings (Burkina Faso MAWF 2011). Cereals are the main food resource for the population, with sorghum at the top (27% share of agricultural production) followed by pearl millet (25%), maize (8%) and rice (1%) (IFPRI 2017). These cereal crops are predominantly (99%) grown on rain fed lands.

Burkina Faso is the third largest producer of sorghum in Africa (behind Nigeria and Sudan) with an average yield of about 1000 kg/ha (Mundia et al. 2019). Sorghum is mainly grown in the Guinea-savannah and Sudano-savannah regions in areas receiving 700–900 mm annual rainfall. Total national sorghum production area is about 1.4 M ha (IFPRI 2017). White sorghums are preferred for food and therefore account for three quarters of national production. The rest is red sorghum, used primarily to brew the local beer, *dolo* and only used for food in times of food grain production shortfalls (Mundia et al. 2019). Both types are predominantly traditional cultivars since they are most adapted to the major agricultural constraints of the country, erratic rainfall and poor soils. Soils in Burkina Faso tend to be highly weathered with poor physical structure, low contents of active clay and organic matter, and low nutrient stores, imposing severe constraints to crop yields (Korodjouma 2022). It is precisely these conditions that make sorghum production vulnerable to *Striga*. *Striga hermonthica* occurs in almost all sorghum production areas of the country (Boussim et al. 2011).

Upland rice, for the same reasons, is also highly vulnerable to *S. hermonthica*. Total rice production in Burkina Faso is much less than sorghum, having only a 1% share of national cereal production with a 49,000 ha harvest area (IFPRI 2017). As in other African countries, Burkina Faso's rice consumption is constantly rising while national production barely covers 46% of the population's needs (Barro et al. 2021). Rice imports nearly tripled in the ten years between 1985 (137,185 t) and 2006 (305,180 t) (Burkina Faso MAWF 2011). To reduce dependence on imports, the Burkinabe government follows a National Rice Development Strategy which includes expanding cultivation of upland rice. Rice is produced by one of three cropping systems in Burkina Faso: irrigated, lowland and rainfed upland. Currently, rainfed upland rice accounts for only 10% of the rice land area (so only about 5000 ha) and 5% of national rice production (Barro et al. 2021). However, it could contribute more to national production, particularly if it can be slotted into the rotation systems of the cotton-growing regions in the wetter south. Being less resilient to drought than sorghum, upland rice is adapted to just those regions of Burkina Faso where the annual precipitation reaches or surpasses 800 mm (Burkina Faso MAWF 2011).

Striga resistance and tolerance is critical for sustained rice and sorghum production in Burkina Faso due to prevalent low rainfall, sandy and low fertility soils in low input agriculture which favors *S. hermonthica* (Boussim et al. 2011). Introducing *Striga* resistance into varieties already adapted to the unique challenges of Burkinabe environments and farmer preferences through mutation breeding offers durable protection (Nikièma et al. 2020). The protocols described in this chapter resulted from attempts to introduce *Striga* resistance through gamma irradiation into several Burkinabe sorghum and rice cultivars with susceptibility to the parasitic weed.

Protocols

Collecting *Striga* seeds. Green mature capsules of *Striga* plants without galls are harvested and air dried on large sheets of absorbent paper in the shade at room temperature (25–30 °C) for about 30 days (Fig. 1). Before drying, the top flowers must be removed and samples should be also shaken to remove any soil clods and other debris. When they are drying, the capsules open and release seeds on the absorbent paper. At the end of the drying process, the seeds recovered directly from the paper are considered as first quality while those that will be recovered on another paper after a light threshing are of second quality. Both batches are sieved using 315, 200 and 180 μm mesh sieves, successively. Seeds harvested at the end of the rainy season are dormant and can only be used in experiments after at least 5–6 months to allow the breakage of seed dormancy. Seeds must be stored in cloth containers (plastic and glass should be avoided for long storage) at room temperature or higher (ideally 30 °C).

Determining germination capacity of *Striga* seeds. Before using a new batch of *S. hermonthica* seeds, it is important to know their germinability. Since *Striga* seed require a period of conditioning under moist conditions for 12–14 days before they will germinate, they need to be surface sterilized and handled aseptically during the conditioning period before their response to germination stimulants is performed.

Under a laminar flow hood, place 0.5 g of *Striga* seeds in a 1.5 mL Eppendorf tube (this amount is sufficient for four 12-well plates). Add 70% ethanol to the tube containing the seeds and shake or vortex occasionally for three minutes. Remove the alcohol with a sterile pipet. Rinse once with sterile de-ionized distilled water (ddH₂O). Add 1 mL 3% bleach solution and shake vigorously or vortex until a brownish green color is obtained and allow to sit for five minutes. Shake again and let stand for an additional 2 min. Rinse with sterile ddH₂O at least five times until the rinse solution (sterile water) becomes clear. These multiple washes ensure removal



Fig. 1 Air drying of *Striga hermonthica* inflorescences (flowering stems) with capsules containing the seeds; **a** fresh inflorescences; **b** dried inflorescences

of sterilizing agents, dust, light seeds and plant debris. After removing the last water wash, the seeds remaining at the bottom of the tube should be clear of impurities.

The cleaned seeds may be conditioned in a multi-well plate or in a Petri dish. In both cases, sterile filter papers and plates must be used and transfers done under a laminar flow hood to ensure the seeds are not overtaken by mold or bacteria during the warm wet conditioning period.

Conditioning Striga seed on a multi-well plate. For this protocol, a sterile 12-well plate is used but 24- and 48-well plates can also be used, adjusting the filter paper circle size to fit the individual cells and volume of ddH₂O to saturate the glass microfiber discs in each well. The filter papers are sterilized beforehand by autoclaving. Multi-well plates can be purchased pre-sterilized. Aim for a density of 25 *Striga* seeds per cm² of glass fiber.

Using sterile forceps under a laminar flow hood, place one sterile 20 mm glass microfiber filter paper disc (Whatman GF/A) per well of a 12-well plate. Suspend surface sterilized *S. hermonthica* seeds in sterile ddH₂O. Using a single channel pipettor with sterile tips, take up suspended seeds in 50 µL and distribute *Striga* seeds on each filter to deliver 50–60 *Striga* seeds. Add 300 µL of additional sterile ddH₂O to each well. The total volume in each well is about 350 µL. The filter paper should be thoroughly wetted. Close the multi-well plate with its cover. Incubate them in the dark at 27–30 °C for 12–14 days.

Conditioning Striga seed on a Petri dish. Working in a laminar flow hood, line the bottom of a sterile 100 mm Petri dish with two sterile 90 mm Whatman No.1 filter paper circles.

Distribute 25–30 glass microfiber filter paper discs (Whatman GF/A) on the larger filter paper circles in the plate. Wet with 3 mL of sterile ddH₂O. With the aid of a pipettor with sterile tips, place 25–30 *Striga* seeds on each of the 11 mm discs. Add an additional 1 mL of sterile ddH₂O to the Petri dish, placing it on the directly on the backing paper circle to avoid dispersing the seed on the smaller discs. The filters should be wet but not under water. Add more or remove water with a pipette in contact with the background paper as needed. Seal the Petri dish with Parafilm M[®] barrier film and then wrap the plate with aluminum foil to exclude light. A few Petri dishes can be stacked together before wrapping if more *Striga* seed needs to be conditioned. Incubate in the dark at 27–30 °C for 12–14 days (Fig. 2).

Stimulating Striga seed germination. After the two week conditioning period, the *Striga* seeds can be germinated in the presence of low concentrations of strigolactones, either synthetic (GR24) or natural from host roots. Working under a laminar flow hood, add 30 µL of a 10 ppm GR24 solution to each well if the *Striga* was conditioned in a 12-well plate. Add an additional 270 µL of sterile ddH₂O to each cell of the plate. Replace the plate lid and slightly shake briefly with a horizontal movement back-and-forth. Incubate at 27–30 °C, in the dark for at least 48–72 h.

To *Striga* seeds conditioned in Petri dishes, add 3 mL of a 1 ppm GR24 solution to the plate applying directly onto the background paper. Seal the dish with Parafilm and wrap in aluminum foil. Incubate at 30 °C, in the dark for at least 48–72 h (Fig. 2).

If GR24 is unavailable, the cut-root technique described by Traoré et al. (2011) may be used as an alternative. This technique is based on the use of cereal root

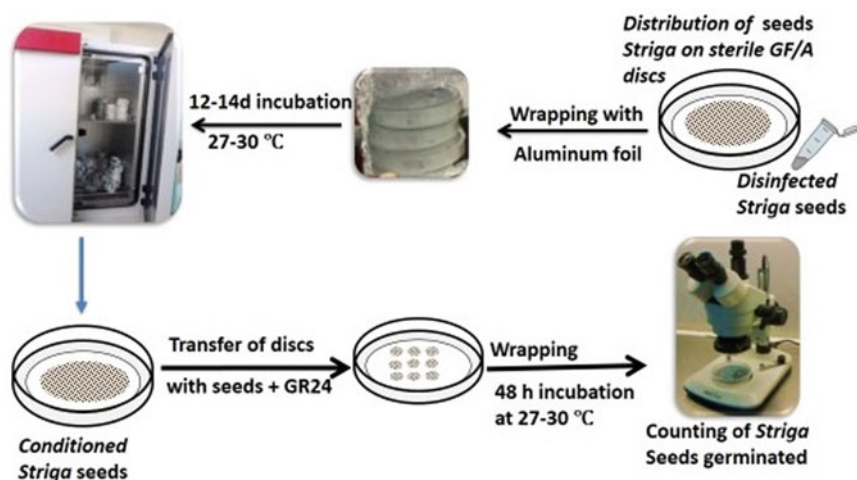


Fig. 2 Illustration of the main steps in assessment of germination capacity of *Striga* seeds using Petri dishes

pieces. In the assessment of *Striga* germination rate, the root of a known *Striga*-sensitive variety is used. For example in sorghum, 14-day old roots are harvested from seedlings grown in pot conditions, washed roughly with water and then cut up in pieces. One gram of the freshly cut sorghum root pieces are then placed in an aluminum foil ring (1.7 cm diameter) to stimulate *Striga* seed germination. Glass microfiber filter discs (Whatman GF/A, 8 mm) carrying conditioned *Striga* seeds are transferred into sterile Petri dishes (9 cm) lined with a double layer of Whatman No.1 filter papers. Discs with seeds are arranged in 4–5 lines (5 discs per radius) around the aluminum foil ring (Fig. 3). The root pieces in the ring are watered with 3 mL of sterile ddH₂O to enable the diffusion of root exudates. The entire root cut technique is illustrated in Fig. 4.

Determining *Striga* seed germination rate. Two to three days after the exposure to germination stimulants (GR24 or sorghum roots), position the plate under a binocular microscope to count both the number of germinated seeds and total number of *Striga* seeds on each disc (Fig. 5). From these counts, calculate the percentage of germination ($= \text{number of germinated seeds} / \text{total number of seeds} \times 100$). Average these values from all discs to determine the germination rate of that particular batch of *Striga* seed.

Screening of cereal mutants for resistance to *Striga hermonthica* under field conditions. Field screening for *Striga*-resistance can start at the M2 generation or if seed is limited, this can be delayed until the M3. For field screening, a minimum of 10,000 M2 plants are screened. As an initial screen following gamma ray mutagenesis, very large populations ($\geq 10,000$ plants) of the early generations (M2–M3) in which recessive mutations leading to *Striga* resistance may be expressed are evaluated in field comparisons to the unmutagenized *Striga* susceptible progenitor line. It is best to start with at least 3–6000 gamma irradiated M1 seeds in order to obtain a sufficient

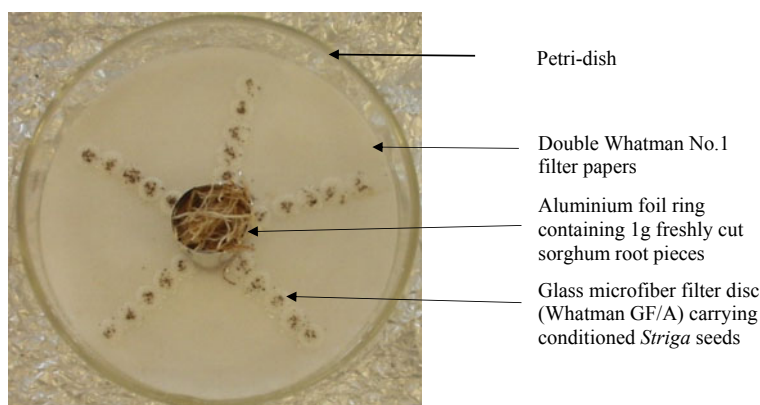


Fig. 3 Representative picture of root-cut technique

segregating M2 population in the range of 10,000 or more to enhance the probability of selecting a targeted mutant. Individual plants should be separated enough to distinguish them from their neighbors. The main criterion in this initial screen is whether an individual mutant plant (derivative of mutagenized seed after one or two generations of self-pollination) appears to be less affected by *Striga* according to the observations taken (e.g. fewer and/or smaller *Striga* emerged around it) relative to the unmutagenized check (Fig. 6). These initial tests concern large populations whose aim is to detect putative resistant mutants. Putative mutants can be advanced by self-pollination to M3 or M4 to confirm the heritability and stability of the *Striga*-resistance trait in subsequent trials.

Field trials should be conducted on historically *Striga*-free ground if available. The plots should be cleared of bushes and trees and their stumps, plowed to a depth of 10–15 cm, breaking up clods and leveling the ground as much as possible. The field should be relatively homogeneous and pre-treated with pesticide to clear termites. The planting area should be away from any tall vegetation that would shade any parts during the day.

For sorghum, the row length should be at least 8 m with 1 m between rows and 0.8 m between plants (Fig. 7). In each planting hole of 5 cm depth, spread approximately 5000 *Striga* seeds of recently tested good germinability. The experimental layout of plots is an “augmented design”, so for each replication, plant the control (unmutagenized parent of the same variety as mutants) on the first row and then repeat after every ten rows of mutant lineages. Label each row indicating at least the name of mutant lineage or parent and the replication number.

For upland rice, the row length should be at least 5 m with 0.5 m spacing between rows and 0.5 m between planting hills. Spread 5000 germinable *Striga* seeds 5 cm deep in each of the hole where an upland rice seed is planted. The experimental set up is an “augmented design”, so for each replication, plant the control (unmutagenized parent line of the mutant) on the first row and then repeat it after every ten rows of

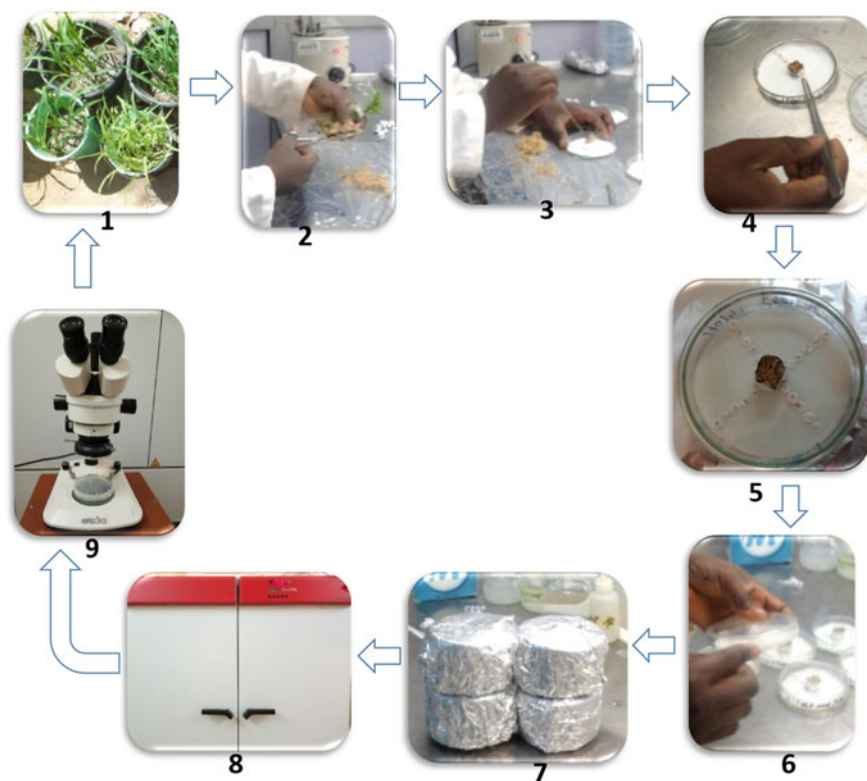


Fig. 4 Illustration of the main steps in carrying out the “cut-root technique” for the stimulation of *Striga* seed germination. (1) Sorghum seedlings are grown for 14 days in pots; (2) cutting of 14-day old sorghum roots into small (< 1 cm) pieces; (3) weighing and inserting 1 g root fragments into the aluminum foil ring; (4) arranging glass fiber discs with conditioned *Striga* seeds around the ring; (5) watering of root-cuts with 3 mL of sterile distilled water; (6) sealing the Petri dish with parafilm; (7) wrapping Petri dishes with aluminum foil; (8) incubating at 28–30 °C for 48–72 h; (9) counting germinated *Striga* seeds under a binocular microscope

mutant lineages. Label each row minimally with the name of mutant or parent and the replication number.

Management of screening plots include mild fertilization, weeding of all but *Striga*, and pest control. Fertilizers should only be applied when the soil is too poor to support cereal crops to modest seed production and doses should be minimal since poor nutrition stimulates *Striga* infection. Host plants should be treated with appropriate pesticides to mitigate pest attacks (insect pest like fall army worm, diseases caused by fungi or bacteria, etc.). Weed the plots twice with hand hoes at the soil surface at two weeks and again at four weeks after sowing, before *Striga* emerge. Any weeding after five weeks needs to be by hand-pulling to avoid disturbing any *Striga* which may emerge anytime after 35 days. Remove all weeds other than *Striga* from plots. The use of herbicide should be avoided from land preparation to harvest.

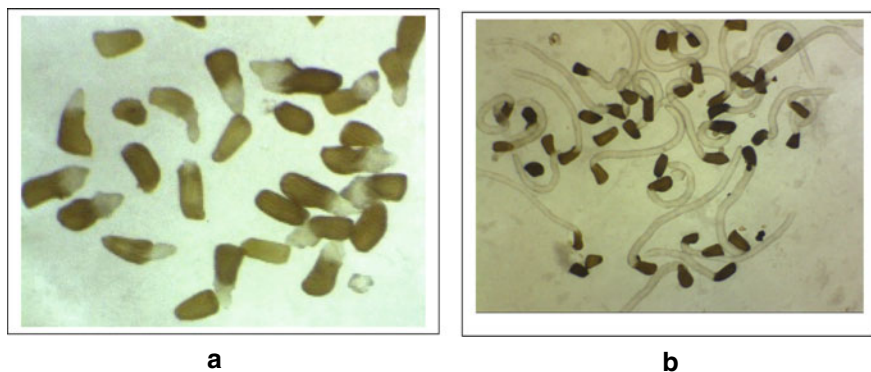


Fig. 5 Germinated *Striga* seeds after 48 h (a) and 72 h (b) after exposure to GR24 or sorghum roots



Fig. 6 Individual sorghum plants in *Striga hermonthica* infested plots late in the initial screening field trial. Putative mutants selected for advanced trials have visibly fewer emerged *Striga* around them (arrow) than unmutagenized checks



Fig. 7 Preparation of field plots marked for planting sorghum and *Striga hermonthica*

Screening in pots under screen-house conditions. Selfed seed from putative *Striga* resistant mutants selected from field M2 or M3 field plots can be verified either in subsequent field plots consisting of multiple progeny of the selected individual or in pots in a screen-house. Screen-house screening is intended to verify, confirm and characterize putative mutants selected under field conditions.

Use plastic pots of adequate size to support plants to maturity (for sorghum, ~ 20 L, e.g., 26 cm × 28 cm) with drainage holes filled with a 2:1 (v/v) mixture of soil and fine sand (Fig. 8). For artificial infestation of pots with *Striga* seeds, 1 kg of sieved sand is roughly mixed with 50 g of *Striga* seeds of which germination capacity is more than 70%. Layer the soil in the pots such that the bulk in the bottom is the 2:1 sand/soil mixture (~ 15 kg). Upon this add a mixture of (~ 3 kg) of the same soil mixture into which was mixed 10 g of the sand/*Striga* seed. The top layer consists of the same 2:1 sand/soil mixture put in the bottom (~ 2 kg). For upland rice, prepare 12 L pots (e.g., 28 cm × 18 cm), adjusting the soil volumes to achieve the same layers as illustrated for the sorghum screening pots in Fig. 8. This technique aims at an infestation rate of approximately 5000 *S. hermonthica* seeds per pot (Marley et al. 1999). Do not plant the cereal seeds yet. When all pots required for the screening are filled with soil substrate, transport them to a screen-house and water to field capacity. Keep them regularly watered so that the soil remains wet to allow conditioning of *Striga* seeds for 12–14 days.

The rice or sorghum can be prepared for sowing after the *Striga* has been allowed to condition in the screen-house pots for at least 12 days. Before sowing cereal seeds

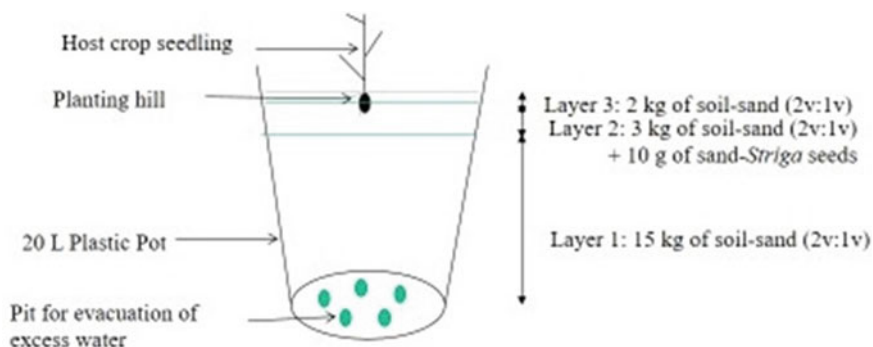


Fig. 8 Schematic representation of screening pot (note volume of soil and *Striga* seed mixture should be adjusted to the size of the pot used)

to be tested, surface-sterilize them with 70% ethanol for 3 min followed by 20% bleach for 5 min. Place these surface-sterilized seeds on sterilized wet filter paper in a Petri dish and incubate at 25–30 °C for 24 h. When the sorghum or rice seeds begin to germinate, with visibly emerged radicles, carefully sow then with forceps in a pre-excavated hole at a depth of 2–3 cm in the pots containing the conditioned *Striga* seeds with a single plant in each pot. Use 3–6 pots as replications for each mutant lineage being tested including positive (*Striga* infested pot + unmutagenized counterpart) and negative (uninfested pot) controls, the replication number will depend on the number of mutants to screen and the available space in the screen-house. Label each pot to indicate the name of mutant, replication number, etc. Keep pots minimally watered to support host plant growth, but not so wet as during the *Striga* conditioning period. Also maintain temperature and light and supply fertilizer sparingly as needed to support normal host plant growth. Apply pesticides or fungicides only if needed to mitigate any health threatening pests during the screening. Use the *Striga*-free control pots as indicators to guide management.

Selection of putative Striga resistant mutants: Observations and records. Detailed selection criteria are impractical in the early generations after mutagenesis (M2 or M3) when screening for possible *Striga* resistance gained through mutation. We used the criterion of fewer emerged *Striga* plants around M2 and M3 individual sorghum plants in the field screening protocol described earlier for 10,000 + plants (Fig. 6). From this screen, putative resistant mutant individual plants were self-pollinated to obtain M4 families of which multiple individuals from putative resistant selections could be more closely examined under *Striga* infestations in field or pots. By the M4, the selected trait (e.g., fewer emerged *Striga*), in so much as it is due to a specific genetic change, is generally fixed, and can therefore be characterized in terms of its impact on the parasitic relationship with *Striga*. It may be affected by other background mutations in the lineage that influence general plant fitness, but these may be sorted out through backcrossing to the original (unmutagenized) line

or through examining multiple plants in advanced generations tracing back to the particular M2 selected individual from which they were derived.

To characterize actual *Striga* resistance gained through mutagenesis, multiple variables may be measured in field and pot trials beyond the initial screen when population size was prohibitive. These include measurements like the time in days from sowing (DAS) to the first *Striga* emergence (Fig. 9a), *Striga* plant number emerged at 70, 90 DAS (Figs. 9b, 10 and 11) and at harvest, *Striga* plant death at 70, 90 DAS and at harvest and a *Striga* plant vigor score at 70, 90 DAS and at harvest (Table 1 and Fig. 12). These measures are compared to *Striga* in infested plots or pots of the original unmutagenized line. They indicate resistance if parasites are reduced in number, slower to emerge, prematurely die or are smaller relative to those on control plants. Resistance therefore depends on *Striga* performance, which is reflective of host plant support of their sustenance and growth.

Striga tolerance, in contrast, is measured by host plant performance under infestation. *Striga* notoriously negatively affects host plant growth. A host plant that succumbs to *Striga*'s negative effects is called sensitive. A *Striga* tolerant plant performs equally or nearly as well whether or not it is parasitized. Gained *Striga* tolerance, which will likely be influenced by reduced parasitism (resistance), may



Fig. 9 *Striga hermonthica* plants at first emergence in field (a) and number of emerged *Striga* at 70 DAS in pot (b) conditions



Fig. 10 *Striga*-infested hills of sorghum plants at 90 days after the sowing



Fig. 11 *Striga*-infested hills of upland rice plants at 70 days after the sowing

Table 1 Scale score of vigor of *Striga hermonthica* plants

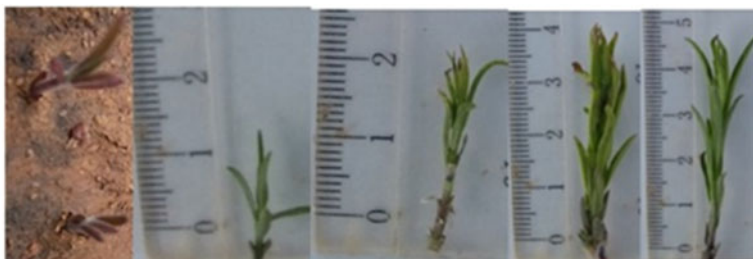
Score	Height of <i>Striga</i> plant (cm)	And/Or	Branch number of <i>Striga</i> plant
1	0		No <i>Striga</i> emerged
2	≤ 5		No branches
3	6–20		1–5
4	21–30		6–9
5	≥ 31		≥ 10

also be measured in these trials by comparing host plant performance with uninfested (*Striga*-free) plots or pots of the same mutant lineage by *Striga* damage scores at 70, 90 DAS and at harvest and through yield components of the host crop like biomass and grain. These must be compared to uninfested plants grown under the same conditions in the trial to indicate true tolerance.

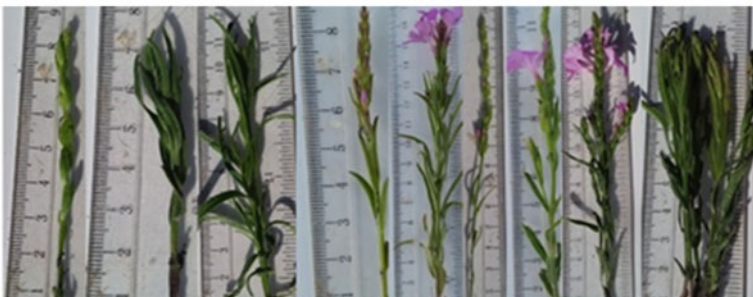
Striga damage can be scored by the percent of bleached or burned leaves, a typical symptom of *Striga* infection. This value is calculated by dividing the number of burned leaves by the total number of leaves and multiplying that value by 100. A more detailed scale (from 1 to 9) considering leaf symptoms due to *Striga* infection described by Kim (1994) can be used that grades a host plant as normal with no visible symptoms of reduced growth or verdancy (1) through increasing stages of severity to complete demise (9) as that shown in Fig. 13.

Verification of putative mutants in pots. Generally, pot screening aims at verifying putative mutant traits observed by the field screening. Because the soil in the pots can be dumped at harvest, attached *Striga* can be separated from host roots after washing away the soil. This allows one to determine the biomass of all attached parasites, as well as obtaining host root and shoot weights and the root:shoot ratio of infested host plants. These additional measures can be used to further define both resistance and tolerance. Resistance may be expressed as reduced *Striga* biomass on the mutant potted plants (Fig. 14) relative to those on unmutagenized control potted plants. Tolerance expressed as milder reductions in host plant shoot height and weight and root weight can be measured by comparing plants in *Striga* infested pots to plants of the same mutant grown in uninfested pots (Fig. 15). *Striga* generally increases host plant root:shoot ratio by stimulating root growth and reducing shoot growth. *Striga* may have less influence on root:shoot ratio in tolerant plants. From such tolerance parameters, indices may be calculated by dividing the measured value from infested pots (e.g. host plant height) by that measured on the same genotype in uninfested pots. Such a value is unfortunately sometimes called a “resistance index”, though it is more precisely an indicator of tolerance. Tolerance is usually influenced by resistance since a resistant plant has fewer parasites and therefore less likely to be affected by *Striga*’s negative impact. Another common measure is percent host plant growth reduction (GR) determined by the equation $GR = \frac{(x-y)}{x} \times 100\%$, where x is an indicator of host plant growth in *Striga*-free pots (e.g., height, shoot or root weight) and y is the same parameter measured on the same genotype under *Striga* infestation. A similar yield reduction (YR) can similarly derived from grain yield substitutions

Score 2



Score 3



Score 4



Score 5

**Fig. 12** Illustrative pictures of *Striga* plant vigor scores



Fig. 13 Premature death of a sorghum plant and no panicle formation due to *Striga* infection

in the formula. These measures, especially those involving underground plant parts, are prohibitively difficult in field grown trials.

Ranking of cereal mutants according to their reaction to Striga hermonthica. Putative *Striga* resistant mutants selected in early generation field screens are ultimately ranked based on additional field and pot testing of their progeny for further characterization. First, each mutant lineage was ranked as susceptible if they showed no significant improvement over their unmutagenized counterpart and dropped from further consideration. Those advanced to later generation trials were classified into one of four phenotypes: resistant, neutral, tolerant and sensitive/susceptible (Table 2). Resistant and tolerant lineages were advanced for further investigation which might include laboratory testing to determine the mechanism of resistance (as in Chapters “[An Agar-Based Method for Determining Mechanisms of Striga Resistance in Sorghum](#)” and “[Histological Analysis of Striga Infected Plants](#)”) and cultivar development.

Protocol validation in the case of mutagenized sorghum and upland rice in Burkina Faso. Application of these protocols to screen gamma irradiated sorghum and upland rice populations succeeded in selecting putative Burkinabe mutants resistant to *Striga hermonthica*. The field screening protocol was conducted on 6770 plants of M3



Fig. 14 Differences in the amount of *Striga* plant biomass influenced by sorghum genotype are obvious by harvest. Left and center panels are putative resistant mutants derived from gamma irradiated lineages, with the unmutagenized control on the right. *Striga* can be removed and weighed at harvest to determine total biomass supported by each host plant



Fig. 15 Various parameters like plant height, shoot biomass, root biomass, root:shoot ratio and leaf damage scores determined from potted host plants (pearl millet pictured here) can indicate tolerance to various degrees of *Striga* infestation by comparing those values with those of the same genotype grown in *Striga*-free pots (left). *Photo credit* Dale Hess

Table 2 Phenotypic classification of a mutant plant according to reaction to *Striga hermonthica*

Classification based on <i>Striga</i> reaction	<i>Striga</i> density 45–60 DAS	<i>Striga</i> density 90–120 DAS	Relative to unmutagenized counterpart	
			<i>Striga</i> biomass* at harvest	Yield components of host crop*
Resistant mutant	0–2 emerged <i>Striga</i>	≤ 5 emerged <i>Striga</i>	Highly reduced	Not affected
Neutral mutant (slightly improved over unmutagenized counterpart)	3–4 emerged <i>Striga</i>	6–15 emerged <i>Striga</i>	Slightly reduced	Affected
Tolerant mutant	≥ 5 emerged <i>Striga</i>	≥ 16 emerged <i>Striga</i>	Slightly higher	Not affected
Susceptible and sensitive mutant (no improvement over unmutagenized counterpart)	≥ 5 emerged <i>Striga</i>	≥ 16 emerged <i>Striga</i>	High	Highly affected

**Striga* plant biomass and host yield components (plant height, grain yield) were determined from potted plants in a screen-house

sorghum families, 3385 plants of M4 sorghum lineages and 3465 plants of M3 upland rice families at Kouaré research Station (11°95'03" N and 0°30'58" E) in the eastern Sudano-savannah region of Burkina Faso. The field soil, levelled to avoid localized ponding (Fig. 7) was sandy-loam, tropical, and ferruginous. During the crop growth, 362.8 mm of rainfall fell over 24 days, representing 43.5% of the annual rainfall of the year. *Striga* infected plants at crop harvest (≥ 3 emerged *Striga* plants per hill) varied from 95.8 to 97.6% for sorghum and 94.7–97% for upland rice within the mutant plants of the same variety. Mutant plants that induced 0–2 emerged *Striga* plants/hill or late emergence of ≤ 3 *Striga* plants/hill (at cereal grain filling stage) or the death of many nearby *Striga* were selected for advanced trials as putative *Striga*-resistant M3 lineages (were from the same M3 head row). These selected *Striga*-resistant lineages represented 1.8–2.7% of all mutant sorghum plants and 2–2.8% of mutant upland rice plants. Six hundred ninety-nine (M3/M4) and 221 (M4/M5) sorghum mutants and 105 M3 and 32 M4 rice mutants were advanced to further trials. The mutant lineages that continued to appear *Striga* resistant in subsequent field trials were advanced to pot screening. Significant results from screening of sorghum mutants in field and screen-house conditions are published (Nikiéma et al. 2020). Screen-house screening confirmed the *Striga*-resistance of two upland rice mutants (Fig. 16).

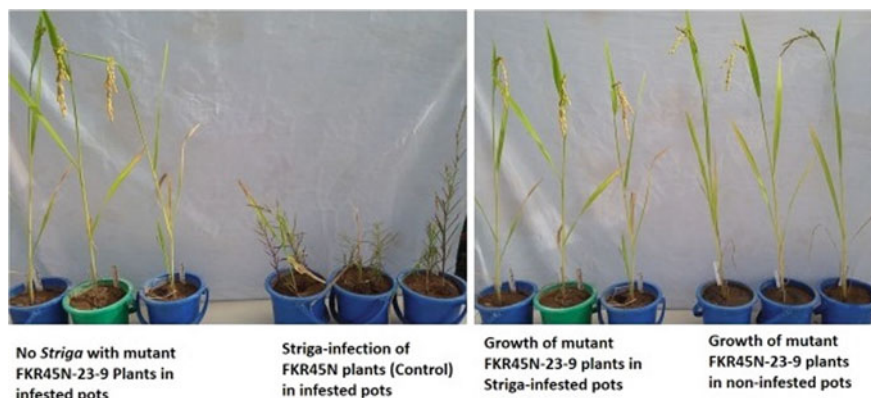


Fig. 16 Example of one *Striga* resistant upland rice mutant selected from gamma irradiated derivatives of a Burkinabe variety. (Left photo) *Striga* emergence in mutant FKR45N-23-9 pots (left) compared to the unmutagenized original line, FKR45N (right). (Right photo) plant growth of the mutant in *Striga* infested (left) compared to uninfested (right) pots

Conclusion

The protocols described in this chapter were successfully used to select *Striga* resistant mutants from gamma irradiated sorghum and upland rice adapted to the challenging environments of Burkina Faso. The narrow window of sorghum and upland rice cultivation in sub-Saharan regions where soils are generally poor and rainfall scarce is quite vulnerable to *S. hermonthica*. Introducing *Striga* resistance through mutagenesis in cultivars adapted to these conditions can help to sustain sorghum and expand upland rice production in the country. Improvements to the field screening trials described in this chapter for *Striga* resistance would be to treat the seeds with pesticides before sowing to prevent losses to termites and birds and to plant just before a rain or to water hills if rain fails to ensure crop emergence. Despite these challenges, some promising *Striga* resistant mutants were selected in both sorghum and upland rice. Further characterization in both laboratory assays (Chapters “[An Agar-Based Method for Determining Mechanisms of *Striga* Resistance in Sorghum](#)” and “[Striga Germination Stimulant Analysis](#)”) and multi-location field trials will determine the ultimate value of this work and lead to cultivars that improve sorghum and upland rice production in Burkina Faso. Similar efforts are described in Chapter “[Mutation Breeding for Resistance to *Striga* Hermonthica in Sorghum and Rice for Sustainable Food Production in Sudan](#)” for sorghum and rice in Sudan and in Chapter “[Phenotyping for Resistance to *Striga* Asiatica in Rice and Maize Mutant Populations in Madagascar](#)” for maize and rice in Madagascar.

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References

- Barro M, Konate KA, Wonni I, Kassankogno AI, Sabot F, Albar L, Somda I, Béna G, Ghesquière A, Kam H, Sié M (2021) Assessment of genetic diversity of rice in registered cultivars and farmers' fields in Burkina Faso. *Crops* 1:129–140
- Boussim IJ, Yonli D, Guinko S, Sallé G (2011) Etat d'infestation, connaissance endogène et approche systématique des espèces du genre *Striga* au Burkina Faso. *Int J Biol Chem Sci* 5:1374–1386
- Burkina Faso, Ministry of Agriculture, Water and Fisheries (2011) National rice development strategy. Retrieved from https://riceforafrica.net/images/stories/PDF/burkina_faso_en.pdf
- International Food Policy Research Institute (IFPRI) and Datawheel (2017) <https://DataAfrica.io>. Accessed Feb 2022
- Kim SK (1994) Genetics of maize tolerance of *Striga hermonthica*. *Crop Sci* 34:900–907
- Korodjouma O (2022) Description of cropping systems, climate, and soils in Burkina Faso. *Global Yield Gap Atlas* <https://www.yieldgap.org/Burkina-faso>
- Marley PS, Ahmed SM, Shebayan JAY, Lagoke STO (1999) Isolation of *Fusarium oxysporum* with potential for biocontrol of the witchweed (*Striga hermonthica*) in the Nigerian savanna. *Biocontrol Sci Tech* 9:159–163
- Mundia CW, Secchi S, Akamani K, Wang G (2019) A regional comparison of factors affecting global sorghum production: the case of North America, Asia and Africa's Sahel. *Sustainability* 11:2135
- Nikiéma MP, Yonli D, Rabefiraisana HJ, Ali A, Ouédraogo N, Traoré H, Yanogo HYA, Dao K, Sawadogo M, Jankuloski L, Ingelbrecht I, Ghanim AMA (2020) Induced resistance to *Striga hermonthica* in sorghum by gamma irradiation. *Am J Plant Sci* 11:1545–1561
- Traoré H, Yonli D, Diallo D, Sereme P (2011) Suicidal germination of *Striga hermonthica* (Del.) Benth. by cotton, cowpea and groundnut genotypes in Burkina Faso. *Int J Agric Res* 6:49–57

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