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Seed Dressing Maize with Imazapyr to Control *Striga hermonthica* in Farmers' Fields in the Savannas of Nigeria

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Abstract: Use of small doses of imazapyr and pyrithiobac for seed coatings of imazapyr-resistant maize hybrids (IR-Maize) offers an effective means to control *Striga hermonthica*. Field trials were conducted in Bauchi and Kano States of Nigeria in 2014 and 2015 under heavy *Striga* infestation to evaluate the potential effectiveness of herbicide coated hybrids maize on *Striga* control in farmers' field. Results showed that herbicide coated seeds reduced number of emerged *Striga* per m^2 and *Striga* damage symptoms in farmers' fields in all the locations. In Kano the number of emerged *Striga* was 4.9 to 7.9 times less in herbicide treated hybrids in comparison with those of the same hybrids planted without herbicide treatment. The *Striga*-resistant open pollinated variety (OPV) (TZL COMP1 SYN) had 6.7 to 8.0 times more *Striga* than the treated hybrids. In Bauchi, the number of emerged *Striga* on the untreated IR-maize hybrids were over four-times higher on the treated IR-maize hybrids than on the untreated hybrids. The *Striga*-resistant OPV check had four-times more *Striga* than the treated IR-maize hybrids and twice more than the untreated IR-maize hybrids across the two years. However, the effects of herbicide seed coating on grain yields were not consistent because of strong seasonal effects. The result revealed that coating of imazapyr-resistant hybrid maize seeds with imazapyr was effective in reducing *Striga* infestation in farmers' fields. Although herbicide seed coating did not give consistent yield advantages of the hybrids over the untreated checks, a combination of herbicide seed treatment and genetic resistance to *Striga* would serve as an effective integrated approach that could significantly reduce the parasite seed bank from the soil and prevent production of new seeds. The IR-hybrids and the OPV checks contained *Striga* resistance/tolerant genes that protected them against drastic yield loss in the *Striga* infested fields in both Bauchi and Kano.

Keywords: maize; *Striga hermonthica*; imazapyr seed coating; *Striga* damage

1. Introduction

Striga hermonthica constitutes one of the most severe constraints to cereal production in the semi-arid and sub-humid areas of sub-Saharan Africa [1]. An estimated 21 million ha of land is infested with *S. hermonthica* in Africa [2]. In Nigeria, over 40% of the 93 million ha arable land in the Savannas is already moderately or severely infested [3]. Surveys in the Northern Guinea Savannah of Nigeria (NGS) showed that *S. hermonthica* has remained a serious problem, attacking millet, sorghum (*Sorghum bicolor* L. Moench), maize (*Zea mays* L.) and upland rice [4–6]. In northeast Nigeria, over 85% of the fields planted to maize and sorghum were infested with *Striga* [7]. Field studies conducted in northern Nigeria showed that *Striga* incidence range from 0% to 100% in farmers' maize fields [8].

The increasing incidence of *Striga* has been attributed to poor soil fertility and structure, intensification of land-use through continuous cultivation and an expansion of cereal production [9]. It was reported that *Striga* population in northern Nigeria was negatively related to total nitrogen, exchangeable potassium and clay content [8]. They also reported that up to 75% of the variations in maize grain yields in farmers' fields could be explained by *Striga* population and soil organic carbon. The extent to which *Striga* reduces the growth of its host is highly variable and depends on factors such as host plant genotype, parasite infestation level, and environment [10]. *Striga* infestation of cereal crops has impacted negatively on the livelihoods of small-holder farmers in northern Nigeria because of its impacts on crop yield and systems productivity. Grain yield losses due to *S. hermonthica* infestation range from 10% to 100% for these crops, forcing farmers to abandon their cereal fields [3,11].

Crop rotation [12,13], intercropping [14], organic [15] and inorganic [16] fertilizers have all been recommended for *Striga* management in farmers' fields. However, these approaches require several seasons of repeated use before they begin to produce yield benefits [17]. Much of the *Striga*-infested area of Africa has very high levels of *Striga* seeds in the soil due to years of neglect (Ekeleme et al. 2014). Thus, there is an urgent need for cost-effective approaches that allow achievement of adequate crop yields while at the same time depleting the *Striga* seed bank in the soil for subsequent planting of cereal crops such as maize [18].

Studies have showed that the use of small doses of imazapyr and pyrithiobac for seed coatings offers an effective means to controlling *Striga* [19–21]. These herbicides inhibit the biosynthesis of branch-chained amino acids [22]. The use of herbicide seed coating reduces yield loss due to *Striga*, and depletes the *Striga* seed bank in the soil, so subsequent *Striga* numbers are less the following year [23]. The application of imazapyr and pyrithiobac as drenches or coatings to maize seeds possessing target-site resistance has been reported to effectively control *Striga* early in the season [20,22,24].

In order to use phytotoxic herbicides to control *Striga* and prevent crop injury, a gene for resistance to these herbicides was incorporated into tropically adapted maize germplasm [25] that already have natural resistance to *S. hermonthica* at the International Institute of Tropical Agriculture. Combining herbicide resistance with natural resistance to agronomic performance of IR-maize (imazapyr-resistant maize hybrids) minimized the risk of *Striga* damage and severe yield loss when the herbicide is washed away due to excess rain [22,25]. Imazapyr-coated seeds of *Striga*-resistant hybrids planted under *S. hermonthica* infestation sustained less than 20% yield loss, showed less *Striga* damage symptoms and supported very few emerged parasites than without seed coating [22,25]. These IR-maize hybrids can be planted in *Striga*-infested areas without imazapyr seed coating at certain intervals to delay the development of high levels of resistance to imazapyr and prolong the effectiveness of the herbicides [25]. However, IR-maize hybrids having natural resistance to *Striga* have been tested on-stations under artificial infestation with *Striga*. Large-scale testing of treated seeds of these hybrids on farmers' fields has not been reported for West Africa. Therefore, the objectives of this study were to evaluate *Striga*-resistant IR-maize hybrid treated with imazapyr under natural infestation with *S. hermonthica* in farmers' fields in two states in Nigeria.

2. Materials and Methods

2.1. Study Area

The study was conducted in two States Bauchi (10°18′ N, 09°50′ E) and Kano (12°00′ N, 08°31′ E) States in northern Nigeria, where *Striga* is endemic and infestation is high. Farmer-managed trials were conducted in 30 villages (Table 1) each in Bauchi and Kano States in Nigeria in 2014 and 2015. Participatory research and extension approaches were used as a basis for farmer involvement [26]. Each year, 30 farms on basis of their severe infestation based on observations were chosen in each State in the preceding season. The area is characterized by a mono-modal rainfall distribution with an average precipitation of 900–1300 mm and growing period of 150 to 180 days (May–October). Figure 1 shows the average monthly rainfall distribution in the two study areas during the experimental years.

The predominant soil types are Alfisols of moderate to low fertility. Important crops are maize (*Zea mays*), sorghum (*Sorghum bicolor*), millet (*Pennisetum typhoides*), soybean (*Glycine max*), cowpea (*Vigna unguiculata*) and groundnut (*Arachis hypogaea*) with both sole and intercropping of legume and cereal being practiced.

Table 1. On-farm locations in Kano and Bauchi States.

State	Number of Fields	Communities
Kano	30	Jibga, Bebeji, Durmanawa, Kofa, Wak, Cutar biki, Anadariya, Gargai, Gidan wake, Tashar Idi, Gidan Dagazau, Rurum, tadinsha, Gidan Gizo, Yado, Gimbawa, Kyangarang, Tashar Goro, Kuguru, Yaryasa, Sumana.
Bauchi	30	Lando, Gidan Sarkin yamma, Dorza, Kwaffa, Felufelu, Tukari, Yashi, Garin Galadima, Dass, Zaranda, Burgel, Gital, Banko, Takwashide Kafin madaki, Kwanar Labi, Kafin Liman, Zamo

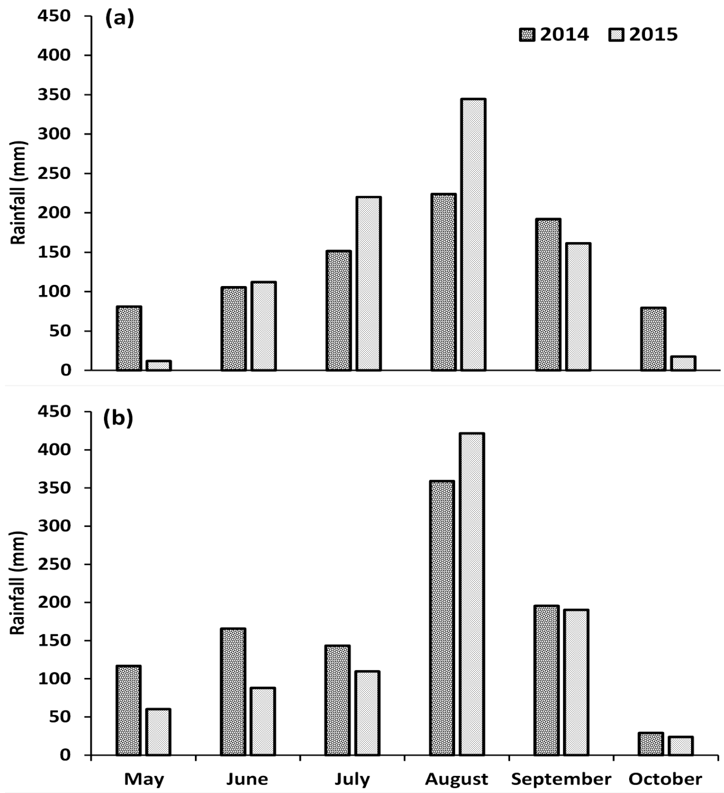

Figure 1. Average monthly rainfall in communities at Kano (**a**) and Bauchi (**b**) in 2014 and 2015.

2.2. Planting Materials and Coating

Two promising IR-maize (IR hybrid 1 and IR hybrid 4) top cross identified in on-station trials in 2013 and two non-IR OPVs (open pollinated variety) (TZL COMP1 SYN and DT STR SYN W) with known polygenic remittance to *Striga* were included in these trials. Imazapyr solution was prepared by dissolving solid imazapyr acid in distilled water and by gradually adding potassium hydroxide to raise the pH of the solution to 6 and 8. Polyvinylpyrollidone (1.8%) was also added as a binding agent to 21 mM of the prepared K-salt of imazapyr. Seeds of each maize hybrid were thoroughly mixed with the imazapyr solution. The seeds were allowed to soak for 24 hours to give a coating of 0.4 mg a.e imazapyr per seed (22). The treated seeds were dried and distributed to extension agents for planting within a week.

2.3. Cultural Practices, Measurements and Statistical Analysis

Each of the 30 selected farmers' fields represented a replicate in each State in each year. In 2014, each on-farm trial was composed of two IR-maize hybrids (1 set treated and 1 set un-treated) along with an untreated-OPV. In 2015, each on-farm trial consisted of the same set of IR hybrids (1 set treated and 1 set untreated) along with two untreated OPVs. In each field, each hybrid or OPV was planted in a 10 × 10 m plot in the previously marked *Striga* infested fields. Four maize seeds were planted in rows 75 cm spaced apart at a spacing of 50 cm. At two weeks after sowing (WAS) maize seedling were thinned to two plants per hill. Other weeds were carefully removed using a hoe at two, six and eight WAS. Two weeks after sowing, fertilizer was applied at the rate of 50 Kg N ha^{-1}, 50 Kg P_2O_5 ha^{-1} and 50 Kg K_2O ha^{-1} using NPK (15:15:15). At five WAS, 50 Kg N ha^{-1} was again applied using urea. Data collected included the number of emerged *Striga*, *Striga* damage severity rating on a 1–9 scale at full silking (10 weeks after planting maize). The whole plots were harvested when the crop was fully mature and completely dry and cobs weighed. Grain yield was computed using 80% shelling of the maize cobs. As the fields were not artificially and uniformly infested and the trials were established on new plots every year, data recorded from all communities in each State were subjected to separate analysis of variance for each year in SAS using the model shown below:

$$Y_{ij} = \mu + L_i + H_j + e_{ij}$$

where Y_{ij} is the observed yield at each location: μ is the overall mean for grain yield; L_i is the effect of the ith location; H_j is the effect of the jth hybrid; and e_{ij} is the residual effect. Treatment means were compared using the LSD at 5% level of probability [27].

3. Results

Herbicide seed coating reduced number of emerged *Striga* per plot in farmers' fields in all the locations. In Kano in 2014, the number of emerged *Striga* was 4.9 to 7.9 times less in herbicide treated hybrids in comparison with those of the same hybrids planted without herbicide treatment. The *Striga*-resistant OPV (TZL COMP1 SYN) had 6.7 to 8.0 times more *Striga* than the treated hybrids (Figure 2). When treated with herbicides in 2015, number of emerged *Striga* was 0.67 and 1.13 per m^2 for hybrid 1 and hybrid 4, respectively (Figure 3). When untreated, the hybrids and the OPVs had number of *Striga* that were significantly higher than those of the treated hybrids. Number of emerged *Striga* was 5.19 per m^2 for hybrid 1 and 5.35 for hybrid 4. Numbers on the OPVs were 3.11 *Striga* per m^2 for DT STR SYN W and 2.03 *Striga* per m^2 for TZL COMP1 SYN. The numbers of *Striga* on the untreated hybrids were also higher than those on the two *Striga*-resistant OPVs (DT STR SYN W and TZL COMP1 SYN) (Figure 3).

In Bauchi in 2014, the number of emerged *Striga* on the untreated IR-maize hybrids were twice those on the treated IR-maize hybrids though the figures were not statistically different. The *Striga*-resistant OPV check had 4 times more *Striga* than the treated IR-maize hybrids and twice more than the untreated IR-maize hybrids (Figure 2). Similarly, in 2015, herbicide treated IR-maize hybrids had number of emerged *Striga* that was significantly lower than that on the untreated hybrids and the OPV checks (Figure 3). When untreated, the number of emerged *Striga* plants was 7.3 times higher on hybrid 1 and 4.6 times higher on hybrid 4 than on the corresponding treated IR-maize hybrids. The OPV DT STR SYN W had 4.7 times more *Striga* than herbicide-treated hybrid 1 and 2.6 times more *Striga* than hybrid 4, while OPV TLZ COMP1 SYN had 3 times more *Striga* than the treated hybrid 1 and 1.6 times more *Striga* than the treated hybrid 4. When untreated the hybrids had number of *Striga* that were significantly higher than that of DT STR SYN W and TZL COMP 1 SYN. *Striga* damage was scored in both locations only in 2015. *Striga* damage rating on farmers' fields ranged from 4 to 5 in Kano and 3 to 5 in Bauchi (Figure 4). Herbicide seed treatment significantly reduced *Striga* damage scores in both locations. Untreated hybrids recorded damage scores that were similar to those of the untreated OPV checks in Kano. In Bauchi, the hybrid IR hybrid 4 had damage score that was significantly higher than the two Striga-resistant open-pollinated varieties (DT STR SYN and TZL Comp 1).

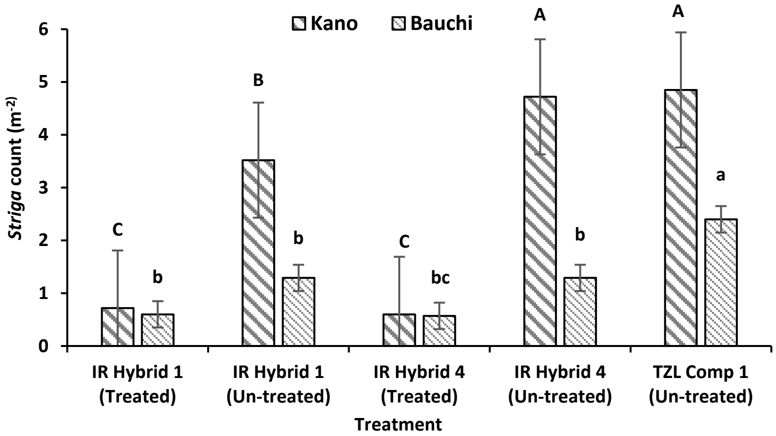

Figure 2. Effect of seed coating of IR maize hybrid with imazaphyr on *Striga* count in farmers' fields in Kano and Bauchi 2014. IR maize: imazapyr-resistant maize hybrids.

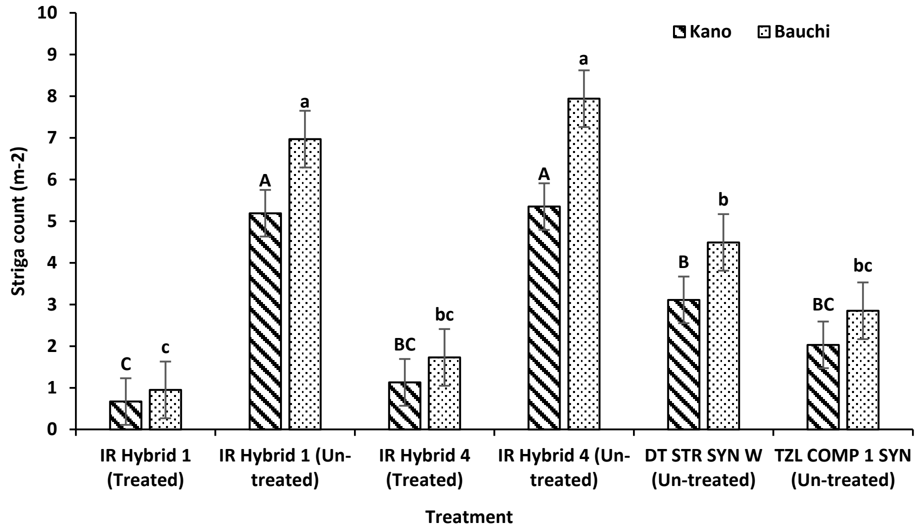

Figure 3. Effect of seed coating of IR maize hybrid with imazapyr on *Striga* count in farmers' fields in Kano and Bauchi 2015.

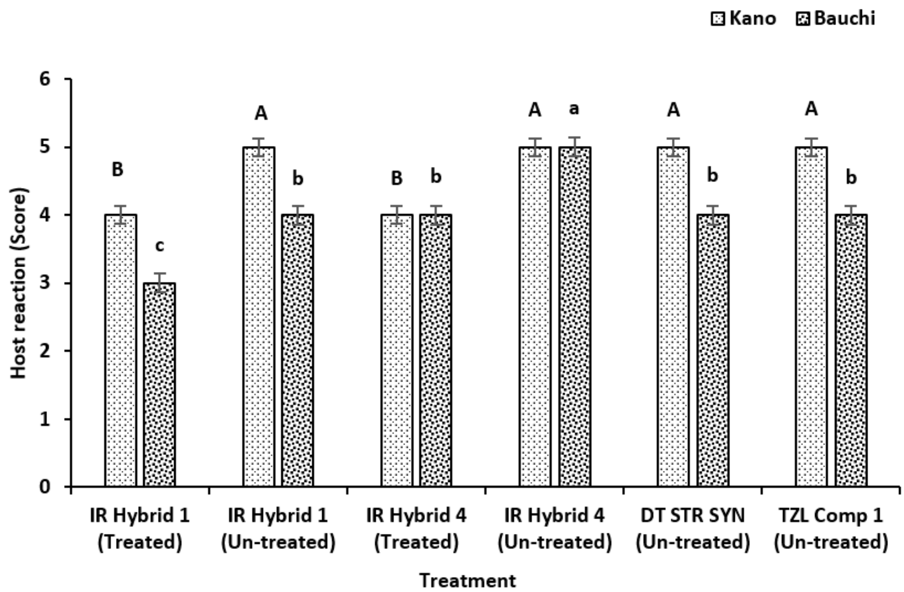

Figure 4. Host damage scores of IR maize hybrids treated with imazapyr in farmers' fields in Kano and Bauchi 2015.

In 2014, IR-Hybrid 1 treated with imazapyr produced grain yield that was not significantly different from the grain yield of the untreated hybrid in Kano (Figure 5). Herbicide treatment of IR-hybrid 4 however, produced grain yield that was significantly higher than that of the untreated hybrid. Grain yield of the OPV TZL COMP 1 SYN was significantly lower than those of the hybrids irrespective of herbicide treatment except for untreated hybrid 4. Grain yield of TZL COMP 1 SYN did not significantly differ from that of untreated hybrid 4. Despite the significant differences in number of *Striga* among the treated and untreated hybrids, differences in grain yield among these hybrids were not significant irrespective of hybrid treatment in Kano in 2015 (Figure 6) probably due to poor rainfall (Figure 1) Additionally, both the treated and untreated IR-maize hybrids produced grain yields that were significantly lower than the OPVs (Figure 6).

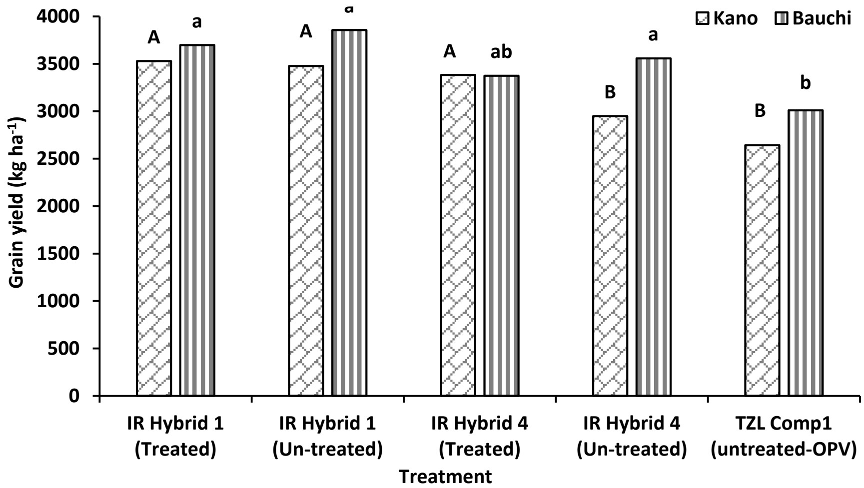

Figure 5. Effect of seed coating of IR maize hybrid with imazapyr on grain yield in farmers' fields in Kano and Bauchi 2014.

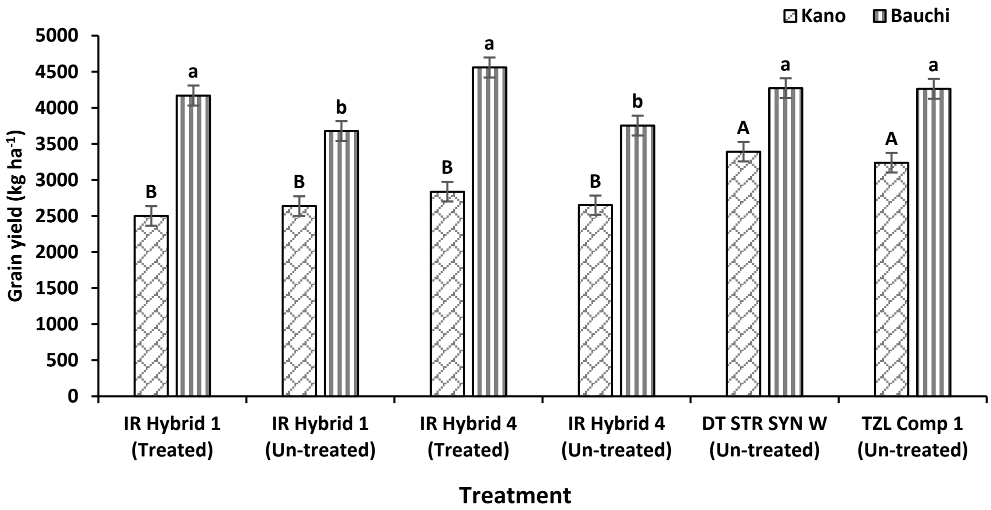

Figure 6. Effect of seed coating of IR maize hybrid with imazapyr on grain yield in farmers' fields in Kano and Bauchi 2015.

In 2014, differences in grain yield among the maize hybrids were not significant in Bauchi irrespective of herbicide treatment (Figure 5). Except for herbicide-treated hybrid 4 that produced grain yield that was not statistically different from the untreated OPV check TZL COMP1 SYN, all the hybrids produced grain yields that were higher than that of TZL Comp1 SYN. In 2015, the treated IR-maize hybrids produced grain yields that were significantly higher than those of the untreated IR-maize hybrids in Bauchi. Grain yields of the treated hybrids did not however, significantly differ from those of the untreated two OPV checks (Figure 6).

4. Discussions

Although, crop rotation and intercropping involving legumes [13,28,29], application of organic and inorganic fertilizers [30], and the use of *Striga*-resistant cultivars [31,32] can partially reduce the *Striga* problem, no short-term control measure has been developed that subsistence farmers could use within their financial resources or that fits well into their traditional cropping systems. The use of imazapyr-resistant maize offers an opportunity to (i) control *Striga* itself so that adequate crop yields can be achieved each cropping season, (ii) deplete the *Striga* seed bank in the soil, (iii) is cost-effective; and (iv) is compatible with existing small-holder cropping systems [33]. Imazapyr seed coating provide an effective measure for controlling *Striga* [34] as a short-term measure until crop varieties with adequate levels of genetic resistance become available [18]. Results from our field trials confirmed the efficacy of imazapyr to reduce *Striga* infestation in maize. Untreated maize hybrids had over 4.4 *Striga* plants per m^2 across the two years in Bauchi and 4.7 in Kano. Number of emerged *Striga* per plot was over 2 to 7 times greater on untreated hybrids in Bauchi in 2014 and 2015. These results are in agreement with earlier results [22,25] who reported that herbicide treatments of seeds of the IR-maize hybrids considerably reduced *Striga* infestation in experimental plots in on-station trials in northern Nigeria. Similar reports of reduction in *Striga* infestation with herbicide seed coating have been obtained in East and Southern Africa [34,35].

In general, all IR-maize hybrids produced comparable yields regardless of herbicide treatment in Kano in 2014, possibly because the hybrids also possess field resistance to *Striga*. Unlike the results in 2014, maize hybrids produced lower grain yields than the OPV checks in Kano in 2015 mainly due to the drought stress that occurred in the area. Rainfall in the zones was low (Figure 4) and its distribution was poor which adversely affected the performance of the hybrids. The heterogeneous nature of the two OPVs used as checks in 2015 may better impact resistance under variable growing conditions with resistance to *Striga* [36]. In Bauchi, response of maize grain yield to herbicide treatment was not consistent. In 2014, IR-maize hybrids produced similar grain yields regardless of the use of herbicide seed treatment, confirming resistance of these hybrids to *Striga* infestation. In 2015, hybrid treated with herbicides produced grain yields that were higher than those of the untreated hybrids. This result shows that when rainfall distribution during the cropping season is good, herbicide seed treatment will give yield advantage over untreated hybrid. This was the case of seed treatment in Bauchi in 2015. Rainfall (Figure 1) during the cropping period of July–September was good and well distributed to support maize growth. Although there was no consistent yield advantage across locations and years associated with the herbicide seed treatment, the number of emerged *Striga* was significantly lower in plots planted to herbicide-coated hybrid suggesting that planting herbicide-coated seed will contribute to reduce *Striga* infestation and seed bank of *Striga*. The lower dose requirement of the herbicide seed treatment makes it ecologically sensible to use in reducing *Striga* infestation on farmers' fields. De Groote [37] reported a very good marginal rate of return for the IR technology when the cost of herbicide was 4 US dollars per ha^{-1}.

5. Conclusions

The results of this study showed that coating IR maize hybrid seeds with imazapyr was effective for *Striga* control. There was however no consistent yield advantage of herbicide seed coating over the untreated hybrids because the hybrids were tolerant to *Striga.* Combination of herbicide seed treatment and genetic resistance to *Striga* would serve as an effective integrated approach that would reduce the parasite seed bank from the soil and prevent production of new seeds. The IR-maize hybrids and the OPV checks containing *Striga* resistance genes did not suffer from drastic yield losses in *Striga* infested fields in both Bauchi and Kano.

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