Advances in Applied Physiology
2025, Vol. 10, No. 1, pp. 8-14
https://doi.org/10.11648/j.aap.20251001.12

Research Article

Economic Benefit Analysis of IR Maize Technology over Local Landraces in Maize Production in Western Kenya

Sibuti Mwita Samwel*, Kimurto Paul Kiprotich, Ogendo Joshua Ondura

Department of Crops, Horticulture and Soils Sciences, Egerton University, Egerton, Kenya

Abstract

Witchweed, (*Striga hermonthica* (Del.). Benth) is a major threat to the realization of yield potentials of cereal crops especially maize. This study was designed to determine the economic benefits of IR coated hybrids against local landraces in western Kenya. The experiment was laid in a Randomized Complete Block Design with three replications. Data on the prices of fertilizer and seed was collected from the Agro-shops around the study site. Labour cost was taken as the price that ICRISAT pays for per Mondays in the station. In addition, the overall yields of IR and local landrace was measured on the on-station and on-farm experiments conducted in Alupe and Rangwe during the consecutive 2018 and 2019 cropping seasons. Data collected was analyzed using SAS analysis tool (Version 9) and the treatment means were further subjected to T-test to determine their significant differences. Gross margins and cost to benefit ratios were also used in data analysis. Yield results indicated higher grain yields on FR425IR of 2.4376 t ha^{-2} compared to 1.152 t ha^{-2} in local landraces. In contrast most hybrids varieties H513, DK8031, Duma43 and DH04 recorded grains less than 1 t/ha. Further, results indicated higher gross margin on treatments of Kes 12,400 in FRC425IR compared to a net loss of Kes 17, 550 on local landrace. Additionally, there was higher Benefit Cost ration of 4.3 and net marginal rate of 3.3. Evaluation of the use of IRM indicated that the technology is profitable and viable. Overall findings of this study indicated that the use of IR technology in maize production would increase farmer income and food security.

Keywords

Marginal Rate of Return, Benefit Cost Ratio, Parasitic Weed, Imidazolinone Resistant

1. Introduction

Maize productivity for majority of smallholder farmers in sub-Saharan Africa (SSA) is highly constrained by parasitic striga weed mainly the *Striga hermonthica Benth*. (Orobanchaceae) which causes severe losses to staple crops [14, 34]. Striga weed causes an estimated yield loss of 35- 80% in rice [33], 50-100% in Sorghum [1], and 21-74% in Maize [5]. The invasiveness of Striga, long persistence and economic impacts is mainly due to its unique biology which is associated with production of large amounts of microscopic seeds [13], that results to high weed density within a short period of time [10]. These seeds have the ability of remaining in the soil for long periods, up to 20 years, causing vast economic damages [31].

Continued intensification of cereal-based systems in the region as a result of rising demographic pressures that has led to an increase in the area under Striga infestation [30].

*Corresponding author: smwita422@gmail.com (Sibuti Mwita Samwel)

Received: 14 November 2024; **Accepted:** 13 December 2024; **Published:** 23 June 2025

Despite the development of high-yielding varieties and improved cultivation methods, Kenya is still unable to meet its domestic demand of maize grains. The deficit in production is bridged through imports from the neighboring countries [12]. In western Kenya the average maize productivity has stagnated at between 1.2-1.6 t ha^{-1} [35]. This situation is triggered by a number of constraints including Striga weed infestation and low levels of soil phosphorous and nitrogen [6, 11]. This not only affects quality but also adversely reduces grain yields. Typical yield losses range from 5 to 70% depending on the degree of infestation and susceptibility of the cultivar [21]. Severe infestation of sorghum by *S. hermonthica* has been reported to cause 30-50% land being abandoned [37].

Several integrated control initiatives have been promoted for adoption by farmers in different regions of SSA to control Striga [2]. These measures include: Integrated management that incorporates technologies such as use of herbicide-resistant cultivars intercropping with legumes and use of improved fallows system [15, 20]. Despite the use of herbicide technology for management of Striga in high-intensive agriculture, levels of herbicide use in SSA remain at very low levels, due to limited access to capital [9]. These make farmers in the affected regions using local recycled seeds due to inadequate capital, lack of knowledge on the availability of IR treated seed and high cost of seed [22]. Further, recommended potential control measures from research have not been adopted, especially in the maize, sorghum and millet based cropping systems. This may be due to; poor understanding of the biology of Striga and long-term effects of control options, low efficacy of individual control options in reducing Striga to tolerable levels, lack of adaptability of control options to the local farming systems, and high cost-benefit ratio of control options compared to existing farmer practice [30].

The use of small doses of herbicide imazapyr and pyrithiobac for seed coatings have shown an early control of Striga [18]. The herbicide has been reported to inhibit production of branched amino acid that is responsible for normal plant growth [3]. Upon absorption by Striga weed, the weed is eradicated and the un-absorbed herbicide combines with water and moves within the soil killing Striga seed in the soil [16]. Additionally, the herbicide is reported to reduce losses associated with Striga, depletes the seed bank and ultimately reduces the amount of new seeds added to the soil the following season [32]. Limited comparative study on the economic benefit of IR technology over the use of commercial hybrids and local landraces has been reported in Kenya. This study was therefore conducted to determine the cost–benefit ratio (CBR) and marginal rate of return (MRR) of Imazapyr-resistant (IR) maize technology against commercial hybrids and local varieties in control of Striga in western Kenya.

2. Materials and Methods

2.1. Experimental Design and Treatments

Experimental treatments were arranged in a randomized complete blocked design with three replicates KALRO ALUPE and Rangwe. Each experimental plot consisted of 5 m by 5 m. Planting was done at spacing of 0.75 m X 0.25 m. During planting 2 seeds was planted per hill and later thinned to 1 plant per hill at 2 Weeks after planting. At KALRO Alupe, the experimental plots were artificially inoculated with one teaspoon full of preconditioned *S. hermonthica* seeds per hole. Basal fertilizer was applied in the form of di-ammonium phosphate (DAP) (18:46:0) during planting and topdressing with calcium ammonium nitrate (CAN) (26:0:0). Topdressing with CAN was done in two splits, with 1^{st} split applied 2 weeks after planting and the 2^{nd} done at 4 weeks after planting (WAP) giving 60 kg N ha^{-1} [28]. Hand weeding was done twice while removing all other weeds except Striga. Local landrace was used as the control in evaluating the economic analysis against IR.

2.2. Data Collection

At harvest, all ears harvested from each plot were dried, shelled. Percentage grain moisture was determined using a DRAMINSKI -Twist Grain moisture tester. Grain yield was adjusted to 12.5% using ear weight and grain moisture, assuming a shelling percentage of 80% according to [19]. Grain yield was determined from the net harvestable area and using the following formula.

$$\text{Grain Yield (kg ha}^{-1}) = \frac{(\text{FW}*10000\ \text{M}^2\ \text{ha}^{-1})*(100-\text{AMC})}{(\text{HarvestArea}*1000\text{kgt}^{-1})*(100-\text{SMC})}*0.81$$

Where, FW= field weight (kg), AMC = actual grain moisture content at harvest and SMC = recommended storage moisture content. On-station grain yield obtained was adjusted to 10% as described by [27] to match yields obtained by farmers before subjecting them to partial budgeting analysis.

2.3. Statistical Analysis

Benefit-Cost analysis was done to assess the economic value of treatments. The partial budget analysis as described by was carried out to assess the costs and benefits associated with IR maize technology compared to use of local landrace in maize production under Striga infested fields [4]. Gross margin (GM) analysis was also done using farm budgeting techniques by Microsoft Excel spreadsheets. Parameters used in determining the performance of maize variety under Striga infestation included; yield in kilogram per hectare and returns to investment in inputs, which was expressed as GM per hectare. In order to compute associated revenues of variety yields was multiplied by 2019 season average market prices (mean of prices immediately after harvest and at the onset of the new season). The GM was the difference between the gross farm revenue earned and the incurred total variable cost. The GM analysis was used to justify whether the selected variety was financially and technically viable to address the need of the targeted farmers [25]. In order to determine GM, all the varieties were subjected to the same seed quantities, fertilizer rates and agronomic practices. The only difference was the cost of the technology, which was the price of IR seed. This study only focused on the Cost-Benefit ratio and the MRR associated with maize production under Striga infestation. All harvested yield at the end of the season priced at the prevailing market price. Economic analysis was done using the prevailing market prices for inputs at planting and for outputs at the time the crop was harvested (Table 1).

2.3.1. Statistical Analysis Model

Combined Analysis of variance was done in SAS using the model shown below:

$$Yij = \mu + Li + Hj + \varepsilon ij$$

Where,
Yij is the observed yield at each location:
μ is the overall mean for grain yield;
Li is the effect of the i^{th} location;
Hj is the effect of the j^{th} treatment;
eij is the residual effect.

2.3.2. Economic Analysis

Economic analysis of maize from different treatments was determined using gross margin and cost-benefit analyses. Cost and benefit estimates were based on revenues and costs incurred in production of maize using the different treatments. Total revenue represented the value of maize harvested from each plot based on prevailing prices at the time of the study. The price of 2 kg of 'Local landrace' at the Busia Municipal Market and 'FRC425IR' from FRESCO Seed Company Ltd. were KES 100 and KES 425 respectively, in the month of September 2019. Variable costs accrued from purchase of seeds and labor involved in land preparation, planting, weeding, harvesting, drying and shelling were determined based on the prevailing market prices (Table 1). Benefit/cost ratio was determined by dividing the revenue by variable costs from each treatment, while gross margin was obtained from revenue less variable cost accrued in each treatment.

2.3.3. Benefit-Cost Analysis (CBA)

Partial budget analysis as described by was carried out to assess the costs and benefits associated with IR maize technology compared to use of local landrace in maize production under Striga infested fields [4]. Gross margin (GM) analysis was also done using farm budgeting techniques by Microsoft Excel spreadsheets. Parameters used in determining the performance of maize variety under Striga infestation included yield in kilogram per hectare and returns to investment in inputs, which was expressed as GM per hectare. To compute associated revenues of variety yields was multiplied by 2019 season average market prices (mean of prices immediately after harvest and at the onset of the new season). The GM was the difference between the gross farm revenue earned and the incurred total variable cost. The GM analysis was done to determine if the selected variety was economically viable (is it worth investing in this varieties) by targeted farmers [25]. To determine GM, all the varieties subjected to the same seed quantities, fertilizer rates and agronomic practices. The only difference was the cost of the technology, which was the price of IR seed. This study only focused on the Cost-Benefit ratio and the MRR associated with maize production under Striga infestation. All harvested yield at the end of the season priced at the prevailing market price. Economic analysis was done using the prevailing market prices for inputs at planting and for outputs at the time the crop was harvested (Table 1).

3. Results

3.1. Input and Labour Prices

Fertilizer, seed, and pesticides prices were obtained from local Agro-shops in the markets found within the Striga infested areas of western Kenya. The input prices: KES4000 for 50kg bag of DAP, KES1600 for 50kg bag of CAN, price for 2kg packet of IR seed (H528IR) KES 450, price of 2 packet seed FRC425IR was KES 500, and price of I kg local seed was assumed to be KES 100. Labour cost was KES 300 price paid by KARLO Alupe to casual Labour per person (MD) and the price of a bag of 90 kilogram of maize was Kes 3000 (Table 1).

Table 1. *Average Input and Output Prices.*

Type	Unit	Quantity	Unit Price (KES)
Grain	Kg	90	3000
DAP	Kg	125	80
DAP	Kg	125	32
IR Seed	Kg	25	225

Type	Unit	Quantity	Unit Price (KES)
Local Seed	Kg	25	100
Labour	Man Day		300

3.2. Grain Yields

Results from this study indicated significant differences between the yields from the IR varieties and the local landrace used. The highest maize yields were obtained from IR coated maize FRC425IR (2.37 t/ha) and lowest on local landraces 1.152 (Table 2). A paired T-test computed on grain yield showed significant (P<0.05) differences among the test maize genotypes. The observed higher grain yields observed on FRC425IR compared to Local landraces indicates the ability of the IR variety to tolerate the effects of Striga weed hence giving higher farm output.

Table 2. *Paired T-test between FRC425IR and Local landrace.*

Variety	yields (t/ha	Difference	Observ	df	mean	stddev	stderror	Tvalue
IR	2.37	1.27***	12	11	1.59	0.51	0.15	8.5
Local	1.152							

Note *** denote statistical significance at 1% level.

3.3. Partial Budget Analysis

Partial budget analysis was carried out based on the yield data and inputs prices collected. Partial Budget evaluation indicated that changing from using local landrace to use of IR maize technology was a profitable venture for the affected small-holder farmers in the Striga hot spot areas (Table 3). The process involved tallying up all costs of required for both varieties FRC425IR and Local and then subtracting that amount from the total benefits from the change. The total revenue was obtained by multiplying average unit market prices with the mean output of the various genotypes tested per hectare (Table 3).

Table 3. *Partial budget analysis.*

Variable	Seed Type	
	Local seed	IR
Adjusted grain yield (bags/ha)	13	26
Average price per 90 Kg bag	3000	3000
Gross output per hectare (Kes)	39,000	78,000
Total Variable Cost	56,550	65,600
Net benefits Gross benefit	-17, 550	12,400

3.4. Computation of BCR and MRR

Total cost incurred in producing IR maize was Kes 65,600, against a gross income of Kes78 000, giving a net return of Kes12, 400. Similarly, the total cost incurred in producing Local landraces was Kes 56,550 against a gross income of Kes 39,000 (giving net negative returns of Kes 17,550). The total Net change realized in changing from local landrace to IR variety was Kes 29,950 and the total gross change in total variable cost was Kes 9, 050 (Table 3).

Therefore,

$$\text{MRR}= \frac{\text{Change in Net benefits}}{\text{Change in total variable cost}} = \frac{\text{Kes } 29{,}950}{\text{Kes } 9050} = 3.3$$

$$\text{BCR}= \frac{\text{Change in Gross benefit}}{\text{Gross change in total variable cost}} = \frac{\text{Kes } 39{,}000}{\text{Kes } 9050} = 4.3$$

3.5. Determination of Gross Margins

Gross margin was obtained from revenue less variable cost accrued in each treatment. Results indicates that it costs more to produce IR maize compare producing local landrace, however the gross margin and the benefit cost ration was higher on using IR coated maize. Generally, comparisons between FRC425IR and the local variety showed no significant differences in cost of land preparation, cost of fertilizer, and cost of Labour (Table 4). Therefore, they were treated as non-experimental variable and hence the two varieties were subjected to the same conditions to determine the gross margin. Further, there was significant differences with respect to the cost of seed, which further reflected in differences in the cost of bags and transportation (Table 4).

Table 4. *Gross margin analysis between FRC425IR and Local landraces in Western Kenya.*

Variety	Input costs	Local	FRC425IR
Yields	bags@ha	13	26
Price	kes@bag	3,000	3,000
Revenue	Kes	39000	78000
Cost of seed	25kgs	2500	6250
Cost of DAP	Kes80@125kg	10,000	10,000
Cost of CAN	Kes32@125	4,000	4,000
Cost of Insecticide	kes2000@1lit	2,000	2,000
Cost of Land preparation	kes	11,250	11,250
Cost of Labour	kes300@85MD	25,500	29,300
Cost of bags	kes50@bag	650	1,400
Transport cost	Kes@bag	650	1,400
TVC		56550	65600
GM		-17550	12400
BCR		0.7	1.2

4. Discussion

The observed yield difference between IR herbicide coated maize genotypes compared to local landrace indicated that coating of IR-maize seeds with imazapyr herbicide suppressed the development of Striga, especially in the early stages. Similar studies reported higher grain yield in plots that received treated maize genotypes [3, 23, 19]. Further, results from this study revealed that the grain yield of FRC425IR maize genotype doubled the overall yields. Similar findings were reported [29]. Despite farmer's preference in using local landraces in the area, results further showed that there use results into negative returns to the farmer. Similar findings in a study on the adoption of IR Maize in Nyanza and western Kenya [25]. In addition, it has been reported that IR coated maize hybrids are more drought tolerant compared to susceptible maize genotypes [7].

Furthermore, economic analysis in the present study demonstrated higher gross margin, higher benefit cost ratio derived from using IR maize. This was attributed to the ability of IR coated maize in suppressing the damages caused by the parasite. Higher yields and higher profit were reported in earlier studies [5, 8, 38]. Further findings in the current study clearly showed improved gross margin and higher Benefit cost ratio therefore changing from local landraces into IR maize technology will be economically worth for farmers challenged with striga. Similar findings showed that IR coated genotype treated with low dose of herbicide was able to increase yields more than four-fold with an additional cost of less than US$4 per hectare (cost of herbicide added to other existing seed treatments). The added cost was equivalent to about 25-50 kg/ha maize yield depending on market prices, suggesting potential benefit: cost ratios of greater than 25:1 even under the least favorable circumstances [17].

However, the low gross margin observed in this study was associated with low market prices of maize grain compared to high input prices at the time of study. In addition, the low economic benefit derived from the use of local landraces in farmers' fields was principally attributable to competition for nutrients by heavy Striga infestation. Present study indicates a higher BCR, thus the change is economically worth. This conforms with suggestion that a change in investment is possible if the BCR is greater than one [24]. Despite this, small holder farmers in western Kenya continue to use local landraces due to the unavailability of IR coated genotypes and high associated costs. Reports indicates 80% of farmers in western Kenya use local landraces seed due to financial constraints [36]. It therefore means that cost of technology is a major consideration in the choice of varieties by farmers alongside other factors. Despite higher cost of IR seed, the extra revenue generated can pay for the cost.

5. Conclusion and Recommendations

The findings of this study showed that the use IR technology

(FRC425IR and H528IR) in maize production in striga prone areas is economically viable. Findings showed a MRR and BCR of 3.3 and 4.3 respectively. Hence, there is need for smallholder farmers to adopt the technology to manage striga weed, improve farm household income and alleviate poverty among maize farming households. Despite the effectiveness of the technology, there is scarcity in the availability of the coated seeds in the striga prone areas. A collaborative initiative between seed companies, research institutions and extension service providers are recommended for dissemination of the technology.

Abbreviations

IR	Imazapyr Resistant
BCR	Benefit Cost Ratio
FRC	Fresco
TVC	Total Variable Cost
GM	Gross Margin
ICRISAT	International Crops Research in Semi-Arid Tropics

Acknowledgments

The author thanks the African Development Bank Group (ADBFG) for funding the effectiveness of Imazapyr-Resistant and selected striga-tolerant Maize (*Zea Mays* L.) varieties on *Striga hermonthica* control and yield of Maize in western Kenya on which this paper is based. Its content was strongly influenced by elaborate discussions with colleagues from the Department of Crops Horticulture & Soil sciences, in particular Dr. Dickson and Mr. Towett who are greatly appreciated. The authors gratefully acknowledge the excellent technical assistance from all field staff of ICRISAT Alupe in western Kenya for their help in collection of data and security of the experiment. The excellent collaboration by farmers and their acceptance of our use of their fields are gratefully acknowledged.

Conflicts of Interest

The authors declare no conflicts of interest.

References

[1] Abunyewa, A. A., & Padi, F. K. (2003). Changes in soil fertility and *Striga hermonthica* prevalence associated with legume and cereal cultivation in the savannah zone of Ghana. *Land Degradation & Development*, *14*(3), 335-343.

[2] Baiyegunhi, L. J. S., Hassan, M. B., Danso-Abbeam, G., & Ortmann, G. F. (2019). Diffusion and adoption of integrated *Striga* management (ISM) technologies among smallholder maize farmers in rural northern Nigeria. *Technology in Society*, *56*, 109–115.

[3] Chikoye, D., Fontem, L. A., & Menkir, A. (2011). Seed coating herbicide-tolerant maize hybrids with imazapyr for *Striga hermonthica* (*Del.*) Benth control in the West African savanna. *Journal of Food, Agriculture and Environment*, *9*(1), 416–421.

[4] CIMMYT Economics Program. (1988). *From agronomic data to farmer recommendations: an economics training manual* (No. 27). CIMMYT.

[5] De-Groote, H., Wangare, L., & Kanampiu, F. (2007). Evaluating the use of herbicide-coated imidazolinone-resistant (IR) maize seeds to control *Striga* in farmers' fields in Kenya. *Variety Protection, 26*, 1496–1506.

[6] De-Groote, H., Wangare, L., Kanampiu, F., Odendo, M., & Friesen, D. (2005). Potential markets for herbicide resistant maize seed for Striga control in Africa.

[7] Ejeta, G. (2007). Breeding for Striga resistance in sorghum: exploitation of an intricate host–parasite biology. *Crop science*, *47*, S-216.

[8] Garba, Y., Ahmed, B., Katung, M. D., Lawal, A. F., & Abubakar, H. N. (2017). Profitability of striga tolerant maize variety (SAMMAZ 17) amongst smallholder farmers in Lapai, Niger State, Nigeria. *South African Journal of Agricultural Extension*, *45*(1), 1-9.

[9] Grabowski, P., & Jayne, T. S. (2016). Analyzing trends in herbicide use in sub-Saharan Africa. Michigan State University, Department of Agricultural, Food, and Resource Economics.

[10] Gressel, J., & Joel, D. M. (2013). Weedy Orobanchaceae: the problem. *Parasitic Orobanchaceae: Parasitic mechanisms and control strategies*, 309-312.

[11] Jamil, M., Kanampiu, F. K., Karaya, H., Charnikhova, T., & Bouwmeester, H. J. (2012). *Striga hermonthica* parasitism in maize in response to N and P fertilizers. *Field Crops Research*, *134*, 1-10.

[12] Jayne, T. S., Yamano, T., Nyoro, J. K., & Awour, T. (2001). Do farmers really benefit from high food prices? Balancing rural interests in Kenya's maize pricing and marketing policy. Tegemeo Institute.

[13] Joel, D. M., Gressel, J., & Musselman, L. J. (2013). Parasitic Orobanchaceae. *Parasitic mechanisms and control strategies. New York*.

[14] Joel, D. M., Hershenhorn, J., Eizenberg, H., Aly, R., Ejeta, G., Rich, P. J.,... & Rubiales, D. (2007). Biology and management of weedy root parasites. *Horticultural reviews*, *33*, 267-349.

[15] Kanampiu, F. K., Kabambe, V., Massawe, C., Jasi, L., Friesen, D., Ransom, J. K., & Gressel, J. (2003). Multi-site, multi-season field tests demonstrate that herbicide seed-coating herbicide-resistance maize controls Striga spp. and increases yields in several African countries. *Crop protection*, *22*(5), 697-706.

[16] Kanampiu, F. K., Ransom, J. K., Friesen, D., & Gressel, J. (2002). Imazapyr and pyrithiobac movement in soil and from maize seed coats to control Striga in legume intercropping. *Crop Protection*, *21*(8), 611-619.

[17] Kanampiu, F., & Friesen, D. (2004). Striga weed control with herbicide coated maize seed. *CIMMYT, Nairobi, Kenya*.

[18] Kanampiu, F., Karaya, H., Burnet, M., & Gressel, J. (2009). Needs for and effectiveness of slow release herbicide seed treatment Striga control formulations for protection against early season crop phytotoxicity. *Crop protection*, *28*(10), 845-853.

[19] Kanampiu, F., Makumbi, D., Mageto, E., Omanya, G., Waruingi, S., Musyoka, P., & Ransom, J. (2018). Assessment of management options on *Striga* infestation and maize grain yield in Kenya. *Weed Science, 66*(4), 516-524.

[20] Khan, Z. R., Midega, C. A., Hassanali, A., Pickett, J. A., Wadhams, L. J., & Wanjoya, A. (2006). Management of witchweed, Striga hermonthica, and stemborers in sorghum, Sorghum bicolor, through intercropping with greenleaf desmodium, Desmodium intortum. *International Journal of Pest Management*, *52*(4), 297-302.

[21] Logan, D. C., & Stewart, G. R. (1991). Role of ethylene in the germination of the hemi-parasite *Striga hermonthica*. *Journal of Plant Physiology, 97*, 1435-1438.

[22] Lyimo, S., Mduruma, Z., & De Groote, H. (2014). The use of improved maize variety in Tanzania. *Journal of Agricultural Research, 9*(7), 643-657.

[23] Makumbi, D., Diallo, A., Kanampiu, F., Mugo, S., & Karaya, H. (2015). Agronomic performance and genotype * environment interaction of herbicide‐resistant maize varieties in eastern Africa. *Crop Science*, *55*(2), 540-555.

[24] Mignouna, D. B., Abdoulaye, T., Alene, A., Manyong, V. M., Dontsop, P. N., Ainembabazi, J. H., & Asiedu, R. (2015). A microeconometric analysis of household consumption Expenditure determinants in Yam-growing Areas of Nigeria and Ghana. *Tropicultura*, *33*(3), 226-237.

[25] Mignouna, D. B., Manyong, V. M., Mutabazi, K. D. S., & Senkondo, E. M. (2011). Determinants of adopting imazapyr-resistant maize for *Striga* control in Western Kenya: A double-hurdle approach. *Journal of Development and Agricultural Economics, 3*(11), 572-580.

[26] Mignouna, D. B., Manyong, V. M., Mutabazi, K. D. S., Senkondo, E. M., & Oleke, J. M. (2012). Assessing the technical efficiency of maize producers with imazapyr-resistant maize for *Striga* control in Western Kenya. *Journal of Development and Agricultural Economics, 4*(8), 245-255.

[27] Muchiri, F. N., Narla, R. D., Olanya, O. M., Nyankanga, R. O., & Ariga, E. S. (2017). Efficacy of fungicide mixtures for the management of *Phytophthora infestans* (US-1) on potato. *Phytoprotection, 90*, 19-29.

[28] Odhiambo, G. D., & Ariga, E. S. (2004, February). Effect of intercropping maize and beans on Striga incidence and grain yield. In *Seventh Eastern and Southern Africa Regional Maize Conference* (pp. 183-186).

[29] Omondi, E. C., Norton, J. B., & Ashilenje, D. S. (2014). Performance of a local open-pollinated maize variety and a common hybrid variety under intensive small-scale farming practices. *African Journal of Agricultural Research, 9*(11), 950-955.

[30] Oswald, A. (2005). Striga control-technologies and their dissemination. *Variety Protection, 24*, 333–342.

[31] Parker, C. (2013). The parasitic weeds of the Orobanchaceae. In *Parasitic Orobanchaceae: Parasitic mechanisms and control strategies* (pp. 313-344). Berlin, Heidelberg: Springer Berlin Heidelberg.

[32] Ransom, J., Kanampiu, F., Gressel, J., De Groote, H., Burnet, M., & Odhiambo, G. (2012). Herbicide applied to imidazolinone-resistant maize seed as a *Striga* control option for small-scale African farmers. *Weed Science, 60*(2), 283-289.

[33] Rodenburg, J., Demont, M., Zwart, S. J., & Bastiaans, L. (2016). Parasitic weed incidence and related economic losses in rice in Africa. *Agriculture, Ecosystems & Environment, 235*, 306–317.

[34] Scholes, J. D., & Press, M. C. (2008). *Striga* infestation of cereal varieties: An unsolved problem in resource-limited agriculture. *Current Opinion in Plant Biology, 11*(2), 180–186.

[35] Shen, L. (2016). *Impact of seed innovation and polices on maize yields in Kenya* [Doctoral dissertation, Rutgers University-Graduate School-New Brunswick].

[36] Wambugu, P. W., Mathenge, P. W., Auma, E. O., & VanRheenen, H. A. (2012). Constraints to On‐Farm Maize (Zea mays L.) Seed Production in Western Kenya: Plant Growth and Yield. *International Scholarly Research Notices*, *2012*(1), 153412.

[37] Werkissa, Y. (2022). Impact of witch weeds (*Striga hermonthica*) on sorghum production and its managements in Ethiopia. *American Journal of Plant Biology, 7*(1), 52-97.

[38] Woomer, P. (2006). Empowering African farmers to eradicate Striga from maize croplands. The African Agricultural Technology Foundation. Nairobi, Kenya.