Prevalence and drivers of seed and pollen-mediated geneflow in sorghum: implications for biosafety regulations and policy in Kenya

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Contributed Paper prepared for presentation at the International Association of Agricultural Economists Conference, Beijing, China, August 16-22, 2009

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Abstract

This paper uses a random sample of 881 farmers drawn from eastern and western Kenya to examine the prevalence and drivers of seed and pollen mediated geneflow in the two major sorghum growing regions. It employs both qualitative and quantitative techniques to assess farmers' awareness of wild sorghum varieties, the practices they use in maintaining varietal purity and the conditioners of their success in maintaining the purity of cultivated varieties. The study finds that, among others, cultural differences, agro-climate and poverty affect the awareness, practices used in maintaining varietal purity and farmers' success in doing so. These findings have implication for biosafety and policy in Kenya due to the clamour to introduce genetically modified bio-fortified sorghum varieties in Africa.

Key words: cultivated sorghum, prevalence of wild sorghum varieties, geneflow, varietal purity, biosafety, Kenya.

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Introduction

Sorghum is one of the most important crops in the world with over 40 million hectares dedicated to its cultivation (FAO, 1993). In Africa, sorghum represents about half the total cereal production on the continent and as such is a major food staple for the population (Belton and Taylor, 2003). It is therefore a vitally important cereal for the maintenance of food security in Africa especially due to its adaptation to harsh environmental conditions of the arid and semi arid climate and its good yield in such conditions (Dicko et al., 2006). There is also recent debate that sorghum (especially the sweet sorghum varieties) can be used a major source of biofuel to ease overdependence of Africa on fossil fuels (Reddy and Sharma, 2007).

There is a wide range of varieties and races of sorghum owing to its biology as well as its drought tolerance and adaptation to several environmental conditions. More than 7000 varieties of sorghum have been identified (Kangama and Rumei, 2005). Many of these varieties as well as the wild sorghum species exist in Africa making the continent the centre of greatest diversity for sorghum. The crop like most others continue to benefit from innovations through science and technology especially in attaining productivity gains to satisfy increased demand for food and agricultural products.

World over there is push for genetic improvement of existing crop varieties to improve their yield potential. The first and second generations of tissue culture biotechnology are increasingly being deployed in many countries to improve efficiency of conventional breeding and aid in the search higher yielding crop varieties. The transgenic technology is being taken up more rapidly in commercial farming with the hope that it can improve the productivity of small holder farming systems and providing more nutritious foods to poor consumers in developing countries (Shmidt and Bothma, 2006). However, there are concerns that introducing genetically modified crop cultivars will negatively impact the environment (Bafana, 2008). One of the potential problems is that novel genes might be unintentionally transferred by pollination to other plants, including weeds and wild relatives of the crop species (Schmidt and Bothma, 2006). There are fears that such transfers could lead to the development of resistant "super weeds", loss of biodiversity within crop species, and possibly even destabilization of the entire ecosystem (Bafana, 2008).

Gene flow from domesticated sorghum cultivars to wild and feral species is well documented in the United States. However, despite being the centre of greatest diversity of sorghum, little is known about the prevalence and conditioners of gene flow in sorghum in Africa. To date, there is limited information published on gene flow from wild to cultivated sorghums and vice versa in Africa. Yet there are efforts to develop and release transgenic sorghums, a situation that could promote intermixing of genes among the conventionally bred cultivars with transgenic, cultivated landraces as well as weedy/wild relatives of sorghum through gene flow.

Transparent and cost effective regulatory systems that inspire public confidence are needed to evaluate risks and benefits on a case by case approach. This study examines the factors that influence gene flow from wild/weedy sorghums to the cultivated varieties under settings intentionally selected to capture variations in culture, agro-climatic conditions, and socio-economic conditions. The aim of this study was to understand the factors driving seed and pollen mediated gene flow in sorghum and the role small farmers play in the process.

Objectives

The specific objectives were to:

(i) Analyze the prevalence and farmer awareness of wild and weedy sorghum varieties.

(ii) Assess the practices used in maintaining purity of cultivated sorghum varieties.

(iii) Examine the factors affecting farmers' success in conserving the purity of cultivated sorghum varieties.

This study focuses on western and eastern Kenya, the two major sorghum growing regions of Kenya and examines the issue of geneflow from among cultivated sorghum species and between cultivated and wild sorghum species in these areas. Geneflow, defined as the movement and incorporation of genes from the gene pool of one population to the gene pool of another, presents one of the greatest risks to diversity the sorghum crop (Slatkin, 1987). Substantial gene flow can cause profound effects on the genetic structure of populations leading to changes in composition of such populations, to adaptive shifts, or even to the extinction of some populations (Small, 1984; Futuyma, 1986; Slatkin, 1987). Gene flow can either be pollen or seed mediated, within cultivated crops or between cultivated crops and wild species. Pollen mediated geneflow emanates from natural out-crossing and is estimated at up to 15% in cultivated sorghum and 30% in wild sorghum. Seed mediated gene flow occurs when seeds of domesticated and wild sorghum varieties are unintentionally mixed and planted together. Biosafety, on the other hand, refers to the safe transfer, handling, and use of any living modified organism resulting from biotechnology.

Data

Data used in this study was obtained from household survey conducted in two major sorghum growing regions of Kenya namely, western and eastern Kenya between July 2006 and March 2007. The study regions were selected to capture production potential, agro-climatic conditions and cultural diversity. The agro-ecological classification was based on Jaeztold and Schmidt (1983) and included lower midlands one to lower midland four (i.e., LM1 – LM4). Based on these criteria five administrative districts namely Siaya, Busia, Teso (western Kenya) and Mbeere and Tharaka (eastern Kenya) were selected. In each district, administrative division, location, sub-location an villages were purposively sampled following the same strategy.

The list of households in each village was compiled and 200 households each in Busia and Siaya districts and 209 from Teso resulting into a total of 609 households in western Kenya using probability proportionate to size random sampling. Similarly, 150 and 122 in households were sampled in Tharaka and Mbeere districts (eastern Kenya) giving a 272 households and an overall total of 881 farmers.

Empirical methods

This study uses a combination of descriptive and quantitative methods to address the objectives. It uses descriptive analysis to present the evidence and awareness of gene flow and regression techniques to examine the factors conditioning success in maintaining the purity of domesticated sorghum varieties. The quantitative analysis is based on a Probit regression model with binary dependent variable defined as success in maintaining the purity of the most preferred sorghum variety. Specifically, success in maintaining quality is measured by the farmer-reported absence of off-types in the domesticated sorghum variety. The estimated Probit equation is specified as:

$$Y_i^* = \beta' Z_i + \varepsilon_i$$

where Y_i^* represents the probability of success or failure to maintain the purity of the most preferred variety by household *i* and difference in benefit to the household of maintaining or not maintaining varietal purity; β is vector of exogenous variables that condition the success in maintaining the purity of household's preferred sorghum variety; and ε_i is the standard normally distribution stochastic term. In this specification, Y_i^* is an underlying a latent variable whose observable counterpart Y_i is defined by:

$Y_i = 1$ if $Y_i^* > 0$ (i.e., household succeeds in maintains purity of preferred variety)

$Y_i = 0$ if otherwise

Table 1 presents the explanatory variables used in the estimation of the empirical model and the expected signs. The dependent variable defined as *success in maintaining purity of preferred variety* is a dummy variable that takes the value 1 when a farmer is successful in maintaining varietal purity, and zero otherwise. A farmer is successful in maintaining the purity of sorghum variety when there is complete absence of off-types in the field.

Table 1: Description of explanatory variables used in the Probit regression model

Variable	Description	Hypothesized sign
Cultural dummies	Proxied by the study district, i.e., *Teso, Siaya* (Luo), *Busia* (Luhya), *Tharaka* and *Mbeere*	+/-
gender	Gender of the household head. (1 = male, 0=otherwise)	+/-
education	Highest education attained	+
road	Distance to nearest main road	+
savedseed	Farmer uses saved seed (1=Yes, 0=otherwise)	+
wildsorghum	Presence of wild sorghum in the area (1=Yes, 0=otherwise)	-
farmsize	Natural log of acres of land owned	+/-
age	Natural log of age of household head	+
ageconze	Agro-ecological zone of the area captured by LM1, LM2, LM3, LM4, and LM5	-
wealthindex	Wealth index of the household	+
offtype	Presence of sorghum offtypes in the farm (1=yes, 0=otherwise)	-
agrovet	Natural log of distance to agrovet store	-
market	Natural log of distance to nearest main market	-
experience	Natural log of years of farming	+

Results

The presence of wild and weedy sorghum species in close proximity with domesticated varieties is necessary for geneflow to occur between the two. Studies suggest that geneflow between domesticated crop varieties is quite common (Arias and Rieseberg, 1994). The same is true also for domesticated and wild species. The effects of geneflow between domesticated varieties and their wild progenitors depend on the direction and potential of pollen transfer. Geneflow can retard progress in breeding and also boost fitness in the cultivated crop/weed hybrids and even improve cultivated crop (Prescott-Allen, 1983; Klinger and Elistrand, 1994).

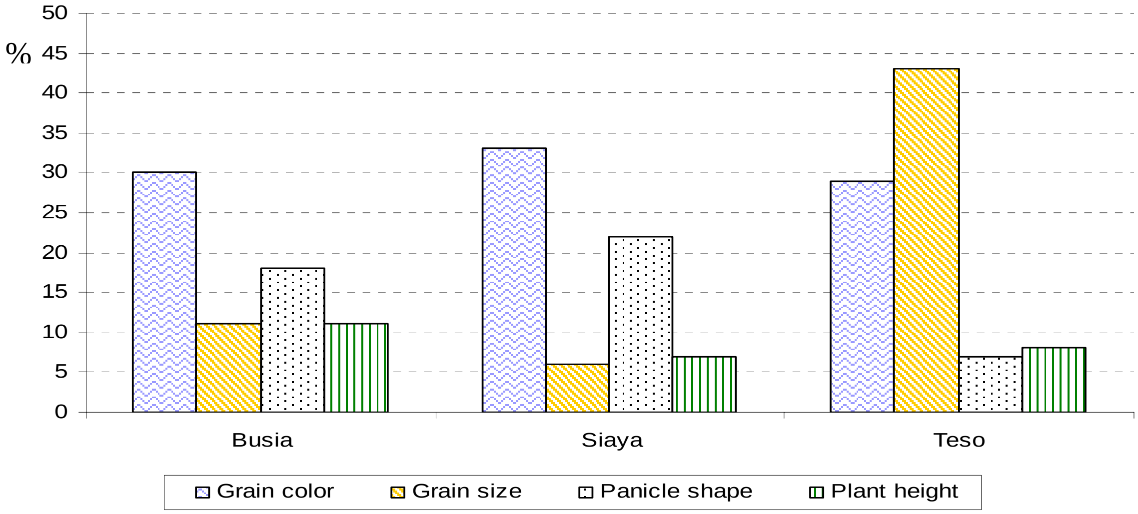
Prevalence of wild sorghum species

A large proportion of the respondents in western Kenya is aware of the existence of wild and weedy sorghum off-types. Overall, 91.7% of the respondents know of the existence of wild and weedy sorghums in their neighbourhoods. In terms of individual survey districts, 96.5%, 93.3% and 85.5%, respectively, have reported that they have seen wild sorghum varieties in their neighborhood. Among the farmers who were aware of existence of wild sorghum species 31.9% said they could identify more than one type in their neighborhood, while the rest could identify only one off-type. The proportion of farmers that could identify more than one type of wild sorghum species in their neighbourhood was highest in Teso (59.3%) and lowest in Siaya (14.7%) indicating much higher awareness of sorghum off-types in Teso.

In eastern Kenya, on the other hand, approximately 54% (n=94) farmers in Tharaka district had observed the wild and weedy sorghum species in their neighbourhood as compared to 22% (n=108) in Mbeere. Only 36% of the 204 responses in eastern Kenya indicated having observed wild and weedy sorghum species in their neighbourhoods in eastern Kenya. Overall, 50% of the respondents in eastern Kenya indicated that it was common to find more than one sorghum off-types in their neighbourhoods.

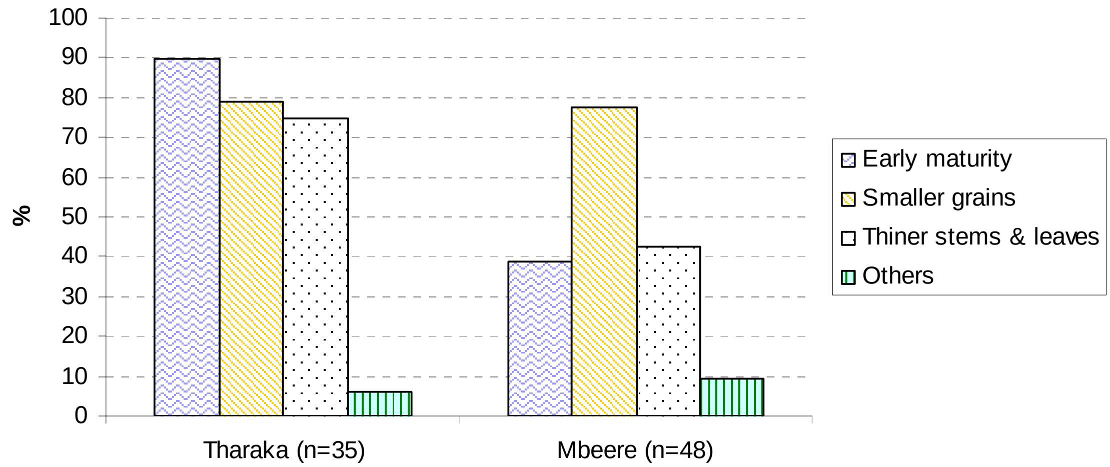
Farmers used different indicators to detect the presence of sorghum off-types in their fields as shown in Figure 1. The indicators differ by district, but the major three are grain colour, grain size, panicle shape, and plant height.

Figure 1: Indicators used by farmers to detect sorghum off-types in western Kenya, 2007



By comparison, respondents in eastern Kenya identified sorghum off-types using grain size, early maturity of the grain, and size of leaves and stem (see Figure 2). In Tharaka approximately 90% of the respondents identify wild sorghums by their early maturity while in Mbeere, the size of the grain is the major distinguishing feature. These findings suggest that the distinguishing features used by respondents in eastern Kenya are markedly different from those in western. For instance, farmers in western (especially Siaya and Busia) Kenya mainly seem to use grain colour to identify wild sorghum. In Teso district, the major feature used in distinguishing wild sorghum from domesticated is the grain size.

Figure 2: Indicators used by farmers to detect wild sorghums in eastern Kenya, 2007



Practices that affect seed and pollen-mediated gene flow in sorghum

In order to understand how the practices farmers use affect conservation of purity of sorghum varieties, we first sought to know the practices farmers use in growing sorghum. Genes can flow from wild to cultivated sorghum varieties or between different types of cultivated varieties through transfer of pollens. Such transfer is aided by planting a mixture of sorghum varieties in one plot or on adjacent plots. We therefore asked farmers about their planting practices. Majority (51%) of the respondents in eastern Kenya intercrop sorghum with other crops namely green grams, cowpea, millets and maize. The planting practices used by farmers in Tharaka and Mbeere districts are presented in Figure 3. Contrary to Mbeere where 24% of the respondents report planting different varieties, farmers in Tharaka use planting practices that prevent flow of genes between wild and cultivated sorghum varieties. Majority of respondents in western Kenya also grow sorghum as an intercrop with different crop crops (see Figure 4) although equally large number of farmers grow it as a pure stand.

Figure 3: Planting practices used by farmers in Eastern Kenya, 2007

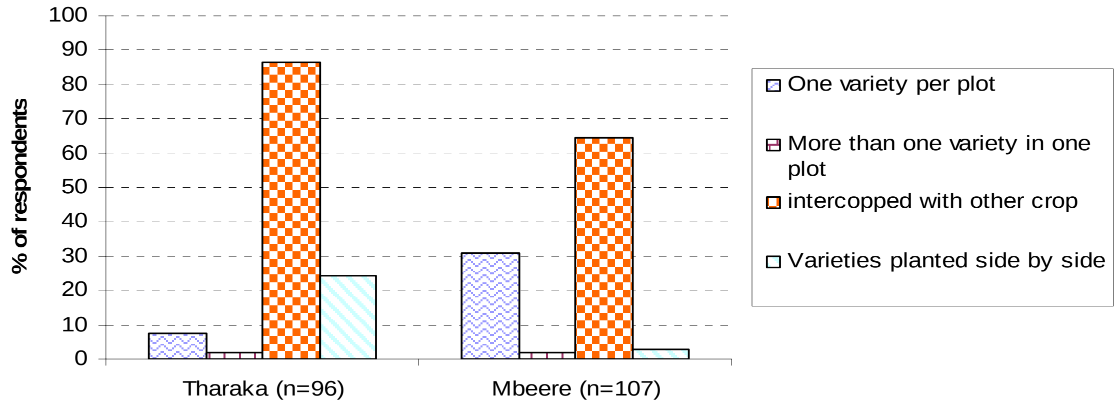
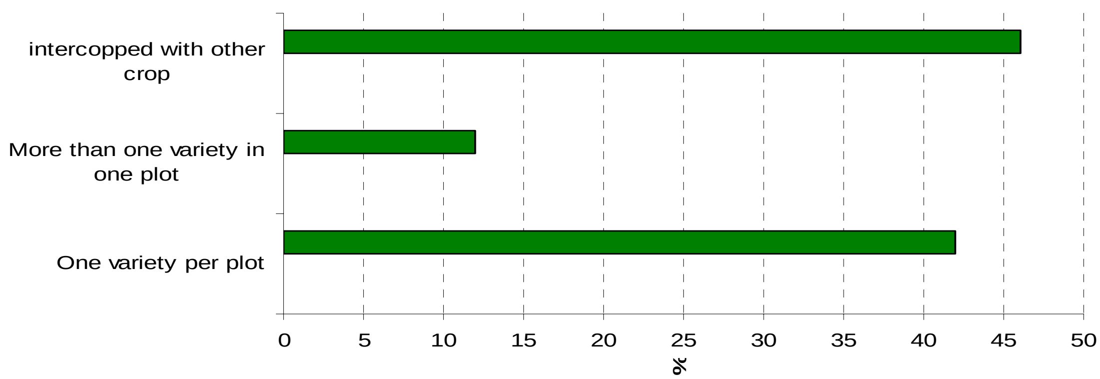


Figure 4: Sorghum planting practices used by farmers, western Kenya, 2007



Practices for maintaining the purity of cultivated sorghum varieties

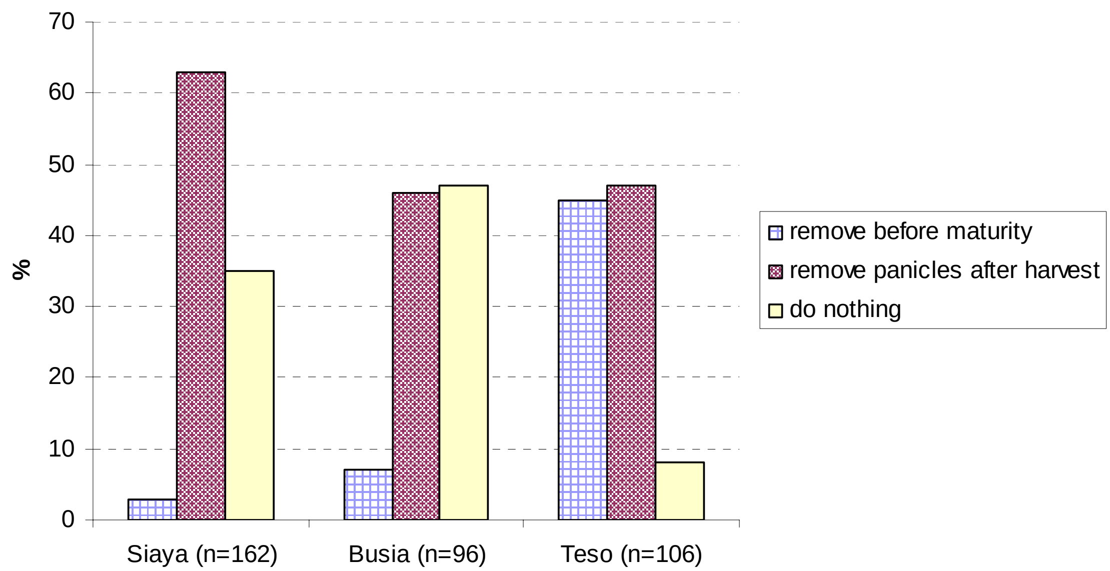
Previous studies suggest that practices used by farmers can influence the rate and extent of flow of genes between wild and cultivated sorghums in a community (Papa and Gepts, 2004; Longely, 1993). These studies especially argue that farmers' conscious selection of seeds and agronomic practices (e.g., weed control) can influence geneflow. We therefore asked the respondents the practices they use in maintaining the purity of cultivated sorghum varieties. The responses in western Kenya are presented in Table 2. Most respondents in western Kenya select the seed in order prevent adulteration of cultivated sorghum varieties with the wild relatives.

Table 2: Practices used by farmers to maintain purity of preferred varieties, western Kenya

Practice	**Count (n=320)**	**%**
Selection the seed before planting	275	86
Removal of off-types maturity	86	27
Separation of sorghum fields	74	23
Planting ahead of other farmers in the village	93	29
Thoroughly weeding out of off-types	77	24

The two major practices used in handling sorghum off-types already in the field are their removal before maturity and selection of panicle during harvest (see Figure 5). Among the practices used, the removal of off-types before maturity is the only practice that is capable of preventing geneflow. It is used by 45% of the farmers in Teso but only a few respondents in Siaya and Busia. A large percentage of farmers in Busia (47%) and Siaya (35%) simply leave the off-types mixed with preferred variety (i.e. doing nothing), a practice that encourages geneflow. These results suggest that majority of farmers in western Kenya handle off-types in ways that encourage geneflow.

Figure 5: Farmers' practices in handling sorghum off-types, western Kenya



By comparison, the most common strategy across the two districts in eastern Kenya is the selection of seed prior to harvesting of the crop. The seed selection is done during the panicle stage. Unlike western Kenya, all the strategies used to maintain purity of preferred varieties involved selecting seed at or after harvesting. Table 3 lists the strategies used in eastern Kenya.

Table 3: Practices for preserving the purity of preferred sorghum varieties in eastern (%), 2007

Strategy	Tharaka (n=96)	(Mbeere (n=108)	Total (n=204)
Select panicle before harvesting	45.8	36.6	41.3
Select panicle during harvesting	47.9	20.4	34.4
Select panicle after harvesting	22.9	25.8	24.3
Select during threshing period	3.1	-	1.6
Do nothing	-	1.1	0.5

As shown in Table 3, some of these strategies can retard pollen-mediated geneflow. However, they are inadequate in stopping the flow of genes from wild to domesticated sorghums via seed. Prevention of seed-mediated geneflow requires the removal of off-types before they flower. The strategies used by the respondents in western Kenya therefore have greater potential in influencing both seed and pollen mediated geneflow much more than those used in eastern Kenya.

Factors affecting the maintenance of purity of cultivated sorghum varieties

The results of the probit regression analysis are presented in Table 4. The results suggest that different factors drive farmers' success in maintaining purity of preferred sorghum varieties in the two study regions.

The estimated p-values[5] are based on Huber-White heteroscedasticity-robust standard errors. Starting with western Kenya, results suggest that being *luhya* or *teso* does not affect the probability farmers' success in maintaining purity of preferred sorghum variety in a statistically significant way. This implies that culture has no statistically significant effect on the likelihood that farmers will succeed in maintaining varietal purity in western Kenya. The results, however, show that the agro-climatic conditions of the area have a significant effect on maintenance of varietal purity. Farmers who live in drier (i.e., LM2

[5] The p-value is the lowest level of significance at which you will reject the null hypothesis that a given explanatory variable has no effect of the dependent variable.

and LM4) are less likely to succeed in maintaining the purity of their preferred sorghum variety relative to those located those in LM1.

Table 4: Drivers of farmers' decision to conserve purity of preferred sorghum varieties in Kenya, 2007: Probit regression results

	Eastern Kenya		**Western Kenya**	
Variable	**Coefficient**	**p-value**	**Coefficient**	**p-value**
siaya	-	-	-	-
busia	-	-	0.25	0.247
teso	-	-	-0.01	0.971
mbeere	-	-	-	-
tharaka	1.34	0.000	-	-
LM1	-	-	-	-
LM2	-	-	-0.34	0.038
LM3	-	-	-0.33	0.157
LM4	-1.53	0.000	-1.33	0.003
LM5	-0.52	0.065	-	-
education	-0.39	0.114	0.01	0.961
farmsize	0.02	0.329	-0.09	0.269
age	0.11	0.731	0.05	0.875
market	-1.20	0.236	-0.24	0.052
savedseed	0.40	0.344	-0.24	0.355
assetindex	0.18	0.193	0.03	0.089
wildsorghum	-0.17	0.021	-0.64	0.000
experience	0.09	0.321	-	-
agrovet	0.91	0.360	0.17	0.092
road	0.07	0.367	0.16	0.008
gender	0.22	0.395	0.02	0.906
offtype	-1.25	0.000	-0.40	0.004
constant	1.74	0.216	1.79	0.143
Prob > chi2	0.000		0.000	
Pseudo R-squared	0.2499		0.0657	
N	233		469	

Some of practices followed by the farmers also affect the likelihood of success in maintaining the purity of preferred varieties. As expected, having wild sorghum in the neighbourhood reduces the likelihood of success in maintaining varietal purity because it facilitates pollen and seed mediated geneflow among cultivated varities and between cultivated and wild varieties. The sign on *offtype* is also negative and statistically significant at 1% level indicating that presence of sorghum off-types in the farm reduces the likelihood of maintaining purity of preferred sorghum varieties.

The institutional factors are represented in the model by access to information (proxied by distance agrovet - *agrovet*). The transaction cost of accessing good/pure seeds are, on the other hand, proxied by distance to nearest main road (*road*) and distance to nearest main market (*market*). The results show that farmers that are located further from information sources are more likely to succeed in maintaining the purity of cultivated sorghum varieties. While this finding seems unexpected, it may be suggesting that farmers that don't access market information use own seed which generally tend to be better selected than seed sourced from the market or other farmers. Consequently, such farmers are more likely to be successful in maintaining the purity of cultivated varieties. Distance to the nearest main market is however negative and significant indicating that farmers located further away from main markets face higher transaction costs hence are less likely to succeed in maintaining the purity of cultivated sorghum variety.

Asset endowment of the households in the study areas was measured using two indicators namely farm size and index of non-land physical assets. The index is computed following Ahuja et al (2004). Results show that farm size has no effect on the likelihood of success in maintaining varietal purity but endowment with physical assets positively affects the likelihood that a farmer will succeed in maintaining varietal purity.

Contrary to western Kenya, results of the model estimated for eastern Kenya show that culture plays a role in the likelihood to maintain varietal purity. Using Mbeere as the reference, we find that farming in Tharaka significantly increases the probability that a farmer will succeed in maintaining varietal purity. Results also show that agro-climatic conditions affect the likelihood of a farmer maintaining the purity of preferred varieties. In particular, the coefficients on LM 4 and LM5 are negative and statistically significant. The results suggest that the farmers located in the drier (LM4 and LM5) agro-climate are less likely to succeed in maintaining varietal purity. These findings are identical to those of western Kenya. The negative effect of harsh climatic conditions on maintenance of varietal purity suggests a link between abiotic (especially weather) constraints and difficulty of maintaining purity of preferred sorghum varieties.

Results further indicate, as in western Kenya, that presence of wild sorghums (*wildsorghum*) in the area and presence of sorghum off-types (*offtype)* in farmer's field are highly statistically significant. The signs of both variables are, as expected, negative indicating that being surrounded with wild sorghums and off-types make it less likely that the farmer will succeed in maintaining varietal purity.

Conclusions and implications

This study finds that wild and weedy sorghums are widespread in the study regions and that majority of sorghum growers are aware of their existence. The overall awareness of wild and weedy sorghums is highest in western region. The study also finds significant differences in the level of awareness of wild sorghum varieties in each district.

Results of this study show that some of the practices used by farmers to preserve the purity of preferred sorghum varieties include planting variety as a pure stand or intercropped with other crops and also selection of seeds/panicles. Many farmers in both eastern and western Kenya select the seeds/panicles at or after maturity while others plant different sorghum varieties side-by-side or mixed together in one plot. These practices are likely to promote both pollen and seed-mediated geneflow.

Results of the probit regression analysis reveal farmers located in drier areas are less likely to be successful in maintaining varietal purity. It also finds that asset poverty (measured by asset ownership index) has a positive but weak effect on maintenance of varietal purity in western Kenya but not in eastern. This latter finding is not surprising given the generally high poverty levels in western Kenya. These findings however suggest that high levels of poverty levels may facilitate geneflow since the poorer farmers are less likely to clean (i.e. select) planting seed and/or uproot wild sorghum out of their plots. In deed the regression results also find that practices such as leaving wild varieties in the field and/or being surrounded by wild and weedy sorghums reduce the likelihood of farmers' success in maintaining the purity of preferred sorghum varieties.

The results of this study indicate that sorghum farmers use practise that can promote rapid spread and intermixing of genes of cultivated and wild/non-cultivated varieties. It thus implies that care has to should be taken in the introduction of transgenic varieties in Kenya. The findings also imply that poorer farmers are less likely to be keen in adopting the practices that maintain the purity of currently cultivated sorghum varieties. Since sorghum is grown mainly by poorer smallholder farmers, the study findings implies that there is need to educate farmers on the need to adopt practices that enhance safe handling and use of cultivated sorghum varieties in order to maintain their purity. Further, the finding that harsh climatic conditions undermine farmers' ability maintain purity of cultivate sorghum varieties suggest that farmers' need to reduce risk and ensure food security override social and environmental benefits of maintaining varietal purity. Overall, the results of this study have biosafety and policy implications for the introduction of transgenic sorghum varieties in Kenya due to the clamour to introduce genetically modified bio-fortified sorghum varieties.

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