African Journal of Agricultural and Resource Economics Volume 10 Number 1 pages 72-85

Estimation of the potential adoption of Aflasafe among smallholder maize farmers in lower eastern Kenya

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Abstract

Aflatoxin contamination in maize and maize products is a major problem in Kenya, especially in the lower eastern part, where crop losses and human fatalities have been reported. Using a pre-tested questionnaire, 480 households were surveyed in the area, which has been identified as a "hotspot" for the lethal Aspergillus flavus *strain S. This study aimed to estimate the potential adoption of Aflasafe, a new aflatoxin control technology that is currently being field-tested in Kenya, Burkina Faso and Senegal. The study found an adoption potential of 82%, which suggests that Aflasafe is likely to command a large market in lower eastern Kenya. The main factors that significantly influenced (positively or negatively) farmers' willingness to pay (WTP) for Aflasafe were: formal education, farmer type, household income, and county of residence in Kenya. The uptake of Aflasafe could be enhanced through extension services and short-term subsidies.*

Key words: aflasafe; aflatoxin; lower eastern Kenya; potential adoption; willingness to pay

1. Introduction

1.1 The aflatoxin problem

Aflatoxins are a group of mycotoxins produced primarily by strains of *Aspergillus*, i.e. *Aspergillus flavus* Link, *A. parasiticus* Speare, *A. nomius* Kurtzman, Horn & Hesseltine, *A. tamari* Kita, and *Emericella* spp. (Muthomi *et al*. 2012). *A. flavus* is commonly implicated as the cause of aflatoxin contamination in grain (Mutegi *et al*. 2012). According to Lewis *et al*. (2005), aflatoxins have both carcinogenic and hepatotoxic effects, depending on the duration and level of exposure. Chronic dietary exposure to aflatoxins is a major risk factor for hepatocellular carcinoma, particularly in areas where hepatitis B virus infection is endemic. Ingestion of higher doses of aflatoxin can result in acute aflatoxicosis, which manifests as hepatotoxicity or, in severe cases, fulminant liver failure (Lewis *et al*. 2005). Fungal contamination and subsequent production of aflatoxin occurs during crop growth, at harvest, at postharvest, and in storage (Wu *et al*. 2008). Aflatoxins form whenever the moisture content exceeds 7% and are commonly found in developing-country dietary staples such as rice, maize, cassava, nuts, peanuts, chillies and spices (William *et al*. 2004).

The earliest record of aflatoxin poisoning comes from Russia in 1861, following the consumption of mouldy grain (Stack & Carlson 2006). In 1891 there were similar reports in Japan. Aflatoxins were first described scientifically in 1913, although the toxin was not isolated at that time (Farag 2008). Then, in 1940, aflatoxicosis was reported in swine following the ingestion of contaminated maize in Turkey. Similar incidents were reported in Alabama, United States in 1950 (Farag 2008). In Britain, one of the most devastating outbreaks was the so-called "Turkey X" disease that killed many turkeys, ducklings and chicks in 1960 (Blount 1961, cited in Ayub & Sachan 1997).

In Kenya, aflatoxin was first reported in 1961, when 16 000 turkeys died from feeding on aflatoxin-contaminated groundnut feeds (FAO/UON 2011). Acute aflatoxicosis outbreaks in humans in Kenya were first described in 1978, and later in 1981, 1982 and 2001 (Muthomi *et al*. 2012). The 1982 outbreak occurred in Machakos, Makueni and Kitui counties, which are now known as aflatoxin "hotspots" following the outbreak from 2004 to 2006 (Korir & Bii 2012). During the devastating outbreak of 2004, 317 cases of aflatoxin poisoning were recorded, with 127 fatalities (Okoth & Kolla 2012). This history points to the ubiquitous and universal nature of aflatoxins, as well as their adverse effects on human and animal health.

According to the International Institute of Tropical Agriculture (IITA 2013), about US$1.2 billion is lost annually worldwide due to aflatoxin contamination, with African countries contributing to about 38% of this loss (which amounts to US$450 million). In the United States, the annual aflatoxin contamination cost has been estimated at US$500 million (Wu *et al*. 2008), with management costs of $20 to $50 million per year (Robens & Cardwell 2003). Lubulwa and Davis (1994) reported social costs of $1 billion annually associated with aflatoxin contamination in maize and peanuts in Indonesia, Thailand and the Philippines. These costs could be higher if the effects of aflatoxin on product taste, odour, texture and colour, as well as the opportunity cost of forgone crop production (due to soil contamination) and trade, are factored in. Developed countries are increasingly using aflatoxin risk as a non-tariff barrier to trade under the precautionary principle (Otsuki *et al*. 2001).

Although no study has so far estimated the cost of aflatoxin contamination and management in Kenya, the cost is believed to be high. For instance, Okoth and Kolla (2012) found that 120 (or 83%) of the 144 food samples screened for aflatoxin contamination in their study had levels greater than the regulatory limit of 10 part per billion (ppb), therefore deeming these samples unfit for human and livestock consumption and trade. Additionally, at least 2.3 million bags of maize were found unfit for human and livestock consumption and trade during the aflatoxin outbreak in Kenya from 2004 to 2006 (Atser 2010). Some of this study's key informants in Kitui County indicated that maize prices dropped by half – from 1 800 Kenyan Shillings to 900 Kenyan Shillings – following an aflatoxin alert in the area in 2009.

Apart from the significant monetary costs associated with aflatoxin contamination, aflatoxins disproportionately affect the poor, and particularly women. For instance, food-insecure resource-poor households (which are predominantly headed by women) are more likely to consume contaminated food rather than sell or even discard it. Additionally, owing to income constraints, such households may not be able to adopt costly-control strategies – thereby reducing crop productivity – particularly if the household is located in an aflatoxin "hotspot". Furthermore, although well-intentioned aflatoxin awareness campaigns can reduce prices for aflatoxin-contaminated food, they may inadvertently result in direct market losses for the poor: it is unlikely that poor farmers can afford throwing away crops that cannot be sold due to aflatoxin contamination. This leads to more severe health impacts associated with farmers' consumption of their own low-priced, contaminated food.

1.2 Resolving the aflatoxin problem

Several biotechnologies have been developed in the last decade for pre-harvest control of aflatoxins. These technologies use atoxigenic fungi to competitively displace toxigenic fungi in the soil (Hell & Mutegi 2011). In the United States, AflaGuard has been developed as a commercial product based on atoxigenic *Aspergillus flavus* strains (Isakeit 2009). In West Africa, two isolates of *A. flavus* have been identified as atoxigenic strains to competitively exclude toxigenic fungi in maize fields (Atehnkeng *et al*. 2008). These strains have been shown to reduce aflatoxin concentrations in both laboratory and field trials by 70% to 99% (Atehnkeng *et al*. 2008). A mixture of four atoxigenic strains of *A. flavus* of Nigerian origin has been granted a provisional registration as Aflasafe in Nigeria (IITA 2010). On-farm trials with Aflasafe are currently on-going in Kenya, Burkina Faso and Senegal (having begun in 2010), and in 2013 Mozambique was included as a target country for biocontrol product development (IITA 2012).

According to Franzel *et al*. (2001:38), adoption potential refers to "the likelihood of uptake of a new technology or practice when required information and material are made available to the farmer". The *ex ante* estimation of potential adoption of a new technology is important in terms of reducing the potential loss of scarce resources that would arise from pursuing a non-viable technology. Additionally, it provides information for policy design, priority setting as well as for gauging the potential market size that a future commercial product would command.

This study estimated the potential adoption of Aflasafe among small-scale maize farmers in eastern Kenya, an area already identified as an aflatoxin hotspot (Korir & Bii 2012). Although several studies have analysed the biological nature, effects and performance of Aflasafe (see, for example, Wu & Khlangwiset 2010; Hell & Mutegi 2011; Mutegi *et al*. 2012), few socio-economic studies on Aflasafe have been done in Kenya. In particular, there is a dearth of information about the cost, acceptability and adoptability of Aflasafe by maize farmers in Kenya. Assessing the factors that drive the uptake of Aflasafe can help in designing dissemination packages and strategies to accelerate its adoption, particularly among resource-poor smallholder farmers in aflatoxin hotspots.

The fact that Aflasafe is not yet available as a commercial product in Kenya means that its adoption cannot be determined explicitly through observed farmer behaviour. Yet information on its adoption profile is needed to guide the commercialisation decision by either its developers or an independent investor. Such information would aid in predicting the potential commercial success and market size of Aflasafe before it is released into the market. Additionally, this information would be useful in setting the initial market price before the forces of supply and demand apply, as well as in providing an important tool for improving research and extension efficiency and for guiding policy.

2. Materials and methods

2.1 Study area

This study was conducted in Embu, Kitui, Machakos and Makueni counties of the former Eastern Province of Kenya – all of which have a long history of aflatoxin outbreaks (Korir & Bii 2012; Muthomi *et al*. 2012). The four counties vary considerably in terms of agro-ecological conditions and socio-economic development. For instance, Embu County is the wettest of the four, with 1 495 mm of rainfall annually (Jaetzold & Schmidt 2006). Makueni and Machakos counties follow, with 500 to 1 050 mm and 500 to 900 mm of annual rainfall respectively. Kitui County is predominantly arid and semi-arid, with 150 to 650 mm of annual rainfall.

Small-scale subsistence agriculture is the dominant economic activity in the four counties. Farmers grow maize, beans, coffee and fruit, and also keep cattle, sheep, goats and chickens. Maize and pulses (dried legumes) are the major staple food crops. The poverty level of Embu County is 40.8% – which is slightly lower than the national average of 46% – while that of Makueni, Machakos and Kitui counties is higher at 49%, 59.6% and 63% respectively (KDHS & ICF Macro 2010).

2.2 Sampling

Two districts per county were purposively selected on the basis of having been involved in Aflasafe trials carried out by the Kenya Agricultural Research Institute (KARI) in 2012. Sixty households, consisting of 30 trial and 30 non-trial farmers, were randomly selected in each district for the survey. Where the number of trial farmers in a district fell below 30, all the trial farmers in that district were selected and the balance topped up with non-trial farmers. The list of trial farmers was obtained from the frontline extension staff of the Ministry of Agriculture in each district.

In order to select non-trial farmers in each district, one non-trial division in the district was randomly selected and all the households in each division were mapped by a geographical information system (GIS) expert. The appropriate number of households in each division was randomly selected from the map and their coordinates were loaded into a number of global positioning systems (GPS). The GPSs were used by the enumerators to identify the non-trial households for the survey. The total sample size was 480 households, comprising 187 trial and 293 non-trial farmers. Figure 1 shows the distribution of survey households in the study area.

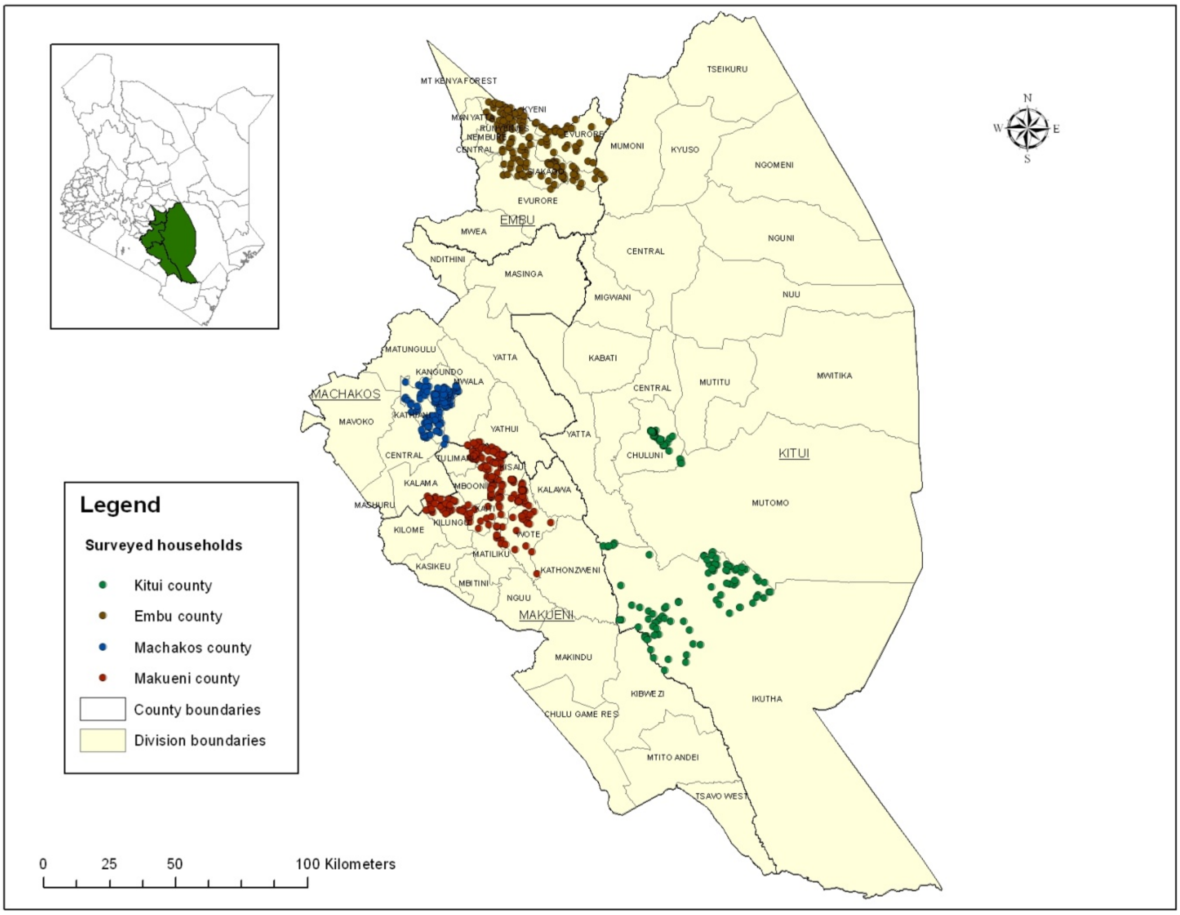

Figure 1. Distribution of households in the four counties of Kenya
Source: Author

2.3 Data collection

The 480 farmers were interviewed using a semi-structured pre-tested questionnaire. The target respondent was the household head. In his/her absence, his/her spouse or a close member of the household familiar with farm operations was interviewed. The questionnaire contained sections on the farmer's socio-demographic characteristics; knowledge on causes, effects and signs of aflatoxin contamination; and his/her willingness to adopt Aflasafe once it is available on the market. Face-to-face interviews were conducted with farmers by well-trained enumerators using the local dialect.

2.4 Data analysis

The questionnaire data were captured in a Microsoft Access relational database. All the data were thoroughly cleaned before analysis using SAS software. Descriptive statistics, including means, standard deviation and frequencies, were computed to characterise the farmers' socio-economic attributes as well as to gauge farmers' perceptions of the effects of aflatoxin contamination at the farm level. The results were presented in tabular and graphical formats.

Regression analysis was used to assess farmers' willingness to pay (WTP) for Aflasafe and the results were used to compute the potential adoption of Aflasafe. According to Ajzen and Fishbein (1969), behavioural intention, BI, accounts for most of behavioural (B) variance; i.e. there is a high correlation between BI and B, implying that if one can predict BI, then B can be inferred from BI. Further, Ajzen (1991) observes that "... intentions to perform [particular] .... behaviours can be predicted with high [degree of] accuracy from attitudes toward the behaviour, subjective norms, and perceived behavioural control; and these intentions, together with perceptions of behavioural control, account for considerable variance in actual behaviour" (p. 179). These relationships are captured in equation (1).

$$B \sim BI = [A - act]w_0 + [NB_P]w_1 + [(NB_S)(MC_S)]w_2 \quad (1)$$

where

B = observed behaviour
BI = behavioural intention
A-act = attitude toward the behaviour in a given situation
NB_P = personal normative beliefs
NB_S = social normative beliefs or perceived expectations of others
MC_S = motivation to comply with social normative beliefs
w_i = empirically determined weights; i = 0, 1, 2.

BI can take *n* values depending on the objectives of the study. In this study, BI was a binary variable taking the value of 1 if the farmer expressed his or her WTP for Aflasafe once it is available on the market, and zero otherwise. Binary responses are best estimated using either logit or probit models (Gujarati 2008; Greene 2011). According to Gujarati (2008), the two models are similar save for the fatter tails in the logit model, i.e. the probit curve approaches the axes more quickly than the logistic curve. Therefore the choice of which model to use in empirical work is arbitrary and innocuous (Maddala 1983). In this study the following logit model was fitted into the data:

$$BI_i = \beta_0 + \beta_1\mathrm{AGE} + \beta_2 AGESQ + \beta_3\mathrm{SEX} + \beta_4\mathrm{EDUC} + \beta_5 FARMERTYPE + \beta_6\mathrm{AWARENESS} + \beta_7\mathrm{WCLASS} + \beta_8\mathrm{DISTANCE} + \beta_9\mathrm{INCOME} + \beta_{10} COUNTY \quad (2)$$

The meaning of the variables in equation (2) is described in Table 1.

Table 1. Meaning of independent variables used to estimate potential adoption of Aflasafe in lower eastern Kenya

Variable	Meaning	Hypothesised sign of effect
AGE	Age of the household head (years)	±
AGESQ	Square of age of household head (years)	+
SEX	Dummy representing gender of household head: (1 = Male; 0 = Female)	+
EDUC	Discrete representing level of formal education of household head: (1 = None; 2 = Primary; 3 = Secondary; 4 = Tertiary)	+
FARMERTYPE	Dummy representing whether the farmer belonged to trial or control group: (1 = Trial farmer; 0 = Control farmer)	+
AWARENESS	Dummy representing whether or not respondent is aware of any biological aflatoxin control method: (1 = Yes; 0 = No)	+
WCLASS‡	Discrete representing wealth class: (1 = "Poor"; 2 = "Middle class"; 3 = "Rich")	+
DISTANCE	Distance to nearest agro-input dealer (km)	-
INCOME	Average monthly household income from all sources (KShs)	+
COUNTY	Discrete representing spatial differences in biophysical, socio-economic and aflatoxin attributes of the four counties: (1 = Makueni; 2 = Kitui; 3 = Machakos; 4 = Embu). Embu County was set as a reference due to its higher agricultural potential and lower poverty and aflatoxicosis levels compared to the rest	+

‡Computed using household assets, including land and livestock owned, with principal components analysis (PCA) (see below)

The coefficients of independent variables in equation (2) were used to calculate the log odds of each response category at the sample means of various regressors using the following formula:

$$\eta_j = \log \frac{p_j}{p_{j+1}} = \sum_i^k \hat{\beta}_i \overline{X}_i \qquad \forall\ i = 1, \ldots, k \text{ regressors including the intercept,} \tag{3}$$

where
η_j = log odds of the jth response category
p_j = jth response category; in this case j=1, 2
p_{j+1} = reference response category
$\hat{\beta}_i$ = estimate of the ith coefficient
$\overline{X}_i$ = sample mean of the ith regressor

The log odds were used to calculate the adoption potential of Aflasafe as the probability of occurrence of the jth response category, p_j, using the formula:

$$p_j = \frac{\exp(\eta_j)}{1 + \exp(\eta_j) + \exp(\eta_{j+1})} \tag{4}$$

The wealth class of various households was computed from the household asset index derived through PCA following Wang and Ahuja (2004). In this case, the household assets comprising type of housing, farm transport/equipment, land, livestock and income were used in the calculation. The PCA was used to generate factor scores, which were then used to compute the asset index using the formula:

$$A_i = \sum_k f_k \frac{a_{ik} - a_k}{s_k} \tag{5}$$

where
A_i = value of asset index for the ith household
f_k = factor score coefficient for the kth asset obtained from PCA
a_{ik} = value of the kth asset for the ith household
a_k = the mean of the kth asset over all households
s_k = the standard deviation of the kth asset over all households

All the households were classified into three categories on the basis of their asset index using the following criteria: (i) if the asset index for a particular household was less than the mean for all households, that household was classified as "POOR"; (ii) if the asset index for a particular household was between the mean and mean plus one standard deviation, that household was classified as "MIDDLE CLASS", and (iii) if the asset index for a particular household was greater than the mean and mean plus one standard deviation, that household was classified as "RICH".

3. Results

3.1 Farmers' socio-economic characteristics

Table 2 presents the gender profiles of the respondents in each of the eight survey districts. There were more female (54.5%) than male (45.5%) respondents among the trial farmers, and more male (58.0%) than female (42.0%) respondents among the non-trial farmers. The higher proportion of women among the trial farmers reflects the underlying importance of women's contribution to agricultural labour in Kenya.

The average age of the heads of household among trial and non-trial farmers was 55.8 (standard error (s.e.[1]) = 1.1; range = 25 to 90) and 51.6 years (s.e. = 0.8; range = 25 to 95) respectively, and was significantly different (p = 0.0025). This indicates that trial farmers were relatively older than non-trial farmers. While it may be difficult to adequately account for this observation, adoption studies show that older farmers are more likely to try new innovations – especially those associated with eliminating a persistent problem such as aflatoxin (Feder *et al*. 1985; Adesina & Zinnah 1993; Adesina & Baidu-Forson 1995). In addition, Mahajan *et al*. (1995) observed that individuals assess the utility of new technologies by relating their perception of the practice to their experience and interpreting the value of that practice to their needs. If that experience suggests that the potential rewards to be gained from an adoption process will be greater than expected efforts or costs, the individual is likely to adopt the innovation (Rogers 1962).

Table 2: Gender of survey respondents in lower eastern Kenya

	Trial farmers			Non-trial farmers		
District	**Males**	**Females**	**Sub-total**	**Males**	**Females**	**Sub-total**
Embu East	19	11	30	24	6	30
Ikutha	10	4	14	28	18	46
Kangundo	10	13	23	21	16	37
Kathiani	9	11	20	24	16	40
Makueni	17	13	30	15	15	30
Mbeere North	5	25	30	15	15	30
Mbooni East	10	10	20	23	17	40
Nzambani	5	15	20	20	20	40
Total	**85**	**102**	**187**	**170**	**123**	**293**

Source: Survey data

[1] s.e. = standard error

Table 3 shows the level of formal education of the household head and whether or not he/she worked on the farm. The majority of the household heads had attained a primary level of education (40.9% of 176 trial farmers and 39.9% of 266 farmers). Among the trial farmers, approximately 40% had attained secondary and tertiary education, which was slightly higher than 36% of the non-trial farmers. Additionally, among the two groups, most of the household heads worked full-time on the farm (64% of 175 trial farmers vs. 54.4% of 263 of non-trial farmers). Education is an important determinant of technology adoption because it tends to reduce farmers' risk aversion, thus enabling them to try out innovations. In addition, well-educated farmers possess enhanced information-processing capabilities that enable them to demand and utilise complex agricultural technologies such as Aflasafe, which improves their technical and allocative efficiency (Thomas *et al*. 1991; Ntege-Nanyeenya *et al*. 1997).

Table 3: Level of formal education and farm labour supply of heads of households among trial and non-trial farmers in eastern Kenya

Characteristic	**Trial farmers**		**Non-trial farmers**	
	Frequency	Percentage	Frequency	Percentage
Level of formal education				
None	21	12.0	35	13.2
Primary	72	40.9	106	39.9
Secondary	52	29.6	86	32.3
Tertiary	31	17.6	39	14.7
Labour supply on-farm				
Full-time	112	64.0	143	54.4
Part-time	52	29.7	104	39.5
Not applicable	11	6.3	16	6.1

Source: Survey data

About half of the trial and two-thirds of the non-trial households were in the "poor" category (Table 4). Very few households were in the "rich" category (21 vs. 36 households among trial and non-trial groups respectively). In general, 282 farmers (or 58.8%) were in the "poor" category. Another 141 farmers (or 29.4%) were in the medium income category, while 57 farmers (or 11.9%) were in the "rich" category. Poverty is both a result as well as a cause of low technology adoption. Additionally, poverty amplifies risk aversion, particularly among poorer households. Such households may forego more profitable but risky technologies in order to avoid a loss. Unfortunately, this may confine households to low-return and low-risk traditional technologies, which keep them in a perpetual poverty trap (Dercon & Christiaensen 2011). Strategies are therefore needed to encourage technology adoption among the poor. Mendola (2007) found that technology adoption reduced the probability of being poor in rural Bangladesh. It is safe to assume that the high proportion (about 60%) of poor households in the study sample are likely to benefit if Aflasafe is widely adopted in lower eastern Kenya.

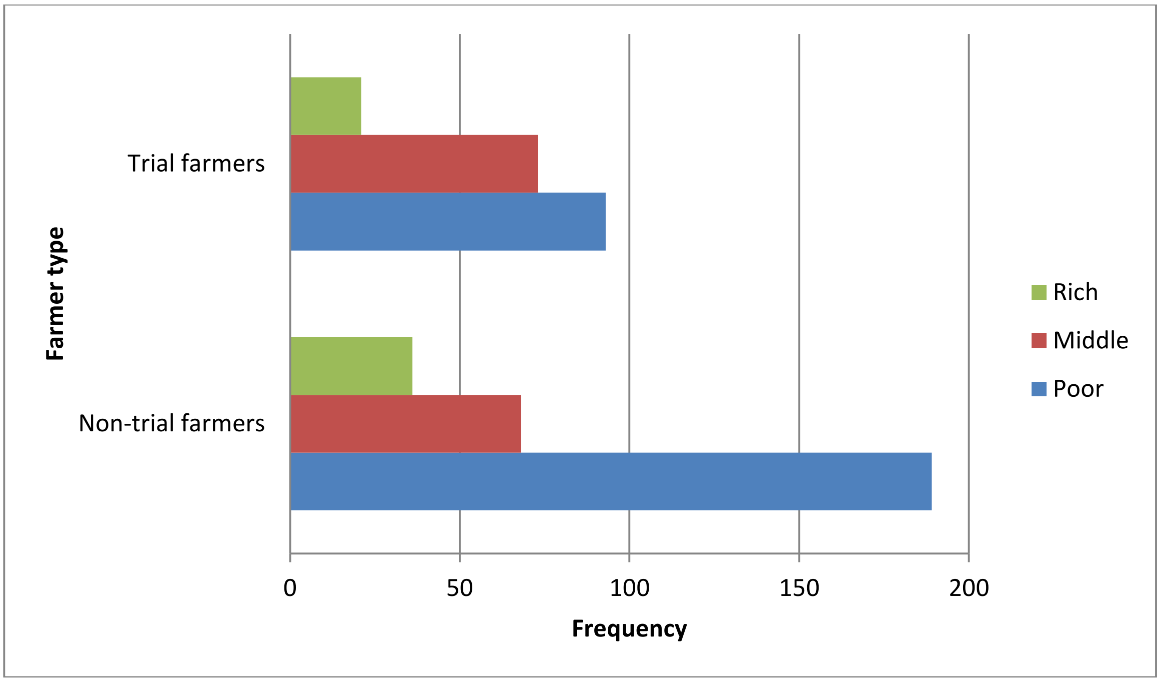

Figure 2: Classification of study households according to income category

3.2 Potential adoption of Aflasafe

Table 4 presents the β-coefficients for various variables in equation (2). The Hosmer-Lemeshow goodness-of-fit test was not statistically significant, hence the null hypothesis of lack-of-fit could not be sustained ($\chi^2 = 8.26$; df = 8; p = 0.4085). Out of the 10 regressors hypothesised to influence the likelihood that a farmer would be willing to pay for Aflasafe once it comes onto the market, only four were statistically significant, i.e. EDUC, FARMERTYPE, INCOME and COUNTY. While primary and secondary education categories were not statistically significant, a change from no education to tertiary education would increase the likelihood of a household's WTP for Aflasafe by 85.9% (p = 0.0102). Being a trial farmer increased the probability of a household's WTP for Aflasafe by 57.3% (p = 0.0002). On the other hand, a 10% increase in monthly household income decreased the likelihood of a household's WTP for Aflasafe by a meagre 0.03% (p = 0.0452), while a switch from Embu to Makueni County decreased that probability by 67.3% (p = 0.0016). However, a shift from Embu to Kitui County increased a farmer's likelihood to pay for Aflasafe by 65.5% (p = 0.0091), *ceteris paribus*.

The β-coefficients in Table 5 were used to calculate the potential adoption of Aflasafe using equations (4) and (5). The probability of a household's WTP for Aflasafe was 0.91, while that of not willing to pay was 0.09; hence, the potential adoption was 82%.

Table 4: Maximum likelihood estimates and odds ratios of factors hypothesised to influence farmers' willingness to pay for Aflasafe in lower eastern Kenya

Variable	Level	β-estimate	Standard error	Wald χ^2	Odds ratio	95% confidence interval
AGE		-0.0209	0.0549	0.1446	0.979	0.7-1.1
AGESQ		0.000084	0.000487	0.0297	1.000	1.0-1.0
SEX	1	0.1468	0.1631	0.8106	1.341	0.7-2.5
EDUC	1	-0.3077	0.2062	2.228	1.178	0.5-2.6
	2	-0.0799	0.2305	0.1202	1.479	0.6-3.6
	3	0.8589**	0.3343	6.5998	3.782	1.3-11.4
FARMERYPE	1	0.5729***	0.1529	14.0304	3.145	1.7-5.7
AWARENESS	1	-0.2578	0.1804	2.0414	0.597	0.3-1.2
WCLASS	1	0.618	0.2081	0.0883	1.160	0.5-2.8
	2	0.0247	0.2111	0.0137	1.118	0.5-2.7
DISTANCE		0.0757	0.0527	2.0645	1.079	1.0-1.2
INCOME		-0.00003**	0.000014	4.0122	1.000	1.0-1.0
COUNTY	1	-0.6733**	0.2136	9.9389	0.406	0.2-0.8
	2	0.6554**	0.2511	6.8124	1.533	0.7-3.3
	3	-0.2106	0.2269	0.8615	0.645	0.3-1.3
INTERCEPT		1.7379	1.5459	1.2639		

*** and ** denote significance at the 1% and 5% levels respectively
Source: Survey data

4. Discussion

The act of adopting agricultural technologies is an expression of rational behaviour that reflects an underlying motivation. In the context of commercial concerns, such motivation is usually based on the need to maximise profits (Varian 1992). In smallholder farming systems, the motivation may be based on maximising household survival, income and/or food security (Ellis 1988). The final adoption decision is made if the perceived discounted marginal benefits of the adoption process are greater than the perceived discounted marginal costs (Beach & Mitchell 1978; Leagans 1979). For emerging technologies (defined here as technologies that are still under development and therefore not available in the market), estimating the adoption potential provides an indication of the potential success of the technology, which can be used as an *ex ante* assessment of the potential market share that a future commercial product will command. Such information is potentially useful to policy makers and other interest groups for defining incentives, institutional mechanisms and policies that could be implemented in order to accelerate the adoption of new technologies such as Aflasafe.

This study found formal education, farmer type, household income and county of residence to be statistically significant in influencing the likelihood that a household would be willing to pay for Aflasafe once it comes into the market. Education and farmer type had the hypothesised signs, while income and county had unexpected ones (see Table 1). Previous studies indicate that formal education tends to reduce farmers' risk aversion, thus enabling them to try out new innovations (Welch 1979). In addition, farmers who are well educated possess enhanced information-processing capabilities that enable them to demand and utilise complex agricultural technologies. By so doing, their technical and allocative efficiency is improved (Thomas *et al*. 1991; Ntege-Nanyeenya *et al*. 1997). The fact that formal education positively influenced the likelihood of a household's WTP for Aflasafe could be attributed to the fact that the more educated farmers had an increased ability to appreciate the benefits of the new technology, which in turn was based on their lower risk-adverse attitude.

Being a trial farmer positively and significantly influenced the household's WTP for Aflasafe. Several studies argue that farmers have subjective preferences for technology characteristics, which play a major role in technology adoption (Fliegel & Kivlin 1966; Adesina & Zinnah 1993). These preferences, in turn, form a proximal antecedent of adoption behaviour and can be altered either positively or negatively by the level of exposure to a new technology through trialing. As the trial farmers in this study had such exposure, it is no wonder that being a trial farmer positively influenced the likelihood that a household would pay for Aflasafe once it is available in the market.

The average household income had been hypothesised to positively influence farmers' WTP for Aflasafe. The reason for this is that higher income would enable farmers to afford the new technology. Kimenju *et al*. (2005) found that income positively influenced consumers' WTP for genetically modified maize meal in Nairobi. In this study, however, the variable turned out to be negative but statistically significant (Table 5). One plausible explanation of the negative effect of household income on WTP for Aflasafe is that higher income (which generally implies more wealth) would support the shift from households producing their own maize (which requires the use of Aflasafe), to relying on the market as a source of food. This therefore would reduce farmers' likelihood to pay for the new technology, *ceteris paribus*.

As indicated earlier, a shift from Embu to Makueni County decreased the likelihood of paying for Aflasafe by 67.3%, while a shift to Kitui County increased the same probability by an almost equal margin of 65.5%. The lower likelihood of farmers' WTP for Aflasafe in Makueni County is surprising, given that the county has been reported to have had a higher risk of aflatoxicosis than Embu County (Lewis *et al*. 2005). One therefore could expect that farmers in Makueni County would be more than willing to pay for a technology that relieves the pernicious problem of aflatoxin contamination in their locality. This finding implies that farmers consider many other factors (other than the magnitude of the problem alone) in their decision to adopt new technologies. On the other hand, the finding that farmers in Kitui County expressed a higher likelihood to pay for Aflasafe compared to those in Embu is consistent with the expectation that producers are always willing to pay for a technology that is perceived to alleviate an identified constraint in their farming business (Mendoza-Escalante *et al*. 2003). According to Lewis *et al*. (2005), Kitui District[2] had the second highest incidence of aflatoxicosis after Makueni, accounting for 101 (or 31.8%) of the 317 patients affected by aflatoxin contamination during the 2004 outbreak. Makueni, Mackakos and Thika districts each had 148 (or 46.7%), 19 (6.0%) and 12 (3.8%) affected patients respectively.

The potential adoption of Aflasafe estimated in this study was 82%, which is relatively high considering that Aflasafe had not been used in the study area before the trials. This finding somewhat reflects the importance that smallholder maize farmers in lower eastern Kenya attach to any solution that addresses the perverse and ubiquitous problem of aflatoxin contamination in the region. Mendoza-Escalante *et al*. (2003) observed that farmers' perceptions of the enormity of production constraints not only determines their likelihood of adopting new technologies, but also increases their willingness to invest in strategies aimed at alleviating those constraints. In a region that is devoid of alternative aflatoxin-control technologies, the high adoption potential found in this study suggests that Aflasafe is likely to have a huge market. However, this will only be achieved if the price of Aflasafe is affordable to farmers. Studies (e.g. Irungu 2011) indicate that many smallholder farmers in Kenya are highly sensitive to price and may forego a potentially profitable venture (such as a promising new technology) if they perceive it to be expensive.

Using the average treatment effect (ATE) model, Dandedjrohoun *et al*. (2012) analysed the determinants of diffusion and adoption of improved technology for rice parboiling among women in Benin. The study found potential and actual adoption rates of 75% and 67% respectively, or an adoption gap of 8%. Although the authors did not account for the adoption gap, that gap reflects the fact that the potential and actual adoption rates may not be equal, particularly given that the former is based on respondents' self-reporting. Kamuanga *et al*. (2001) found farmers' WTP values to be

[2] Counties in Kenya were created after the promulgation of the new constitution in August 2010.

higher than their actual contributions of labour for tsetse fly control in Burkina Faso and attributed it to a non-commitment bias associated with the WTP methodology. That is, because the respondents do not have to face the consequences of their choices, they tend not to state their true WTP. Therefore, the high potential adoption of Aflasafe may not necessarily translate into high actual adoption, unless appropriate mechanisms are put in place to enhance it.

5. Conclusion

An *ex ante* estimation of potential adoption is an important exercise as it improves the agricultural research process by preventing a potential loss of scarce resources arising from pursuing a non-viable technology. It is also important both for priority setting as well as for gauging the potential market size that a future commercial product would command. This study estimated the adoption potential of Aflasafe in lower eastern Kenya, a "hotspot" area for aflatoxicosis. Using a relatively large sample size of 480 households, the study found a high adoption potential of 82%, which suggests that the new Aflasafe technology is likely to command a huge market share in lower eastern Kenya once it comes into the market. While this percentage may not necessarily translate into high actual adoption, we suggest that certain mechanisms can enhance adoption. One example is the provision of extension services to teach farmers the importance and method of application of Aflasafe. Another is the provision of a short-term Aflasafe price subsidy – considering that about 60% of the study respondents are in the "poor" category. The subsidy could be withdrawn gradually as farmers appreciate the benefits of Aflasafe and the adoption rates rise.

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