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Formal and Informal Seed Systems in Kenya: Supporting Indigenous Vegetable Seed Quality

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ABSTRACT *Indigenous vegetables play an important role in Kenyan food security, but production is limited by poor seed quality. Traditionally, seeds have been traded through informal networks, but a new formal seed sector is emerging. This study assessed the relative potential for formal or informal seed systems to meet the need for high-quality indigenous vegetable seed. By evaluating determinants of farmers' seed purchasing behaviour, we conclude that informal seed systems have greater potential to meet this need and should be strengthened. This study suggests that policy-makers should use context-specific data to guide decisions on seed policy.*

1. Introduction

Globally, the most common sources of crop seeds are local farmer systems (Almekinders & Louwaars, 2002; Louwaars, de Boef, & Edeme, 2013; Munyi & De Jonge, 2015). African Leafy Vegetables (ALVs), which are a diverse set of species that form the backbone of traditional diets in western Kenya (Lotter, Marshall, Weller, & Mugisha, 2014; Muhanji, Roothaert, Webo, & Stanley, 2011), are no exception to this rule (Abukutsa-Onyango, 2005). Over 90 per cent of ALV growers save their own seed, though many (72%) also purchase seed from local markets (Abukutsa-Onyango, 2005). ALVs provide an important income-generating opportunity, especially for women selling both produce (Weinberger, Pasquini, Kasambula, & Abukutsa-Onyango, 2011) and seed (Abukutsa-Onyango, 2005). A large portion of the critical micronutrients in traditional diets come from ALVs as well, including vitamins A, B, and C and minerals like calcium, iron, zinc, and potassium (Orech et al., 2007; Uusiku, Oelofse, Duodu, Bester, & Faber, 2010). Longstanding informal seed systems have made ALV seeds widely available and accessible (Abukutsa-Onyango, 2005; Okeno, Chebet, & Mathenge, 2002), but in terms of seed security (McGuire & Sperling, 2013; Sperling & McGuire, 2012), quality is still a major limitation (Afari-Sefa et al., 2012; Okeno et al., 2002). Alternative options are emerging, as seed companies that contract seed production are beginning to sell their own seed varieties, which we will refer to as formal seed systems. Various terms have been used for farmer seed systems, traditional seed systems, and local seed systems (Almekinders & Louwaars, 2002), but we will group these as informal.

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ALVs can be purchased through both formal and informal systems, but growers also obtain informal seed through trade, barter, and gifts, making up a dynamic and complex system that varies from community to community (Abukutsa-Onyango, 2005). The need for high quality ALV seed has been growing with increasing market demand for fresh ALVs in urban markets (Mwangi & Kimathi, 2006) and high-yielding seed varieties can help to fill this gap. In cities across Kenya, the demand for ALVs has begun to outstrip the supply (Mwangi & Kimathi, 2006) and governmental and non-governmental programmes are beginning to promote ALV production for their nutritional potential (Cernansky, 2015; Orech et al., 2007; Uusiku et al., 2010). Connecting farmers to the high quality germplasm they need could increase yield, boost farmer income, and link urban consumers with these healthy vegetables. Though the seed supply may be sufficient to meet the needs of the current subsistence-level production, future seed systems will have to meet the demands of growing urban populations as well. This seed will have to be affordable to smallholder farmers while also meeting growers' expectations for quality in terms of germination and yield. The purpose of this paper is to evaluate the current quality of seeds from the formal and informal seed systems for their potential to fill this gap.

1.1. African leafy vegetable seed systems

ALVs have a place in both formal and informal seed systems in Eastern Africa (Afari-Sefa et al., 2012; Munyi & De Jonge, 2015), but for policy-makers and organisations planning interventions with limited resources it is important to distinguish between situations where formal or informal seed systems may be most effective at connecting farmers with high quality germplasm. Our contribution to the literature is in finding ways to evaluate the potential for formal seed integration across diverse settings and among thousands of different crop species, which can enable policy-makers to make informed decisions to avoid unsustainable or inappropriate seed programmes. This paper tested one proposed framework for evaluating formal and informal seed systems in the context of ALVs in western Kenya. Thiele (1999) proposed a model for evaluating the appropriateness of formal seed systems based on four factors: 1) the rate of seed degradation, 2) the yield gap between formal and informal systems, 3) the farmers' available resources, and 4) the degree of market integration. An increase in any of these factors is predicted to improve the likelihood of formal seed market adoption in that context.

The purpose of this paper is to evaluate current ALV seed systems in western Kenya in the context of this framework to determine the potential of formal or informal seed markets to deliver high quality germplasm to farmers. The rate of seed degradation and the yield gap between formal and informal systems were estimated based on field data from ALV seeds collected in western Kenya, which were used to establish quality in terms of seed germinability and yield potential. Farmer resources and market access were assessed from household survey data. Based on the evaluation of these four factors, we can answer the question of whether formal or informal seed systems have a greater potential to address the needs for high quality germplasm in this region.

1.2. Limitations of formal and informal seed systems

Informal seed markets, including local networks for farmer-saved ALV seed, have been the basis of farmers' agricultural inputs for centuries and, for local varieties and less common crops, they may be the only source for seed (Almekinders & Louwaars, 2002; Munyi & De Jonge, 2015). Technical support for ALV growers is minimal or non-existent and seed enterprises have been slow to grow into this market gap, especially in sub-Saharan Africa (Tripp & Rohrbach, 2001). Seed programmes in the 1960s and 1970s focused on diffusing high-yielding varieties of only a few crops, while investments in the 1970s and 1980s increased public involvement in seed systems (Louwaars et al., 2013). Structural adjustment policies in the 1980s and 1990s reduced public sector presence but private companies did not fill in gaps in the market as expected. These policies were based on a linear expectation of the progression of seed systems from informal to formal, which ultimately did not take place (Louwaars et al., 2013).

Formal markets, though growing, are limited by the small amounts of seed demanded by individual farmers, the difficulty of reaching these growers, and the changing demand from year to year (Almekinders & Louwaars, 2002; Thiele, 1999). Formal seed markets have increased the quality and reliability of seeds of many crops, and may have the potential to do the same for ALVs, but farmer-saved seeds may offer resilience to local biotic and abiotic stresses (Almekinders & Louwaars, 2002; McGuire & Sperling, 2013). Kenyan policy, like the policies of many other countries in Africa, has focused almost exclusively on formal seeds, but this may ignore the potential strengths of informal seed systems (Louwaars et al., 2013; Munyi & De Jonge, 2015). McGuire and Sperling (2013) found that, in emergency situations, informal seed systems provided resilience even though seed aid programmes focused on distributing formal seed varieties. Seed programmes run by NGOs may also limit the development of indigenous seed industries by undercutting prices (Tripp & Rohrbach, 2001).

Given the vast diversity of accessions available, improved cultivar development is certainly possible in either the formal or informal sector, but breeding for cultivar development is rare for these species (Abukutsa-Onyango, 2005; Weinberger & Msuya, 2004). Even if informal markets are better at selecting and diffusing varieties, technical support should be able to strengthen the quality and reliability of production and storage systems (Sperling, Boettiger, & Barker, 2014; Thiele, 1999).

1.3. Alternative seed system approaches

Alternative methods have been proposed for integrating the strengths of the formal and informal seed markets. Recognising the importance of trying to improve seed quality through formal markets while supporting robust informal markets, the Tanzanian government established a seed standard called Quality Declared Seed (QDS) (Food and Agricultural Organization, 2006). The QDS system has intermediate seed standards between those commonly found in formal and informal markets and was designed to address gaps in the existing seed market rather than compete with commercial ventures (FAO, 2006).

However, QDS systems have been criticised for relaxing seed quality standards without having consistent positive effects, in addition to adding higher transaction costs that can exclude smallholder participation (McEwan, Namanda, & Lusheshannija, 2012; Sperling et al., 2014). Certification programmes in general can generate high transaction costs that may not be valued by the end user (Sperling et al., 2014). The Integrated Seed System Development (ISSD) framework has been proposed for guiding a pluralistic approach to seed sector development that promotes interaction between formal and informal systems, while calling for a diversity of strategies and interventions (Louwaars & De Boef, 2012; Louwaars et al., 2013; Thijssen, Borman, Verhoosel, Mastenbroek, & Heemskerk, 2013). These alternative frameworks and programmes point to the need for better understanding of formal and informal seed systems, with specific attention to the goals of each unique situation (for example, food provision or nutritional enhancement) (Sperling & McGuire, 2012).

2. Materials and methods

2.1. Seed quality

This research compared both the seed quality of available formal and informal seed varieties as well as the factors influencing farmer decisions to participate in formal and informal seed markets. The first section addressed the relative seed quality of formal and informal seeds in terms of germination and yield.

2.1.1. Seed materials. Amaranth (*Amaranthus* spp.) and nightshade (*Solanum* spp.) seeds were collected from formal and informal sources in western Kenya in June, 2015. The only formal seed vendor for both amaranths and nightshades was Simlaw Seeds, a subsidiary of Kenya Seed Company. Seeds were also provided by the AVRDC (World Vegetable Center) in Arusha, Tanzania from land races collected across East Africa: these have not yet been released for sale and do not have a fixed price. Seed species, sources, and prices for each of the 24 different varieties are shown in Table 1.

Table 1. Seed sources and prices (in Kenyan Shillings) by species and variety based on prices as of June 2015

Variety	Species	Seed Source	Source (Variety Name)	Price (KSH/g)
1	Amaranth	Formal	Simlaw Seeds	2.99
2	Amaranth	Formal	AVRDC (UGAM40)	
3	Amaranth	Formal	AVRDC (AC45)	
4	Amaranth	Formal	AVRDC (ExZim)	
5	Amaranth	Formal	AVRDC (AC38)	
6	Amaranth	Formal	AVRDC (ExMwanga)	
7	Amaranth	Informal	Kakamega	2.31
8	Amaranth	Informal	Eldoret vicinity	2.92
9	Amaranth	Informal	Eldoret vicinity	2.44
10	Amaranth	Informal	Eldoret vicinity	2.38
11	Amaranth	Informal	Kipkaren	1.04
12	Amaranth	Informal	Lessos	1.16
13	Nightshade	Formal	Simlaw Seeds	3.96
14	Nightshade	Formal	AVRDC (SS42)	
15	Nightshade	Formal	AVRDC (SS52)	
16	Nightshade	Formal	AVRDC (ExHai)	
17	Nightshade	Formal	AVRDC (SS49)	
18	Nightshade	Formal	AVRDC (BG16)	
19	Nightshade	Informal	Kakamega	3.02
20	Nightshade	Informal	Eldoret vicinity	3.78
21	Nightshade	Informal	Kakamega	3.56
22	Nightshade	Informal	Kipkaren	2.30
23	Nightshade	Informal	Lessos	1.76
24	Nightshade	Informal	Eldoret vicinity	2.61

2.1.2. Seed germination. Twenty seeds from each accession were placed on moist filter paper in petri dishes and maintained in a germination chamber at 70 per cent humidity and 25°C under constant light. Three replicates were evaluated for each variety and the experiment was repeated twice at an interval of two months. Germinated seeds (defined as emergence of the radicle from the seed coat) were recorded and removed every day for a period of 14 days. Mean time to 50 per cent radicle emergence was also calculated (Hanson, 1985).

2.1.3. Yield comparison. Seedlings from each variety were grown in soil to four weeks and transplanted into the field. This experiment was conducted as a randomised complete block design with three blocks and four replicates for each variety within each block. Plants were harvested only once, six weeks after transplanting and fresh weight was measured. Leaf area was measured by image analysis (ImageJ, National Institutes of Health) of digital photographs of excised leaves. The experiment was repeated twice.

2.2. *Econometric analysis*

The second part of our research evaluated how well the model proposed by Thiele (1999) matches farmers' decisions to purchase or save their own seeds. Specifically, the importance of market access and available resources are compared with other farmer-specific factors based on the available literature on technology adoption.

2.2.1. Household data collection. Our model is based on a household survey carried out across 95 villages in eight counties in western Kenya in 2013. This survey was administered to 302 households on the status of ALV market chains and their farming practices (Table 2). Characteristics of households that used saved seed and purchased seed are given in Table 4.

Table 2. Descriptive statistics of variables and hypothesised effects for formal ALV seed adoption

Variable	Definition	Mean (SD)	Expected sign
seedsource	What was the seed source for your primary ALV? 1 if purchased, 0 otherwise	0.47 (0.50)	
Farmer Characteristics			
western	Household is in the Western Province cluster, 1 if yes, 0 otherwise	0.35 (0.48)	+,-
rifthi	Household is in the Rift Valley high market access cluster, 1 if yes, 0 otherwise	0.44 (0.50)	+,-
riftlo	Household is in the Rift Valley low market access cluster (reference category), 1 if yes, 0 otherwise	0.21 (0.41)	+,-
female_manager	Who is the main producer of your ALV crops? 1 if female, 0 otherwise	0.58 (0.50)	-
joint_manager	Who is the main producer of your ALV crops? 1 if jointly, 0 otherwise	0.23 (0.42)	+,-
amaranth	What is the most important ALV you grow? 1 if amaranth, 0 otherwise	0.16 (0.37)	+,-
nightshade	What is the most important ALV you grow? 1 if nightshade, 0 otherwise	0.57 (0.50)	+,-
cowpea	What is the most important ALV you grow? 1 if cowpea, 0 otherwise	0.08 (0.27)	+,-
age	What is the age of the head of your household (years)?	48.38 (10.59)	-
ampmem	Are you a member of AMPATH receiving training? 1 if yes, 0 otherwise	0.59 (0.49)	+
hhh.sex	What is the sex of the head of household? 1 if male, 0 female	0.57 (0.50)	+
primary	What was the highest level of education someone in your household has attained? 1 if primary or less, 0 otherwise	0.21 (0.41)	-
secondary	What was the highest level of education someone in your household has attained (reference category)? 1 if secondary or less, 0 otherwise	0.63 (0.49)	+
college	What is the highest level of education someone in your household has attained? 1 if college or more, 0 otherwise	0.16 (0.37)	+

(*continued*)

Table 2. (*Continued*)

Variable	Definition	Mean (SD)	Expected sign
Resources Available			
salary	Is there someone in your household who has permanent (salaried) employment? 1 if yes, 0 otherwise	0.08 (0.27)	+
obtained	Have any of your household members obtained credit in the last two years? 1 if yes, 0 otherwise	0.28 (0.45)	+
income	What was your household income for 2012? (Kenyan Shillings, log transformed)	82707.09 (121601.76)	+
savemoney	Are you able to save money for unexpected expenses? 1 if yes, 0 otherwise	0.53 (0.50)	+
mth_food	In 2012, for how many months did the household have adequate food staples from your own production?	7.15 (3.34)	+
motorcycle	Does your household own a motorcycle? 1 if yes, 0 otherwise	0.09 (0.29)	+
motorvehicle	Does your household own a motor vehicle? 1 if yes, 0 otherwise	0.01 (0.12)	+
large.livestock	How many goats, cows, and sheep does your household own? (log transformed)	3.70 (4.63)	+
seedprc	What was your seed input cost for your primary ALV in 2012? (Kenyan shillings)	1163.05 (453.72)	-
Market Access			
sell_alvs	Did you sell any ALVs in the last two years? 1 if yes, 0 otherwise	0.99 (0.08)	+
extension	Has anyone in the household accessed agricultural extension in the last 12 months? 1 if yes, 0 otherwise	0.62 (0.49)	+
reason.grow.price	What is the main reason your household grows ALVs? 1 if good prices, 0 otherwise	0.34 (0.48)	+
reason.grow.eat	What is the main reason your household grows ALVs? 1 if home consumption, 0 otherwise	0.38 (0.49)	-
timemkt	How long does it take to get to the main market? (minutes, log transformed)	58.38 (104.46)	-

A multi-stage cluster sampling design was used in this study based on the heterogeneous characteristics of agro-ecological zones, socio-economic conditions, and relative importance of ALVs. Three clusters were identified: Western Province, Rift Valley low market access, and Rift Valley high market access. Training on ALV production and marketing had been carried out in each of these regions through farmer groups and these project sites were purposively sampled. Out of 20 sites that had participating farmer groups, 11 were considered to be sufficiently representative and a proportional number of sites was selected from within each cluster. Lists of all farmer groups involved were used to form the sampling frame and 10 survey respondents were randomly selected per site. Ten additional households that were not members of the farmer groups were also selected for interview at each site. Nearby villages where no training activities had taken place were identified and two were randomly selected. From these additional villages, lists of all households were constructed with help from village elders and extension agents. A random sample of 10 households were selected per site for the survey as well. This sample is comprised of 168 households where training had been received and 134 households where it had not.

2.2.2. Conceptual model. Households are assumed to maximise their utility subject to their constraints of budget, resources, information, credit, and availability of the formal seed and complementary inputs (Asfaw, Shiferaw, Simtowe, & Lipper, 2012; Ghimire, Huang, & Shrestha, 2015). Based on technology adoption literature (Adesina & Zinnah, 1993; Asfaw et al., 2012; Ghimire et al., 2015; Rogers, 2003; Thiele, 1999), explanatory variables are expected to fall into broad categories of household/farmer characteristics, resource availability, and market access. Farm and farmer characteristics include the ALV crop, the sex and age of the ALV manager, and the highest level of education achieved in the household. Resources available were approximated by on-farm and off-farm assets while market access was evaluated through market participation and extension access. Though the utility function is unobserved, our goal was to better understand how these categories of variables impact farmer seed adoption in order to better predict farmer behaviour.

The utility of adopting formal seeds (U_{i1}) and the utility of using saved seeds (U_{i0}) is subject to farm and farmer-specific attributes such that the difference between the two (U_i*) will determine farmer adoption. If the utility gained by adopting is more than the utility of not adopting ($U_i^* = U_{i1} - U_{i0} > 0$) then it is assumed that the farmer will participate in the formal seed networks. These utilities are unobservable but can be expressed as a function of the observable elements in the latent variable model (Equation 1). Following Asfaw et al. (2012) and Ghimire et al. (2015), the adoption decision can be modelled in a random utility framework:

$$U_i^* = \beta X_i' + u_i$$

$$with\ U_i = \begin{cases} 1 if\, U_i^* > 0 \\ 0\, otherwise \end{cases} \tag{1}$$

Where U_i* is the latent variable which represents the household's likelihood of adopting formal seeds for their primary ALV crop, denoted as one if the farmer adopts and zero otherwise. A vector of explanatory variables is represented by the term X_i' and β is a vector of parameters to be estimated. The error term is represented by u_i which is assumed to be independent and normally distributed. A probit model was used to estimate the probability of household adoption of formal ALV seeds and estimated marginal effects to assess the influence of each of the explanatory variables. All analyses were conducted in R 3.1.2 (Fernihough, 2014;Fox & Weisberg, 2011; R Core Team, 2015a, b; Zeileis, 2004; 2006; Zeileis & Hothorn,2002).

2.2.3. Empirical model. Many factors have been shown to affect farmer seed saving behaviour and technology adoption. Table 2 lists the variables included in the model related to farmer characteristics, resources available, and market access, as well as their descriptive statistics and expected sign.

Available resources are seen as the most critical determinant of technology adoption in the economic constraint model (Adesina & Zinnah, 1993; Fernandez-Cornejo, Hendricks, & Mishra, 2005), which suggests that resource factors (both on-farm and off-farm income) determine technology use. To adequately account for income and other household assets we included income, ownership of a motorcycle or motor vehicle, number of livestock owned, whether the household was able to save money for unexpected expenses, size of landholding, whether they obtained credit in the last two years, and how many months of food they were able to provide for their household from their own production. All of these variables are hypothesised to have a positive effect on formal seed adoption. Seed price was also included to account for the financial burden this adoption would require, and this was hypothesised to have a negative sign.

Market access is critical to the information-diffusion model (Rogers, 2003), which suggests that information is the key limiting factor driving improved seed or other technology adoption. Credit constraints and lack of information were shown to be equally likely to limit formal seed adoption in Uganda (Shiferaw, Kebede, Kassie, & Fisher, 2015). We included accessing extension services in this model to account for the effect of information diffusion and hypothesised that it would have a positive sign (Table 2). Market access can be impacted by the difficulty of reaching the marketplace, and to account for this, we included the time required to reach the local market and hypothesised that this would have a negative sign. Many farmers stated that the main reason they grow ALVs was their good price at market, and this was also hypothesised to be positively associated with market access in comparison to the other major reasons for growing ALVs, such as home consumption. The most direct measure of farmer market access is whether or not they sold ALVs in the last two years and this was also hypothesised to positively affect the likelihood of formal seed adoption.

To account for factors other than available resources and market access, variables related to farmer characteristics were also included (Table 2). The effect of location as indicated by cluster (Western Province, Rift Valley high market access, and Rift Valley low market access) was included, as formal seeds may be better adapted to some regional climates than others. This may have a positive or negative sign. Ghimire et al. (2015) showed that education was positively associated with improved rice variety adoption, though Mwaura, Muluvi, and Mathenge (2013) showed that education may impact male and female growers differently. We hypothesised that education level would have a positive sign in this model for formal seed adoption.

Women have been shown to have a lower frequency of adoption of improved varieties (Doss & Morris, 2001) and new management practices (Marenya & Barrett, 2007) but Mwaura et al. (2013) showed that female- and male-headed households were accessing ALV seed support systems at equal rates. Female-controlled income has been shown to have a more positive effect on child and household welfare (Quisumbing, 2003) so understanding this gender gap could be critical to positive health outcomes. For this model, female-headed households and female-managed ALVs were hypothesised to have lower rates of formal seed use. Age has also been shown to affect technology adoption as younger farmers may be more willing to bear risk (Polson & Spencer, 1991) and may have a negative sign, although Shiferaw et al. (2015) showed that some older farmers in Uganda may be more likely to adopt formal seeds.

Although all the households surveyed were ALV growers, some households received training on production, marketing, seed saving, and also received improved ALV seed varieties through agricultural extension officers. This training was only available to members of farmer groups associated with the Academic Model Providing Access to Healthcare (AMPATH). This training may have made households more likely to purchase seeds after using up the improved germplasm that was provided, or it may have encouraged them to save their own seed after gaining guidance in this area. The species of the main ALV grown by the household may also be an important factor in determining improved variety adoption, as availability of improved variety varies with species (Lotter et al., 2014). Amaranth (*Amaranthus* spp.), nightshade (*Solanum* spp.), and cowpea (*Vigna unguiculata*) were the most commonly grown ALVs, and may have a positive or negative sign in comparison with all other ALVs grown.

All explanatory variables are divided into categories of farmer characteristics, resource availability, and market access. Eight variations of the empirical model were estimated: 1) using only factors related to farmer characteristics, 2) using only factors related to available resources, 3) using only factors related to market access, 4) using factors related to farmer characteristics and resources available, 5) using factors related to farmer characteristics and market access, 6) using factors related to resources available and market access, 7) using all factors, and 8) using a forward stepwise regression model to select only those factors most relevant to formal seed adoption. The eight models are used to uncover the relative importance of each of these categories of variables in determining farmer behaviour. Akaike Information Criterion (AIC) values are used to compare between models, which are a relative measure of quality in statistical models (Akaike, 1974). Multicollinearity diagnostic tests were performed on each model based on the variance inflation factor (VIF) (Fox & Weisberg, 2011). No VIF values were greater than three, well below the critical value of 10, indicating that multicollinearity was not a serious problem in any of these models.

3. Findings

Our results combined data from seed quality assessments (seed germination and plant yield) with evidence from our model of farmer participation in formal seed markets. These sections corresponded with the four factors Thiele (1999) proposed would predict formal seed system integration.

3.1. Seed quality

3.1.1. Rate of seed germinability. Seed germination over time was used to assess the rate of seed degradation, which was not significantly different over time ($p > 0.05$). Seed germination was 148 per cent higher in informal seeds for amaranth and 190 per cent higher in nightshade, though time to germination, a proxy for seed vigour, was not significantly different (Table 3). This indicates that formal ALV seeds do not offer farmers benefits in terms of seed quality. More formal seed would need to be purchased in order to compensate for low germination rates, adding to the financial burden of purchasing formal seed varieties. The lack of difference in germination over time may indicate that these seeds degrade slowly, even when sourced from the informal system. This characteristic may strengthen farmers' preference for informal seeds, since the higher-quality formal seed packaging is not as necessary to extend the shelf life of the seeds.

3.1.2. Yield comparison of formal and informal seeds. Informal seed varieties had greater fresh weight and leaf area than formal seed varieties for amaranth but not nightshade (Table 3). The yield of amaranths from informal seed varieties was 57 per cent higher than formal seeds and had 42 per cent greater leaf area (Table 3). These differences were not significant for nightshade varieties, but it is clear that formal seeds of either species are not providing any benefits in terms of yield to growers. This suggests that an investment in purchasing seeds would not pay off through better ALV sales.

Though variation exists between species, neither formal amaranth nor nightshade seeds have shown higher quality than informal seeds in terms of germination or yield. Based on these data, purchasing seeds from formal sources may not be the best option. Formal seeds were available at a slightly higher price per gram (Table 1), but this is based on very few available formal seeds in the market and may not be true for other species or other areas. Farmers may not be aware of the differences in quality, but they may be using both formal and informal seed systems as sources of new varieties that can offer other benefits, such as pest or disease resistance (Almekinders & Louwaars, 2002; Sperling & McGuire, 2010). Despite low quality, the formal market may continue to be used as a last resort for poorer farmers, as an alternative to the labour demands of saving seeds, or for those farmers seeking out new varieties (David & Sperling, 1999; McGuire, 2008; Sperling, 1994; Sperling & McGuire, 2010). Even if this is the case, our first conclusion is that the expansion of the formal ALV seed market must be accompanied with a research and development effort that improves seed quality over what is available informally. For the first two factors that we evaluated, rate of seed degradation and yield gap, we can conclude that these would not provide an incentive to adopt formal ALV seed.

Table 3. Germination (%), mean time to germination (days), fresh weight (g), and leaf area (cm^2) by species and seed type. Standard error values appear in parentheses following mean values. Significant differences within species and between seed types are indicated by asterisks

Species	Seed Type	Germination (%)	Time to Germination (days)	Fresh Weight (g)	Leaf Area (cm^2)
Amaranth	Formal	23.62 (6.12)	4.38 (0.44)	20.09 (2.10)	324.04 (29.19)
Amaranth	Informal	58.50 (10.68)***	3.64 (0.53)	32.95 (2.76)***	460.87 (34.34)***
Nightshade	Formal	28.84 (12.09)	6.76 (1.17)	5.66 (0.74)	113.83 (15.26)
Nightshade	Informal	83.50 (2.66)***	4.91 (0.28)	5.31 (0.67)	101.04 (11.04)

Notes: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

3.2. Econometric analysis

3.2.1. Descriptive statistics. Descriptive statistics, explanation of the variables, and the hypothesised effects are shown in Table 2. Half of the surveyed households used saved seed (53%) for their primary ALV crop, which is consistent with existing literature (Abukutsa-Onyango, 2005). The majority of ALV crops were managed by women (58%), confirming the findings of Abukutsa-Onyango (2005) and Weinberger et al. (2011).

Variables summarised in Table 2 are separated by formal and informal seed adopters in Table 4. There were few differences between formal seed adopters and non-adopters (Table 4). Households where ALV plots were managed by men had a higher proportion of participation in the formal seed market. This confirms the findings of Doss and Morris (2001), who showed that, in some cases, men have higher rates of technology adoption. The other difference between the two groups was the stated price of seeds, which was significantly less for those who purchased seeds ($p < 0.01$). This suggests that economic constraint may play an important role in farmers' decision whether to purchase seed or not (Adesina & Zinnah, 1993; Fernandez-Cornejo et al., 2005).

3.2.2. Model comparison. Probit model results are presented in Table 5 and marginal effects in Table 6. These models allowed us to compare the relative contribution of each category of variables to the outcome, farmers' seed purchasing behaviour. The AIC values were then used to compare between models (Akaike, 1974).

3.2.3. Farmer characteristics. When only farmer characteristics are considered, location was significant as well as the species of ALV (Table 5). Western Province and Rift Valley high market access clusters were both less likely to adopt formal seeds than Rift Valley low market access areas. Planting nightshade and cowpea, as compared to all other ALVs, decreased the probability that households would purchase seeds by 17 and 29 per cent, respectively (Table 6). Location was consistently significant in every other model in which it was included, with Western Province significantly less likely to adopt formal seeds.

Location- and species-specific constraints may be strongly influenced by local seed availability, agronomic conditions, and cultural differences. The information-diffusion model (Rogers, 2003) suggests that as information about a new technology spreads among neighbours, it is more likely to be adopted in that area. This may help explain the strong association between location and preferred ALV crop (Fisher's Exact Test, $p < 0.01$). For example, cowpea growers were much less likely to purchase formal seeds, but this varied depending on the location. Low formal seed availability or quality may discourage formal seed adoption, but lack of information about formal seeds could be contributing to limited demand. This may help to explain the higher formal seed adoption in the Rift Valley low market access cluster, where formal seed may have been more widely distributed than in Western Province cluster. Ultimately, differences in regional climates may make some species of ALVs less productive in certain areas and local seed systems would reflect these differences.

Table 4. Characteristics of households that use saved seeds and purchased seeds for their primary ALV crop

	Saved Seeds		Purchased seeds		
	Mean	SD	Mean	SD	P value
Farmer Characteristics					
western	0.48	(0.50)	0.39	(0.49)	0.36
rifthi	0.47	(0.50)	0.43	(0.50)	0.76
riftlo	0.41	(0.49)	0.60	(0.50)	0.10
female_manager	0.65	(0.05)	0.53	(0.05)	0.14
male_manager	0.14	(0.03)	0.24	(0.03)	0.03**
joint_manager	0.22	(0.04)	0.24	(0.04)	0.94
amaranth	0.13	(0.03)	0.19	(0.04)	0.19
nightshade	0.62	(0.05)	0.52	(0.05)	0.31
cowpea	0.10	(0.03)	0.04	(0.03)	1.00
other	0.15	(0.04)	0.25	(0.04)	1.00
age	48.71	(1.10)	48.24	(1.04)	0.53
ampmemb	0.57	(0.05)	0.57	(0.05)	0.88
hhh.sex	0.53	(0.05)	0.59	(0.05)	0.40
primary	0.45	(0.50)	0.47	(0.51)	1.00
secondary	0.47	(0.50)	0.44	(0.50)	0.83
college	0.10	(0.31)	0.07	(0.25)	0.48
Resources Available					
salary	0.05	(0.03)	0.10	(0.03)	0.36
obtained	0.30	(0.44)	0.25	(0.41)	1.00
log(income)	10.93	(0.04)	10.66	(0.04)	0.15
savemoney	0.52	(0.05)	0.54	(0.05)	0.27
mth_food	6.90	(0.34)	7.54	(0.33)	0.36
log(acres)	1.22	(0.06)	1.16	(0.05)	0.57
motorcycle	0.10	(0.03)	0.07	(0.02)	1.00
motorvehicle	0.00	(0.02)	0.04	(0.02)	0.52
log(large.livestock)	1.25	(0.08)	1.03	(0.08)	0.84
seedprc	12.32	(0.42)	10.49	(0.38)	0.01**
Market Access					
sell_alvs	1.00	(0.04)	0.99	(0.04)	0.29
extension	0.65	(0.05)	0.59	(0.05)	0.28
reasongrowprice	0.33	(0.04)	0.34	(0.04)	0.94
reasongroweat	0.35	(0.05)	0.43	(0.05)	0.32
log(timemkt)	3.66	(0.11)	3.52	(0.09)	0.26

Notes: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$, **** $p < 0.001$.

Though some farmer characteristics proved to be important in determining formal seed adoption, others had no significant impact. Contrary to Ghimire et al. (2015), education level did not impact farmer behaviour in formal seed adoption. The mean age of adopters and non-adopters was almost identical (Table 4) and was not significant in any model. It was also surprising that the gender of the ALV farmer was not significant in any of the models either, despite significantly greater proportions of male ALV farmers purchasing seeds (Table 4). Gendered differences in ALV production practices will be important to monitor if demand for ALVs continues to grow and ALVs shift from being a primarily subsistence to a more commercialised crop. Abukutsa-Onyango (2005) documented certain communities where men are taking over ALV production as profitability increases. With growing demand for ALVs in urban centres (Mwangi & Kimathi, 2006), it will be critical to verify that these vegetables are not being used to widen existing gender disparities.

3.2.4. Resources available. When only farmer resources are considered, the model improves slightly in terms of the AIC value (Table 5). Within the category of available resources, seed price was the

Table 5. Parameter estimates for each model of farmer adoption of formal ALV seeds

Model Term	Farmer characteristics	Resources available	Market Access	FC+RA	FC+MA	RA+MA	Full model	Stepwise
Intercept	1.03	1.73	5.37	3.90***	6.26	7.06	9.35	3.88****
Farmer Characteristics								
Western	−0.68**			−0.89**	−0.69**		−0.86**	−0.69**
Rifthi	−0.54*			−0.50	−0.47		−0.33	
Female_manager	−0.40			−0.31	−0.46		−0.20	
Joint_manager	−0.29			−0.16	−0.36		−0.03	
Amaranth	0.06			−0.47	0.11		−0.47	
Nightshade	−0.48			−0.71**	−0.50*		−0.77**	−0.45*
Cowpea	−0.89*			−1.44**	−1.08**		−1.60***	−0.98**
Age	0.00			0.00	0.00		0.00	
Ampmemb	−0.01			0.01	0.13		0.09	
Hhh.sex	0.13			0.25	0.12		0.29	
Primary	0.09			0.02	−0.02		−0.15	
College	0.21			0.45	0.23		0.42	
Resources Available								
Salary		0.58**		0.65		0.56	0.63	0.67
Obtained		−0.22		−0.36		−0.20	−0.37	
Log_income		−0.18		−0.25*		−0.18	−0.24	−0.27**
Savemoney		0.35		0.22		0.38	0.29	
Mth_food		0.04		0.02		0.06	0.03	
Log.acres		−0.08		−0.02		−0.07	−0.02	
Motorcycle		−0.51		−0.81		−0.48	−0.79	
Motorvehicle		6.10		5.90		6.16	6.40	5.77
Log.livestock		−0.13		−0.05		−0.08	0.00	
Seedprc		−0.08***		−0.12****		−0.09***	−0.13****	−0.10****
Market Access								
Sell_alvs			−5.05		−4.89	−4.85	−4.99	
Extension			−0.18		−0.31	−0.08	−0.07	
Reasongrowprice			0.12		0.09	0.17	0.17	
Reasongroweat			0.28		0.41	0.15	0.25	
Log.timemkt			−0.14		−0.12	−0.20	−0.25*	−0.20
AIC Value	208.4	194.1	202.7	203.6	212.7	200.3	209.2	182.7

Notes: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$, **** $p < 0.001$.

Table 6. Marginal effects for each model of farmer adoption of formal ALV seeds

Model Term	Farmer characteristics	Resources available	Market Access	FC+RA	FC+MA	RA+MA	Full model	Stepwise
Farmer Characteristics								
Western	−0.24**			−0.23**	−0.26***		−0.25**	−0.22***
Rifthi	−0.19*			−0.16	−0.15		−0.10	
Female_manager	−0.15			−0.16	−0.10		−0.06	
Joint_manager	−0.10			−0.12	−0.05		−0.01	
Amaranth	0.02			0.04	−0.14		−0.13	
Nightshade	−0.17*			−0.18*	−0.22**		−0.23**	−0.15*
Cowpea	−0.29**			−0.32***	−0.35****		−0.37****	−0.28***
Age	0.00			0.00	0.00		0.00	
Ampmemb	0.00			0.04	0.00		0.03	
Hhh.sex	0.05			0.04	0.08		0.09	
Primary	0.03			−0.01	0.00		−0.04	
College	0.08			0.08	0.14		0.13	
Resources Available								
Salary		0.20			0.20	0.19	0.19	0.22
Obtained		−0.08			−0.11	−0.07	−0.07	
Log_income		−0.06			−0.08*	−0.06	0.09	−0.09***
Savemoney		0.12			0.07	0.13	0.01	
Mth_food		0.02			0.01	0.02	−0.01	
Log.acres		−0.03			−0.01	−0.02	−0.11	
Motorcycle		−0.17			−0.23*	−0.15	−0.22	
Motorvehicle		0.57****			0.57****	0.57****	0.57****	0.56****
Log.livestock		−0.05			−0.02	−0.03	0.00	
Seedprc		−0.03***			−0.04****	−0.03***	0.04****	−0.03****
Market Access								
Sell_alvs			−0.55****	−0.55****		−0.55****	−0.55	
Extension			−0.07	−0.11		−0.03	0.02	
Reasongrowprice			0.05	0.03		0.06	0.05	
Reasongroweat			0.11	0.15		0.05	0.08	
Log.timemkt			−0.05	−0.04		−0.07	−0.08*	−0.07

Notes: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$, **** $p < 0.001$.

most highly significant factor ($p < 0.001$), which was negatively associated with formal seed purchasing. Having a stable wage, as indicated by salary, was also significant and increased the probability of purchasing seeds by 20 per cent (Table 6). Salary was only a significant determinant of formal seed adoption when available resources were considered alone.

These factors suggest that farmers will purchase seeds when their prices are low or when they have a stable and reliable source of income. This supports the economic constraint model (Adesina & Zinnah, 1993; Fernandez-Cornejo et al., 2005; Shiferaw et al., 2015), which suggests that technology adoption will be determined by available resources of each household.

3.2.5. Market access. When only market access factors are considered, no variables are significant at any level (Table 5). The marginal effect for selling ALVs was significant and negatively related to purchasing seed. Distance to the market is negatively associated with purchasing seeds in the full model, as it is in the stepwise forward model.

This does not strongly support the framework proposed by Thiele (1999), suggesting that market access limits formal seed adoption. In some cases, distance from the market was negatively associated with purchasing seeds, but in general this was not a significant effect. This suggests that other factors are more important in determining farmers' behaviour.

3.2.6. Stepwise model. When a stepwise forward regression is used, the lowest AIC value is reached and five of the eight variables included are significant (Table 5). Farmer characteristics of location and ALV species are again significant, but available resource factors such as seed price are highly significant and negatively related to purchasing seeds (Tables 4 and 5). An increase in seed price of 100 Kenyan Shillings (0.99 USD) decreases the probability of purchasing seeds by 3.3 per cent (Table 6). The presence of a salaried family member increases the probability of purchasing seed but not significantly, though household income decreases the probability (Tables 5 and 6). For every 1 per cent increase in income the probability of purchasing seeds decreases by 9 per cent, contrary to our initial hypotheses.

Though this contradicts our hypothesis, this trend has been observed in other seed systems across sub-Saharan Africa (David & Sperling, 1999; McGuire, 2008; Sperling, 1994). In each of these cases, relatively rich farmers have used primarily their own harvest for seed, while poorer farmers rely on the seed available in the markets. As Sperling and McGuire (2010) suggest, this could be because poorer farmers purchase seeds because they lack alternatives while richer farmers purchase seeds when they choose to seek out new varieties. Poorer farmers may be unable to save enough from their harvests to plant again the next season and would then have to rely on purchased seed. On the other hand, households that had at least one member with salaried employment were more likely to purchase seeds, which may suggest that when income is secure and reliable farmers are willing to invest in formal seeds. Without this security, even wealthier households may prefer to save their seed and purchase formal seed only when they have no other options or when they want to add diversity to their ALV varieties.

3.2.7. Implications. Given the significantly lower quality of formal seeds and lack of improved yield, it may be difficult to understand why 47 per cent of surveyed farmers are still willing to purchase formal seeds. Several factors may be contributing to this effect. As mentioned above, formal seed systems may be a last resort for farmers who lack alternative options. As Abukutsa-Onyango (2005) shows, farmers often use both formal and informal systems to meet their ALV seed requirements, but this balance may shift from year to year depending on the relative price of seeds. Finally, farmers consider other qualities besides germination and yield when purchasing inputs. Formal seed systems may offer diversity, pest resistance, or stress tolerance. However, breeding and selection efforts for ALVs have been minimal to non-existent in both formal and informal seed systems in the past (Abukutsa-Onyango, 2005; Okeno et al., 2002).

The role of the formal market could be strengthened through several measures. First, farmers' decisions to save or purchase seeds were impacted by location, species, and income level, but seed price was the most significant determining factor. This suggests that if seed companies were able to reduce their prices, adoption of formal ALV seed would increase. Second, quality in terms of both yield and germination must be improved to at least match currently available informal seed. As shown above, formal seed quality was less than or equal to informal seeds for both species evaluated. Imposing higher quality standards on contracted seed growers could help, and over time, this could build trust between ALV growers and formal seed companies. In addition, men who managed ALV production purchased seeds in greater numbers, which suggests that as more men become involved in ALVs, they may rely more on the formal seed system. Abukutsa-Onyango (2005) noted that men took over ALV production as it became more profitable, suggesting that increasing demand may shift ALVs from a primarily female- to male-dominated crop. This trend should continue to be monitored to assess the implications of changing gender dynamics in ALV markets.

Saving seeds instead of purchasing them takes time and may be impacted by how households value the trade-off between the time to save seeds and the cost of purchasing them. Based on the average vegetable plot size of our sample and broadcast seeding rates recommended by Palada and Chang (2003), this would cost farmers an average of 2937 KSH ($28.72) per season, though this could be dramatically reduced by using transplanted seedlings. With average seed yields (Abukutsa-Onyango, 2005), the same amount of seed would require 9.2 m^2 out of the mean plot size of 1513 m^2. Until seed companies and agricultural input retailers are able to guarantee at least the same quality as farmers are able to collect themselves, it will be difficult to encourage (indeed, would be inappropriate to encourage) farmer loyalty to formal seeds when they do not perform as well. This suggests that policy focusing exclusively on formal seed systems, as has been common in Kenya (Munyi & De Jonge, 2015), may not necessarily help farmers access higher quality seeds.

4. Conclusions

As our data have shown, there is much improvement needed in developing and promoting certified ALV seed varieties. Improving formal seed quality to match that of farmer-saved seeds is a necessity, as is providing a consistently high quality product. Improving access to, and distribution of, formal seeds is still a challenge, but keeping the price low is the most important factor in determining ALV seed purchasing behaviour. Contrary to the model proposed by Thiele (1999), there is little support for the hypothesis that market access positively impacts formal seed adoption, but farmer resources are critical to consider. We propose a modified version of this framework based on our results; that adoption of formal seed is based on 1) seed germinability, 2) relative yield, 3) available resources, and 4) farmer characteristics. Based on this framework, farmers are better able to access high-quality ALV germplasm through the informal seed market in Kenya.

Currently, there is very little incentive for households to adopt formal seed, despite the high percentage (47%) of the sampled households that did. With few available varieties and low quality, farmers may be better off saving their own seeds or purchasing seed from their neighbours rather than participating in formal seed systems. Though we found that quality in informal ALV seeds was high, technical support could raise this even higher. Promoting breeding efforts in both sectors could also improve access to diverse germplasm and strengthen resilience to future stresses. Higher quality in the formal seed sector could also be encouraged by more companies entering the market, which would create competition and raise quality standards in this sector.

This research evaluated the relative quality of formal and informal ALV seed and the findings show that informal seed systems have greater potential to address the need for high-quality germplasm. In the context of western Kenya, we recommend strengthening informal markets rather than supporting formal market development, contrary to current policy. The QDS system may be appropriate in this context, as a bridge between the gaps in formal and informal systems. ISSD may be an effective approach as well, which could strengthen both formal and informal systems and scale up their benefits. Our proposed framework can help guide policy-makers in choosing between different approaches by helping to evaluate the relative strengths of formal and informal seed systems. This can provide species- and location-specific recommendations on whether programmes like QDS or ISSD would be appropriate. However, if resource-limited conditions make focusing on one seed system a priority, in this context, our data suggest that supporting informal seed systems would better connect farmers to quality seeds.

These findings can only be applied to ALVs, which were the subject of this study, but this framework could be used to assess the relative qualities of formal and informal seed markets in other crops. It would not be appropriate to apply these context-specific recommendations to other crops, nor would it be appropriate to assume that other seed systems accurately represent ALVs. Policy-makers should use context-specific data and research to guide their decisions on seed policy, and based on this study we would recommend including seed quality assessments, farmer-specific characteristics, and available resources in any model to evaluate formal seed adoption.

Guaranteeing the high quality of seeds can help farmers budget resources accordingly as well as improve yields and generate income. Local governments should focus on strengthening informal seed systems to provide high quality ALV seeds to their farmers, as this system has the greatest potential to help farmers in this context.

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