The role of varietal traits in the adoption of improved dryland crop varieties: The case of pigeon pea in Kenya

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This study uses a multivariate probit model and the Poisson regression to examine the role of varietal attributes in farmers' adoption of improved pigeon pea *(Cajanus cajan)* varieties in Taita District, Kenya. It is based on data collected from 200 households stratified by adoption of improved pigeon pea varieties between April and May 2009. The study finds correlation in the decisions made by farmers to adopt different varieties, implying that using simple probit analysis could yield biased and inefficient results. The results further indicate that the major pigeon pea varietal traits driving rapid adoption are drought tolerance, pest tolerance, yield, ease of cooking, taste and price. Early maturity, a major focus of recent research, has no effect on farmers' adoption decisions. These findings imply that developers of improved crop varieties should pay attention to consumption and market characteristics in addition to production traits to increase technology uptake and satisfy farmers' multiple needs.

Keywords: pigeon pea; varietal traits; adoption; multivariate probit; Poisson regression; Kenya

Cette étude utilise un modèle probit multivarié et la régression de Poisson pour examiner le rôle des attributs variétaux dans l'adoption des fermiers de variétés améliorées du pois pigeon (Cajanus cajan) dans le district de Taita au Kenya. Celle-ci se base sur les données concernant 200 ménages stratifiés par adoption de variétés améliorées du pois pigeon, entre avril et mai 2009. L'étude révèle une corrélation entre les décisions prises par les fermiers

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d'adopter différentes variétés, insinuant que l'utilisation d'une analyse basée sur un modèle probit simple pourrait entraîner des résultats biaisés et inefficaces. De surcroît, les résultats indiquent que les traits variétaux du pois pigeon qui sont les plus importants et qui influencent une adoption rapide sont la résistance à la sécheresse et aux insectes, la production, la facilité de cuisson, le goût et le prix. La maturité précoce, un élément très important sur lequel se sont penchées les recherches récentes, n'influe aucunement sur les décisions des fermiers en matière d'adoption. Ces résultats impliquent que les concepteurs de variétés améliorées devraient porter leur attention sur la consommation et les caractéristiques du marché, en plus des traits de la production, pour accroître l'intérêt porté à la technologie et répondre de manière positive aux nombreuses nécessités des fermiers.

Mots-clés : *pois pigeon ; traits variétaux ; adoption ; modèle probit multivarié ; régression de Poisson ; Kenya*

1. Introduction

Pigeon pea (*Cajanus cajan)* is a dryland crop that is well adapted to low rainfall patterns and thrives in low fertility soils. Its production is not labor intensive, which is a major advantage in conditions of declining labor availability caused by rural-urban migration and HIV/AIDS, among other factors. Other benefits of pigeon pea include its good nutritional properties and ability to withstand abiotic stress and declining soil fertility. It is therefore a crop that can reduce the hunger gap in many sub-Saharan countries.

In spite of the numerous benefits of growing pigeon pea, its production in Kenya has remained heavily constrained, especially over the last decade, by pests and lack of good planting material. In response to these constraints, national and international research organizations (the latter spearheaded by the International Crops Research Institute for Semi Arid Tropics – ICRISAT) embarked on a targeted breeding program in the early 1990s to address these challenges and promote the crop in Africa. These efforts yielded at least five improved pigeon pea varieties with production and consumption traits that were superior to those of the local varieties. These varieties have been released since the end of 2003 for use by farmers. They include Katumani 60/8, ICPL 89091, ICEAP 00068, NPP 670 and ICP 6927. The release of these varieties was followed by an intensive promotion program funded by ICRISAT and other funded projects such as Africa's Innovation in Dryland Areas (AIDA) project in Kenya. A survey conducted by ICRISAT in 2007 in Kenya found widespread adoption of some of these varieties even in areas where pigeon pea was little known (ICRISAT, 2007).

While numerous studies have been done on pigeon pea production (Jones et al., 2000; Jones et al*.,* 2002; Muricho, 2002; Rusike & Dimes, 2004; Obare et al., 2006; Odeny, 2007; Audi et al., 2008), the role that varietal traits play in the adoption of recently released varieties remains unknown. Moreover, economists investigating varietal adoption have focused on the role of farm, farmer, household, physical environment and economic factors in explaining adoption behavior (Nkonya et al., 1997; Doss et al., 2003; Muyanga, 2009; Finger et al., 2009). Other studies have examined the factors that affect the diffusion of improved varieties (Gellaz et al., 2004; Diagne, 2006; Fok et al., 2007). However, they too do not focus on the role of varietal attributes per se in technology adoption and diffusion, with the exception of Gellaz et al. (2004), who assess the impact of general superiority of variety on diffusion without specifying what 'superiority' entails. Similarly, several studies that have examined

the role of risk in the adoption of improved varieties and agricultural technologies (Sakurai, 2002; Doss et al., 2003; Bennett et al., 2004; Cavatassi et al., 2011) have generally failed to access control for the effect of the other varietal attributes. Unlike these studies, our study focuses on the effect of a vector of varietal traits on farmers' decision to adopt improved pigeon pea varieties and their effect on the intensity of adoption.

The second motivation of this study is methodological. Most previous studies on the adoption of improved crop varieties have used the conventional logit and probit regression approach which implicitly assumes that the decision to use one variety is uncorrelated with the decision to adopt the others. Generally when more than one improved variety exists, as is the case in the present study, each with varying production, consumption and marketability traits, farmers will simultaneously adopt several varieties in order to satisfy their many needs. Consequently, the decision to adopt one variety is likely to be correlated with the decision to adopt another (Marenya & Barrett, 2007; Velandia et al., 2009). Hence, previous studies that have estimated independent probit equations, assuming the independence of adoption decisions and ignoring joint adoption decisions, are likely to suffer inefficient estimates (Greene, 2008). This paper uses multivariate probit regression analysis, which explicitly allows for correlation in the error terms of the adoption equations to analyze the effect of varietal attributes on the adoption of pigeon pea varieties. It then uses Poisson regression to assess the effect of varietal attributes on the number of pigeon pea varieties adopted by farmers.

The paper focuses on pigeon pea farmers in Taita District. This has become one of the major pigeon pea growing areas of Kenya, having witnessed very rapid diffusion of the crop following its introduction by the University of Nairobi in the 1980s. Kenya is the world's second largest producer of pigeon pea (the leader is India), which makes it an interesting case to study. The rest of the paper is organized as follows. Section 2 presents the methods and the variables used in the empirical analysis, Section 3 reports and discusses the results, and Section 4 concludes with policy recommendations.

2. Methodology

2.1 Study area

Taita District lies in agro-ecological zone IV of Coast Province, Kenya. This is a transition zone between semi-arid and semi-humid areas. It has between 115 and 145 growing days per year (medium to medium/short growing season) and a mean annual temperature of between 15 and 180°C in the Lower Highland zone. The Upper Midland zone has 75 to 104 growing days (i.e. short to very short growing season) and a mean annual temperature of 210 to 240°C. The district comprises six administrative divisions: Wundanyi, Mwatate, Tausa, Mwambirwa, Tsavo West National Park and Voi. The main crops grown here are maize, beans and pigeon pea, in rank order of profitability. Pigeon pea production is mainly concentrated in the lowland areas, Mwatate and Voi, whereas in the highland areas such as Wundanyi, dairy farming and leafy vegetable production predominate. Mwatate and Voi are predominantly high adoption areas for improved pigeon pea varieties; Wundanyi on the other hand is predominantly a non-adoption region.

With regard to land use, wildlife conservation covers 62% of the total district. Of the remaining 38%, 28% is under sisal production, implying that the total population is

concentrated in only 18% of the total district area. The average land size is 5.4 acres. This clearly points to the fact that cultivable land for food production is scarce and hence household food insecurity is common in the area.

2.2 Data and sampling

Primary data collected at household level in 2009 are used in this study. A stratified multi-stage random sampling technique was used to arrive at the units analyzed. The selection of the study sites was guided by the level of adoption of improved pigeon pea varieties in the district. Using this criteria, three adoption regions were identified: high, medium and low. The regions were demarcated to coincide with administrative units (divisions). One division was randomly selected from each category to give a total of three regions: Mwatate division (high adoption), Voi division (medium adoption) and Wundanyi division (low adoption). Next, two locations were randomly selected from each division. Lists were made of all sub-locations and two were randomly selected from each location to obtain 12 sub-locations.

For each of the sub-locations, a list was made of all the villages and two were randomly selected. Finally, all the farmers in the villages were identified and two lists were made: 306 adopters and 144 non-adopters of improved pigeon pea varieties. These formed the strata. The purpose of stratification was to ensure that a statistically representative sample of farmers was obtained. Adopters were remarkably high (68%) compared with non-adopters (32%). Probability proportionate to size sampling technique was used to obtain a sample size of 200 households. Out of these, 137 were adopters and 63 non-adopters. Data on farmer characteristics, farm characteristics, capital endowments, varietal attributes and geographical characteristics were then collected from the sampled farmers, through personal interviews using a pre-tested questionnaire. The data were analyzed using SPSS and Stata.

2.3 Theoretical framework

Pigeon pea production and commercialization is mainly inhibited by its susceptibility to a wide range of pests and diseases. Insect pests feeding on flowers, pods and seeds are the plant's single most important biotic constraint, resulting in field losses of over 50% (Minja et al., 1999; Odeny, 2007). To control these pests and diseases farmers must invest in chemical treatment, an option which remains costly and largely unaffordable to smallholders. Labor is another cost. The length of time to maturity and yield determines the amount of labor needed for pigeon pea production and directly influences the opportunity cost of using land to grow this crop. We therefore assume that a farmer chooses a pigeon pea variety that embodies the most desired attributes in order to minimize the cost of production. Thus, consider a farmer who aims to minimize the cost of producing pigeon pea given by:

$$C(\mathbf{WX}) \tag{1}$$

Subject to a production function specified as:

$$q(\mathbf{X}, \mathbf{V}, \mathbf{T}, \mathbf{K}, \mathbf{z}); \tag{2}$$

where C is the total factor cost; $\mathbf{W}$ is a vector of input prices; $\mathbf{q}$ is the output of pigeon pea; $\mathbf{X}$ is a vector of conventional inputs such as fertilizer, pesticides and other chemicals used by the farmer; $\mathbf{V}$ is a vector of seed varieties embodying a vector of varietal traits including

drought tolerance, early maturity, pest resistance and yield; and **T** is the total labor requirement comprising family labor (**l**) and hired labor (**h**). Lastly, **K** and **z** are fixed capital inputs and institutional factors respectively.

The farmer's optimization problem therefore is to choose **V** to minimize the cost of production subject to labor availability and a specified quantity of output **q^o**. That is:

$$\underset{V}{Minimize}\ C(WV) = \sum W_v V \tag{3}$$

Subject to:

$$q \geq q^0 \tag{4}$$

$$T \geq l + h \tag{5}$$

Equation (4) shows that the pigeon pea output constraint need not hold exactly, whereas equation (5) shows that the family labor and the hired labor together should at least equal the total effective labor requirement.

The Lagrangian expression associated with the cost minimization problem is:

$$L = W_v V + \lambda_1 \left[q^0 - q(x,v,T,k,z) \right] + \lambda_2 \left[T - l - h \right] \tag{6}$$

The first order conditions are:

$$V : W_v - \lambda_1 \left(\frac{\partial q}{\partial v} \right) - \lambda_2 \left(\frac{\partial l}{\partial v} - \frac{\partial h}{\partial v} \right) = 0 \tag{7}$$

$$\lambda_1 : q^0 - q(x,v,T,k,z) = 0 \tag{8}$$

$$\lambda_2 : T - l - h = 0 \tag{9}$$

The Lagrange multiplier λ_1 represents the marginal value of output, whereas λ_2 is the marginal cost of labor or the additional cost associated with an additional unit increase in labor. The second order sufficient condition for cost minimization requires that the determinant of the Bordered Hessian be negative. The Bordered Hessian comprises second partial derivatives of the Lagrangian expression with respect to V, λ_1 and λ_2.

Assuming that the second order sufficient condition is satisfied, the first order condition equations can be solved for $V_p{}^*$ yielding the conditional factor demand equations as functions of output **q**, input prices **W**, convectional inputs **X,** fixed factors **K** and institutional factors **z**. That is:

$$v_p^* = v_p^* (w,q,x,k,z) \tag{10}$$

Equation (10) above also gives the input adoption function. Our interest in this case is the adoption function for improved pigeon pea seed, which is postulated to be a function of varietal traits such as yield, pest tolerance, drought tolerance and taste.

2.4 Empirical model and description of variables

We use a multivariate probit model to analyze the effect of varietal traits on the probability of adopting improved pigeon pea varieties. This model accounts for joint decision making by farmers and the potential correlation in the adoption decisions (Marenya & Barrett, 2007; Velander, 2009). The multivariate probit is an extension of the bivariate probit. It uses Monte Carlo simulation techniques to jointly estimate the multiple probit equation system (Geweke, 1989).

The general multivariate probit model is specified as follows:

$$Y_{ij}^* = X_{ij}\beta_j + \varepsilon_{ij} \tag{11}$$

where Y_{ij} for $j = 1, 2,\ldots,m$ represents an unobserved latent variable of the improved varieties j adopted by farmer i ; X is a $1 \times k$ vector of observed variables that affect the variety adoption decision; β is a $k \times 1$ vector of unknown parameters to be estimated; and ε is a vector of stochastic (error) terms. Each Y_{ij} is a binary variable representing the adoption decision by farmers. The varietal adoption functions in equation (10) above, which are derived from the first order conditions of cost minimization, enter into equation (11) as a composite system of **m** equations representing the number of varieties available to farmers, as shown in (12) below.

$$\begin{cases} Y_1^* = \beta_1 X_1^{'} + \varepsilon_1, \ \ Y_1 = 1 \ \ if \ \ Y_1^* > 0, \ Y_1 = 0 \ otherwise \\ Y_2^* = \beta_2 X_2^{'} + \varepsilon_2, \ \ Y_2 = 1 \ if \ \ Y_2^* > 0, \ Y_2 = 0 \ otherwise \\ Y_3^* = \beta_3 X_3^{'} + \varepsilon_3, \ \ Y_3 = 1 \ if \ \ Y_3^* > 0, \ Y_3 = 0 \ otherwise \\ Y_4^* = \beta_4 X_4^{'} + \varepsilon_4, \ \ Y_4 = 1 \ if \ \ Y_4^* > 0, \ Y_4 = 0 \ otherwise \end{cases} \tag{12}$$

The varieties encountered in the study area included one local variety and three improved varieties. The error terms (across $j = 1,\ldots,m$ alternatives) are assumed to have multivariate normal distributions with mean vector equal to zero and a covariance matrix **R** with diagonal elements equal to one. The system of equations obtained was jointly estimated using a simulated maximum likelihood method which yields consistent estimates and is asymptotically equivalent to the true maximum likelihood estimators for large samples. The implicit functional form of the estimated empirical model is specified as:

Adopt = f(socio-economic factors, institutional factors, varietal attributes, agro-ecological factors) + ε (13)

where *Adopt*, a dichotomous dependent variable in each of the **m** equations, is the decision by farmer *i* to adopt pigeon pea variety *j*. It takes the value of 1 if farmer *i* adopts variety *j* and 0 otherwise. The empirical model contained the following explanatory variables:

  i)   *Socio-economic variables*: age, gender, education, years of farming experience, off-farm income, land size, value of non-land assets and distance to market.

ii) *Institutional variables*: extension contact, membership in farmer organizations.

iii) *Varietal attributes*: high yield, drought tolerance, pest tolerance, early maturity, good taste, good price, ease of cooking.

iv) *Agro-ecological factors*: dummy for agro-climate given by Wundanyi = highland and Voi = lowland.

Joint decision making by farmers was tested using the standard likelihood ratio (Wald) test. Specifically, we tested the null hypothesis that the correlation in decision making in adopting one variety against the others is zero (i.e. rho21 = rho31 = rho41 = rho32= rho42= rho43= 0)[1] against the null hypothesis that there is correlation in the decision to adopt at least one pair of the varieties.

Economists analyzing varietal adoption have historically defined intensity of adoption as the amount of land allocated to improved crop varieties. Such a definition translates into the use of conventional methodological approaches such as the Tobit and the two-stage Heckman models. However, where farmers face multiple options, as is the case in the present study, intensity of adoption can be measured by the number of improved pigeon pea varieties adopted by a farmer, which is a count variable. One of the most commonly used methods of estimating count variable regression models is the Poisson model (Okello & Swinton, 2010). This study therefore used this model to analyze the effect of variety attributes on the intensity of varietal adoption of IPVs (improved pigeon pea varieties). Greene (2008) shows that the expected number of events, Y_i , in this case the number of pigeon pea varieties adopted per period, is given by:

$$E(Y_i | X_i) = \exp(\alpha + X'\beta) \text{ for } i = 1, 2, ..., n \tag{14}$$

The model is estimated using the same set of explanatory variables included in the multivariate probit above. However, only farmers growing at least one of the improved pigeon pea varieties are included in this analysis. The variables, their definitions and hypothesized signs are presented in Table 1.

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Table 1: Description of variables used in the multivariate probit and Poisson regressions

Variable	Description of variable	Hypothesized sign
Katumani 60/8	Grew Katumani 60/8 pigeon pea variety during 2008 long rainy season (1=yes; 0=otherwise)	Dependent variable
ICPL 89091	Grew ICPL 89091 pigeon pea variety during 2008 long rainy season (1=yes; 0=otherwise)	Dependent variable
ICEAP 00068	Grew ICEAP 00068 pigeon pea variety during 2008 long rainy season (1=yes; 0=otherwise)	Dependent variable

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[1] Rho refers to the correlation coefficient among the error terms of the adoption equations. Rho21, for instance, is the correlation coefficient among the error terms of equations (1) and (2). Only four varieties were analyzed.

Kitaita	Grew Kitaita pigeon pea variety during 2008 long rainy season (1=yes; 0=otherwise)	Dependent variable
Socio-economic variables		
Gender	Gender of the farmer (1=male; 0=otherwise)	+/-
Age of farmer (years)	Natural log of age of the farmer (years)	+/-
Education of farmer (years)	Education level of the farmer (1=primary; 2=secondary; 3=tertiary)	+
Off-farm INC (1000 Kshs)	Natural log of off-farm income earned in 2008 (Kshs)	+
Farming experience (years)	Natural log of years of experience in growing pigeon pea	+
Land SZ (acres)	Natural log of farm size	+
Non-land assets (1000 Kshs)	Natural log value of non-land assets (Kshs)	+
Distance to the market (km)	Natural log of distance to the nearest market (km)	-
Institutional and policy variables		
Extension contact	Natural log of number of farm visits by extension personnel in a year.	+
Group membership	Farmer belongs to a group/association (1=yes; 0=no)	+
Variety trait variables		
Drought tolerance	Variety drought tolerant (1=yes; 0=otherwise)	+
High yield	Variety high yielding (1=yes; 0=otherwise)	+
Pest tolerance	Variety pest tolerant (1=yes; 0=otherwise)	+
Early maturity	Variety early maturing (1=yes; 0=otherwise)	+
Taste	Variety has desirable taste (1=yes; 0=otherwise)	+
Price	Variety fetches a price premium (1=yes; 0=otherwise)	+
Ease of cooking	Variety cooks faster (1=yes; 0=otherwise)	+
Agro-ecological variables		
Voi location (% households)	Voi location dummy with Mwatate location as benchmark. (1=Voi; 0=otherwise)	+/-
Wundanyi location (% households)	Wundanyi location dummy with Mwatate location as benchmark. (1=Wundanyi; 0=otherwise)	+/-

Focusing on varietal traits, pest tolerance is important because pigeon pea is highly susceptible to pest attack. Chemical treatment of these pests remains unaffordable to the smallholder farmers. The pest tolerance trait is therefore hypothesized to positively influence adoption. On the other hand, the yield superiority trait is important as far as marketed surplus is concerned. It is therefore hypothesized that yield superiority positively influences the adoption of varieties that embody it.

Taste is an important attribute since most farmers grow pigeon pea for both home consumption and sale in the study area. A recent study found that taste is an important attribute for most farmer-consumers (Mishili et al., 2009). It is therefore hypothesized that taste positively influences the likelihood of adopting varieties that embody this trait. The selling price of the dry grain pigeon pea is also hypothesized to be positively related to adoption, as an economic incentive to cultivate a crop and hence a motivation to adopt a technology that is economically advantageous. Lastly, we hypothesize that the ease of cooking positively affects the likelihood of adoption because it eases the problem of scarcity of firewood.

3. Results and discussion

Table 2 presents summary statistics of the variables used in this paper by category. It shows that the mean age of non-adopters is higher than that of adopters. The mean age of adopters was 36 years, as compared to 45 years for non-adopters. Table 2 further indicates that most of the adopters were female, had approximately 12 years of pigeon pea farming experience and had at least secondary school education. The average farm size was 6.2 acres for adopters, as compared to 4.8 acres for non-adopters. We also find that the value of non-land assets was higher for adopters than for non-adopters. The valuation of non-land assets was Kshs 107,000 and Kshs 53,000 for adopters and non-adopters respectively. These results reaffirm the important role that socio-economic characteristics play in variety adoption.

Table 2: Summary statistics for adopters and non-adopters of improved pigeon pea varieties, Taita district, 2009

	Adopters (N=134)		Non-adopters (N=61)	
	Mean	Std deviation	Mean	Std deviation
Socio-economic factors				
Gender	0.34	0.12	0.87	0.13
Age of farmer (years)	36	3.45	45	4.67
Education of farmer (years)	2.11	0.33	1.09	0.24
Off-farm income (1000 Kshs)	46.55	4.11	23.46	3.97
Farming experience (years)	12.50	3.97	6.75	1.86
Land SZ (acres)	6.20	2.45	4.80	0.35
Non-land assets (1000 Kshs)	107.2	6.52	53.4	4.78
Distance to the market (km)	8.14	1.21	75.02	0.26
Institutional and policy factors				
Extension contact (farm visits by officers)	10	1.40	4	0.13
Group membership (% households)	77	18	58	24

Distance to the nearest main market is used in this study as a proxy for market access. Table 2 shows that adopters were located approximately 8 km from the main market and had received at least 10 farm visits by extension officers during the year prior to the survey. On average, 77% of adopters were members of farmer groups and associations, hence the high rate of adoption. Only 55% of non-adopters belonged to farmer groups.

Table 2 further shows that Wundanyi is predominantly a non-adoption region, as compared to Mwatate and Voi which are high adoption areas.

3.1 Pigeon pea variety attributes and farmers' perceptions of each variety

The results presented in Table 3 show farmers' perceptions of IPVs on a case by case basis. The results show that, of the three IPVs considered, ICPL 89091 variety has the best ability to withstand abiotic stress. Ninety percent of the farmers interviewed reported that ICPL 89091 was drought tolerant and could better withstand harsh environmental conditions.

Table 3: Pigeon pea variety attributes and farmers' perceptions of each variety

Trait question	Katumani 60/8 (N=134) % of farmers reporting		ICPL 89091 (N=134) % of farmers reporting		ICEAP 00068 (N=134) % of farmers reporting	
	YES	NO	YES	NO	YES	NO
Drought tolerance	79	21	90	10	71	29
High yielding	81	19	88	12	84	16
Pest resistance	69	31	63	37	75	25
Early maturity	65	35	61	39	59	41
Good taste	33	67	86	14	53	47
Ability to earn price premium	81	19	87	13	41	59
Ease of cooking	34	66	22	78	75	25

Farmers' response with regard to drought tolerance was 79% for Katumani 60/8 and 71% for ICEAP 00068. Table 3 further shows that ICPL 89091 gave the best yield in terms of kilogram per acre of land planted, had the taste the farming households (consumers) liked best, and fetched the best price in the market. In spite of its popularity, however, ICPL 89091 required the longest cooking time in terms of wood energy consumption. Only 34% of adopters interviewed said that this variety cooked faster. On the other hand, adopters said that ICEAP 00068 was the easiest to cook of the three IPVs. Seventy-five percent of farmers interviewed said that ICEAP 00068 required less firewood to cook and was thus preferred for home consumption.

3.2 Joint decision making on adoption of pigeon pea varieties and test of significance of varietal attributes

The empirical results of the multivariate probit model are presented in Tables 4 and 5. Of the five improved pigeon pea varieties released to the farmers, only three (ICPL 89091, ICEAP 00068 and Katumani 60/8) were adopted in significant quantities by farmers in the district (Otieno, 2010). The other varieties are grown by only a handful of farmers and were dropped from further analysis. Hence only three varieties were included in the estimation of the multivariate probit model. Kitaita, which is a local variety, was included in the analysis for purposes of comparison. Diagnostic statistics appear at the bottom of the two tables. Specifically, Table 4 presents the Wald test that farmers' decision to adopt one variety is correlated with the decision to adopt another (or other) varieties.

Table 4: Results of the Wald test of joint decision to adopt different pigeon pea varieties
Table of p-values of test of simultaneous decision making by farmers to adopt different pigeon pea varieties, where 1=Katumani 60/8, 2=ICPL 89091 3=ICEAP 00068; 4=Kitaita (local variety)

	coeff	p-value		coeff	p-value
/atrho21	1.015	0.000	rho21	0.804	0.000
/atrho31	0.756	0.000	rho31	0.654	0.000
/atrho41	-0.639	0.000	rho41	-0.564	0.000
/atrho32	0.756	0.000	rho32	0.638	0.000
/atrho42	-0.621	0.000	rho42	-0.552	0.000
/atrho43	-0.583	0.000	rho43	-0.525	0.000

Notes: N=195: Likelihood ratio test of rho21 = rho31 = rho41 = rho32= rho42= rho43= 0: chi^2 (6) = 46.1771; P-value=0.000

The p-value of the Wald test statistic for the overall significance of the model is 0.000, indicating that the multivariate probit regression is highly significant overall. The likelihood ratio test of rho (ρ) is highly significant (p-value=0.000), further indicating that a multivariate probit specification fits the data well. The correlation coefficients between the error terms of the adoption equations are all significant, implying that the decision to adopt one variety affects the decision to adopt other varieties. The correlation coefficients between the four varieties are all positive and significant at the 1% level. These findings suggest that using ordinary probit or logit regression to assess the role of varietal attributes in the adoption of improved pigeon pea varieties yields inefficient estimates. Given these findings, we used multivariate probit regression, which explicitly takes into account joint adoption decisions made by farmers. The results of the estimated multivariate probit regression model are presented in Table 5.

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Table 5: Factors affecting adoption of improved pigeon pea varieties in Taita district: Results of multivariate probit regression

Variable name	Katumani 60/8		ICPL 89091		ICEAP 00068		Kitaita (local variety)	
	coeff	p-value	coeff	p-value	coeff	p-value	coeff	p-value
Socio-economic variables								
Gender	-0.743	0.021**	-0.142	0.632	0.343	0.136	0.496	0.043**
Inage	-0.753	0.520	-1.146	0.337	-0.786	0.512	0.495	0.622
Education	0.496	0.001***	-0.001	0.994	0.347	0.010***	-0.404	0.001***
Inoff -farm INC	-0.198	0.047**	-0.026	0.742	-0.167	0.080*	0.064	0.374
Inland SZ	1.366	0.036**	0.668	0.168	0.104	0.849	-0.983	0.024**
Inexperience	0.901	0.016**	0.511	0.156	0.748	0.057*	-0.018	0.954
InnonlandAssets	0.584	0.063*	0.884	0.005***	0.569	0.029**	-0.202	0.377
Indistance market	0.243	0.768	-0.192	0.845	0.361	0.592	-0.641	0.375
Institutional and policy variables								
Inextension contact	0.281	0.523	0.364	0.374	-0.115	0.754	-0.293	0.366
Group membership	1.774	0.000***	1.173	0.000***	1.130	0.000***	-0.943	0.001***
Variety trait variables								
Drought tolerance	0.496	0.073*	1.167	0.001***	0.632	0.046**	0.138	0.642
High yield	0.714	0.042**	0.817	0.004***	0.573	0.017**	0.608	0.017**
Pest tolerance	1.568	0.000***	0.926	0.001***	0.363	0.240	-0.271	0.249
Early maturity	0.315	0.320	0.003	0.991	0.187	0.532	0.095	0.711
Taste	0.254	0.423	0.510	0.087*	0.460	0.105	0.200	0.393
Price	1.013	0.002***	0.918	0.010***	0.477	0.127	0.176	0.527
Ease of cooking	-0.221	0.495	-0.055	0.843	0.521	0.079*	-1.188	0.453
Agro-ecological factors								
Voi dummy	-0.893	0.055*	-1.571	0.000***	-1.173	0.001***	0.051	0.856
Wundanyi dummy	-0.877	0.074*	-0.787	0.049**	-1.151	0.000***	0.021	0.955
_cons	-1.843	0.301	-2.359	0.019**	-5.513	0.041**	3.136	0.141

Notes:: N= 195; Log pseudo likelihood= -213.91228; Wald chi^2 (80) = 630.00; p-value = 0.0000

Joint hypothesis test for variety trait variables: chi^2(28) = 89.43; Prob > chi^2 = 0.0000

***, ** and * indicate significance at 1%, 5% and 10% levels respectively.

3.3 Role of varietal attributes in the adoption of improved pigeon pea varieties

As hypothesized, the results in Table 5 indicate that farmers in Taita District adopted Katumani 60/8 partly because of its desirable attributes of drought tolerance, pest tolerance, yield potential and ability to earn a price premium. Drought tolerance, yield potential, pest tolerance and price had positive and statistically significant coefficients. Pest tolerance and price were statistically significant at the 1% level, whereas drought tolerance and yield were statistically significant at the 5% level. The early maturity trait did not appear to affect farmers' decision to adopt Katumani 60/8. The finding on the early maturity trait is consistent across all the improved pigeon pea varieties (IPVs) considered in the analysis. The result is, however, contrary to our expectations. The insignificance of this variable may be because farmers are more concerned with pigeon pea attributes of yield stability, market incentives, and pest and drought tolerance than the early maturity trait which is often assumed to be of importance to them. This result indicates that early maturity is not the main or only criterion for farmers.

Table 5 shows very peculiar findings as far as the adoption of ICPL 89091 is concerned. Unlike the case of Katumani 60/8, farmer-specific factors had no effect on the likelihood of adoption of ICPL 89091 (the most popular variety). Rather, it was variety attributes such as drought tolerance, yield potential, pest resistance, taste and the variety's ability to earn a price premium that affected their decision. All the variety attributes had positive coefficients. Drought tolerance, yield and pest resistance were all statistically significant at the 1% level whereas taste and price were significant at the 10% and 5% levels respectively. Notably, ICPL 89091 is the only IPV whose adoption was significantly affected by taste.

The results presented in Table 5 also show that drought tolerance, yield potential and ease of cooking affected the likelihood of adoption of ICEAP 00068. Drought tolerance and yield potential are statistically significant at the 5% level whereas ease of cooking is significant at the 10% level. On the basis of these results, we can conclude that ICEAP 00068 has the best cooking time. It is therefore highly likely that this variety was popular in those areas where firewood is scarce.

The last two columns of Table 5 present the results of Kitaita (local) variety. We note that all the trait variables included in the multivariate probit model are not significant for this variety, except yield potential, which further corroborates the trait superiority of the improved pigeon pea varieties.

Other variables that affected the adoption of ICEAP 00068 are off-farm income, gender, group membership, education, pigeon pea farming experience, asset endowment and regional disparities. The signs of the coefficients of these variables are congruent with the hypothesized signs in Table 1. The joint hypothesis test for the effect of agro-ecological differences on adoption of IPVs was highly significant at 0.000. The null hypothesis that agro-ecological differences do not affect varietal adoption is therefore rejected in favor of the alternative hypothesis that agro-ecological differences affect the decision to adopt the Katumani 60/8 variety. Overall, these results reaffirm the role of socio-economic, agro-ecological, institutional and policy factors in the adoption of new technologies.

3.4 Factors affecting the intensity of varietal adoption

Table 6 presents the results of the Poisson regression model fitted to examine the intensity of varietal adoption. The standard errors are robust for heteroskedasticity. The diagnostic statistics appear at the bottom of the table and generally show that the model fits the data well.

An important finding is that high yield and early maturity traits did not affect the intensity of varietal adoption. Among the factors that did affect adoption of the three IPVs are variety traits and socio-economic and institutional variables. The results specifically indicate that drought tolerance, pest resistance, ease of cooking and the ability of the variety to fetch a price premium increased the number of IPVs adopted. Drought tolerance is probably important because there are frequent droughts in the study region. The importance of insect pest resistance may in turn be due to the serious economic damage pests can cause to some varieties of pigeon pea (Shanower et al., 1999; Minja et al., 1999). Taste is statistically significant at the 5% level, which shows how important a role consumption attributes play in increasing the intensity of adoption of IPVs. The varieties' ability to fetch a price premium in the market is positively and significantly associated with the intensity of their adoption. This finding is congruent with the hypothesis that market incentives affect farmers' decisions. As expected, a price premium is an incentive for farmers to supply more for the market. This variable is closely linked to the taste attribute, since varieties that taste better are likely to be higher priced than those that lack this attribute. The statistical significance of ease of cooking could be attributed to the scarcity of firewood in some areas of the region and the high incidence of poverty in the district. (Firewood is scarce because of attacks by wild animals on those who venture into the forests to collect it.)

Table 6: Poisson regression results of factors affecting the intensity of adoption of improved pigeon pea varieties in Taita district

	coeff	p-value
Socio-economic variables		
Gender	-0.021	0.740
lnage	-0.251	0.497
lneduc	0.194	0.000***
lnexperience	0.055	0.636
lnoff-farm income	-0.023	0.295
lnland size	0.176	0.337
lnnon-land assets	0.057	0.490
lndistance market	-0.362	0.536
Institutional and policy variables		
lnextension contact	0.114	0.409
Group membership	1.582	0.001***
Variety trait variables		
Drought tolerance	0.172	0.051**
High yield	0.074	0.322
Pest tolerance	0.196	0.005***
Early maturity	0.076	0.485
Taste	0.171	0.042**
Price	0.374	0.016***
Ease of cooking	0.162	0.050**
Agro-ecological variables		
Voi dummy	-0.217	0.039**
Wundanyi dummy	-0.423	0.068*

*Notes:*N=134, Goodness-of-fit chi^2 = 182.61 (Deviance statistic)
Prob > chi^2(174) = 0.312
Dispersion ratio: 182.61/174=1.04
***, ** and * indicate significance at 1%, 5% and 10% levels respectively.

Among the socio-economic factors, education affected the intensity of adoption of IPVs. The high level of statistical significance (1%) shows that formal schooling means managerial ability and greater cognitive capacity, hence the likelihood of adopting improved varieties. The results show that one more year of schooling increases the expected value of the number of IPVs adopted by 19%. The finding that education enhances adoption of the improved agricultural technologies in our study corroborates the findings of Marenya and Barrett (2007) and Shiferaw et al. (2009).

Among the institutional factors, group membership is statistically significant and positively related to the intensity of adoption of IPVs. The result shows that being a member of a farmer group increased the expected value of the number of IPVs adopted by 58%. This finding is probably due to the numerous benefits that groups confer on their members (Wambugu et al., 2009). For instance, members have easy access to training and information and can also benefit from the collective investments that can be made by such a group. The lack of statistical significance of government extension is very likely due to too much focus on modern crops and neglect of traditional dryland crops such as pigeon pea.

Overall, the Poisson regression results suggest that farmers adopt more than one improved variety to satisfy multiple needs of the household that depend on unique attributes of different varieties. Intuitively, it seems that IPV adopters in this sample adopt more than one variety in order to spread the risks and achieve both own consumption and income earning goals. Since local conditions can vary widely, with respect to production constraints, consumer preferences and market demand, farmers may be adopting more than one type of variety in order to maximize overall utility. Consequently, factors such as drought tolerance, pest resistance, taste, ease of cooking and good price matter a great deal in explaining the higher intensity (or range) of IPVs adopted by the majority of farmers – given that a combination of these factors helps to satisfy the wide range of farmer objectives and needs.[2]

4. Conclusion and recommendations

The study finds that of five improved pigeon pea varieties released to the farmers in the study area, only three have so far been widely adopted: ICPL 89091, Katumani 60/8 and ICEAP 00068. The popularity of these varieties is mainly attributed to their superior production, consumption and economic traits.

The results of the multivariate probit regression model fitted to examine the effect of variety attributes on adoption of improved pigeon pea varieties indicate that there is indeed correlation in the decision to adopt the different improved pigeon pea varieties. The implication of this finding is that estimating independent probit equations for each variety may lead to inefficient and incorrect estimates for the standard errors of the parameters.

The results from both the multivariate probit and the Poisson regression show that farmers consider inter alia drought tolerance, pest resistance, taste, ease of cooking and price in choosing which variety to adopt. The early maturity trait has no significant effect on adoption of IPVs. This result contradicts current pigeon pea research efforts in Africa which are focused on developing early maturing varieties.

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[2] We thank one of the anonymous reviewers for contributing the points contained in this paragraph.

Two policy implications emerge from the above results. First, interventions to develop new crop varieties should not focus solely on the often-assumed desirable traits such as early maturity but should also pay attention to the consumption and market attributes. Second, non-yield production characteristics such as taste, price and ease of cooking are significant factors in farmers' assessments of the value of a new variety. This implies that future efforts aimed at pigeon pea varietal improvement should pay attention to these attributes to increase technology uptake. The findings also have important implications for future research and development and the targeting of technologies, namely that such efforts should recognize farmers' multi-strategy needs and thus the demand for different varietal traits which are likely always to require more than one improved variety.

Acknowledgement

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