Journal of Agriculture and Rural Development in the Tropics and Subtropics
Vol. 122 No. 1 (2021) 43–52

https://doi.org/10.17170/kobra-202102113203 ISSN: 2363-6033 (online); 1612-9830 (print) – website: www.jarts.info

Determinants of protected tomato production technologies among smallholder peri-urban producers in Kiambu County, Kenya

Josiah M. Ateka*, Robert M. Mbeche, Kavoi M. Muendo

Department of Agricultural and Resource Economics, Jomo Kenyatta University of Agriculture and Technology, Nairobi, Kenya

Abstract

Climate variability and the rise in incidences of pests and diseases continue to undermine production of high value vegetables among smallholder farmers in sub-Saharan Africa. In order to respond to these challenges, protected farming technologies (PFT) (such as greenhouses) which modify the plant environment and therefore aid in avoiding the harmful effects of climatic factors have been promoted. Greenhouses protect the crops against high solar radiation and heavy rainfall that have the potential of destroying vulnerable crops like tomatoes. Consequently, PFT is associated with better yields and farm incomes. However, the adoption of PFT among smallholder farmers, not least in Kenya is low. Drawing on the Agricultural Household Model (AHM) theoretic framework, this paper assessed the determinants of adoption of PFT among smallholder tomato farmers in Kenya. Tomato is the second most important horticultural vegetable crop in Kenya after potatoes in terms of production volumes and value. Data for the study were collected from a cross sectional multistage random survey of 104 tomato farming households and analysed using maximum likelihood probit model. The probit results revealed that the age of a farmer, educational level, household size, total household income and access to credit positively influenced the likelihood of PFT adoption. The likelihood of adoption was negatively related to distance to input markets and access to the county government extension services. Overall, the results of this study suggest that an integrated promotional strategy that accounts for household heterogeneities and focuses on institutional arrangements that support the accumulation of human and financial capital would enhance PFT adoption.

Keywords: Protected farming, greenhouses, adoption, agricultural household model, probit maximum likelihood

1 Introduction

The production of high value vegetables has potential to improve the livelihoods of poor smallholder farmers. This is because they are less land intensive and have higher farmgate values compared to cereals and other staple crops (Johnson *et al.*, 2008; Mariyono *et al.*, 2017). However, commercial production of vegetables among smallholder farmers is undermined by several factors including poor market access and dependence on rainfed production systems which are highly susceptible to extreme weather variability and pests and diseases (Odame *et al.*, 2009; USAID, 2012; Research Solutions Africa, 2015). In order to mitigate against these factors, various protected cultivation technologies have been developed (FAO, 2013a). The technologies vary from simple cover shade netting, film plastics or sophisticated greenhouses and equipment (FAO, 2013a; Baliyan, 2014) which modify the plant environment and therefore aid in avoiding the harmful effects of climatic factors like temperature, humidity and rainfall (FAO, 2013b). The level of investment in the technology, as well as management, depends primarily on the cost of technology, resource capacity and prevailing ecological conditions.

Various benefits are associated with protected cultivation. These include, their ability to achieve a better control against aerial borne pests and diseases, and other ecological parameters, therefore leading to better yields and profitability (Muñoz *et al.*, 2007; FAO, 2013a; Geoffrey *et al.*, 2014; Guodaar, 2015; Hilmi, 2016; Nordey *et al.*, 2017). Protected farming systems can also support an all-round–the-year production; which can enable farmers to leverage on better prices (USAID, 2012; Panwar *et al.*, 2014; Bseiso *et al.*,

* Corresponding author: Atekajm56@gmail.com; jateka@jkuat.ac.ke;
Phone: +254-721-624182

Published online: 5 March 2021 – Received: 8 June 2020 – Accepted: 5 February 2021

2015). In addition, protected farming is ecologically more sustainable because of use of comparatively less synthetic chemicals than open field production (Muñoz *et al.*, 2007; Geoffrey *et al.*, 2014; Guodaar, 2015). Finally, protected farming is associated with efficient land-use, a factor that is gaining increased significance in many sub-Saharan Africa (SSA) countries where land is emerging as one of the most limiting production constraints. In light of the aforementioned benefits, protected farming technologies have rapidly spread in Middle East, Mediterranean region and Europe for production of melons, tomatoes, strawberries, cucumber, green beans and other high value crops (Connell *et al.*, 2012; FAO, 2013a; Fernández *et al.*, 2018). While protected cultivation has variety of agriculture applications, it is mainly applied in the production of horticulture crops like vegetables and ornamental flowers (FAO, 2013a).

In Kenya the utilisation of greenhouses, (the leading protected vegetable farming technology in the country) has been widely promoted as part of efforts to support a growing vegetable subsector (Geoffrey *et al.*, 2014; Omoro *et al.*, 2015). The sector makes an important contribution as a key source of household income and livelihood (Mithöfer *et al.*, 2008). In Kenya, greenhouses have been used commercially to produce cut-flowers for export since late 1990s. The scenario has however slowly changed overtime with small scale farmers adopting it to grow high value food crops such as tomatoes, strawberries and melons among other crops (Sanzua *et al.*, 2018). There are three greenhouse technology designs; low, medium and high-level technology. The low-level technology greenhouses consist of a fixed metal or wooden structure with a fixed polythene cover. Because these often lack any kind of ventilation, such greenhouses are not suitable for hot areas. The medium technology level refers to greenhouses that come with options which allow ventilation openings and cultivation under hot climatic conditions. High-tech greenhouses come with automated systems to monitor and control crop growing environment. However due to high investment costs, high-tech greenhouses are not used by Kenyan small and medium-scale farmers (Van der Spijk, 2018). In the country, greenhouses are largely concentrated in the central, Rift Valley and western highlands but are slowly spreading into the humid areas of Kenya including eastern and coastal areas (Justus & Yu, 2014; Sanzua et al., 2018).

However, despite some promotional efforts by government agencies, NGOs and private companies[1], utilisation of greenhouse farming among smallholder farmers in Kenya (as well as many SSA countries) is low – estimated to an average of 5% (Geoffrey *et al.*, 2014; Van der Spijk, 2018; Karuku *et al.*, 2016; Bseiso *et al.*, 2015; Nordey *et al.*, 2017). There are however no official figures on greenhouse use in Kenya (van der Spijk, 2018). There are also reports that some farmers in the country have even abandoned greenhouses after the first crop cycle, in spite of initial investment costs (Omoro *et al.*, 2015; Van der Spijk, 2018; Agriculture and Food Authority (AFA), 2018). It is therefore important to assess the determinants of adoption of protected technologies such as greenhouses to inform wider understanding.

This paper assesses the determinants of adoption of greenhouse technology which is one of the leading protected farming technologies in the production of tomatoes in Kenya. We focus on tomato which ranks second in importance among the produced vegetables (after potatoes) in terms of production volume and value; putting Kenya among the top African producers (Ochilo *et al.*, 2019). The crop comprises 6.7% and 14% of the total production for horticulture and vegetables respectively (Geoffrey *et al.*, 2014). While literature on technology adoption is extensive (see for example Feder *et al.*, 1985; Chirwa, 2005; Rahman, 2008; Sitomwe *et al.*, 2016) research on adoption of protected farming technologies is limited. These include studies on trends in adoption of greenhouse technology and its utilisation (García-Martínez *et al.*, 2010; Geoffrey *et al.*, 2014), effects of greenhouse adoption on productivity and profitability (Muñoz *et al.*, 2007), and effect of greenhouse technology in managing climate variability risks (Muñoz *et al.*, 2007; FAO, 2013b; Guodaar, 2015). While these studies have begun to shed light on uptake of protected farming, a number of these are largely descriptive and the theoretical motivations that underlie adoption have largely been ignored. This paper draws on the agricultural household utility model to assess the decision of households to adopt or not to adopt greenhouse technology.

2 Materials and methods

2.1 Study area

The study was conducted in Kiambu County[2], one of the leading tomatoes producing counties in Kenya (AFA, 2018). The county is found in Central Kenya, a region known to

[1]Protected farming is being promoted as part of Kenya's National Agriculture and Livestock Extension Programme NALEP (NALEP, 2011) and Kenya's Agricultural Sector Development Strategy. In addition, greenhouse farming among smallholder farmers has been supported by agencies such as the Horticultural Crops Development Authority (now the Horticultural Crops Directorate), the Smallholder Horticultural Marketing Programme (SHoMaP) – a partnership between the Ministry of Agriculture and the International Fund for Agricultural Development and companies such as Amiran and Syngenta (Omoro et al., 2015).

[2]Kiambu county is one of the 47 devolved governance units in Kenya

contribute 80 % of the total tomato production together with the Rift valley area and Nyanza counties (Odame *et al.*, 2009). Kiambu County covers an area of 2,543.5 km^2 and lies between Latitudes 0°45'58.05" and 0°16'13.26" South of the equator and Longitude 36°30'23.91" and 37°21'37.60" East. The county consists of 12 sub-counties[3] and experiences a bi-modal type of rainfall with the long rains falling between mid-March to May followed by a cold season (usually accompanied with drizzles and frost) during June to August and the short rains between mid-October to November (County Government of Kiambu, 2018). Annual rainfall varies between 600 mm to about 2,000 mm while temperatures range from 7 °C to 34 °C in the Upper Highlands to the Lower Midlands.

Agriculture is the dominant economic activity in the county and contributes 17.4 % of the county's income. It is the leading sector in terms of employment, food security, income earnings and overall contribution to the socio-economic well-being of the people (Republic of Kenya, 2014). Majority of the people in the county depend on agriculture for their livelihood, with 304,449 persons being directly or indirectly employed in the sector. Coffee, tea and pineapples are the main cash crops while maize, beans, potato and tomato are some of the main food crops in the county (County Government of Kiambu, 2018). The county is divided into four topographical zones, namely, Upper Highland (UH), Lower Highland (LH), Upper Midland (UM) and Lower Midland zones (LM).

2.2 Data

The data used in this study were obtained through a cross-sectional survey of tomato producing households. A multistage random sampling procedure was followed to select tomato producing households in consultation with sub-county agricultural officers. The first stage of sampling was a purposive selection of five sub-counties in Kiambu County, namely Thika, Juja, Ruiru, Gatundu South and Gatundu North from the 12 sub-counties. These sub-counties were purposively selected because they are the main tomato producing areas within the county. At the second stage, a list of tomato farming households in the selected sub-counties was generated with the help of the ward agricultural officers and village elders. The list generated a total of 104 tomato farming households who were interviewed. Majority of the respondents (70.2 %) were utilising the open field system with only 29.8 % using protected farming technologies (PFT). Data were collected between January and April 2016.

[3]Gatundu South, Gatundu North, Juja, Thika, Ruiru, Githunguri, Kiambu, Kiambaa , Limuru, Kikuyu, Kabete, Lari.

The questionnaire applied to collect data contained questions on the key economic activities of households including information on land use, input use, various household characteristics, indicators for input and market access, institutional arrangements and technology adoption. Data were entered into SPSS version 20, cross checked and cleaned before being transferred to STATA version 13 for statistical analysis.

2.3 Analytical framework and variables

This study builds on the theory of agricultural/farm household utility model (De Janvry *et al.*, 1991) and the random utility framework (McFadden, 2000) to develop a framework for assessing household decisions on use of vegetable production technology. The study considers a dichotomous setting where a vegetable producing farm household can either use the conventional open field production system (OFS) or utilise the protected farming technology (PFT). Following previous studies (Chuma *et al.*, 2020; Kimaru-Muchai *et al.*, 2020), the household's decision to choose OFS or PFT is assumed to depend on the differences in the expectations of the household about the net returns associated with the two technology regimes based on their respective costs and benefits (McFadden, 2000). Consequently, the farm household will choose PFT if the expected net returns associated with technology is at least greater than the expected net return from the alternative technology, OFS as shown in:

$$(TB^{PFT} - TC^{PFT}) \geq (TB^{OFS} - TC^{OFS}) \qquad (1)$$

Where (TB^{PFT} and IC^{PFT}) and (TB^{OFS} an TC^{OFS}) are the benefits and costs associated with the PFT and OFS technologies, respectively. The comparison in equation (1) is underpinned by the random utility model, which assumes that when an economic agent (household or individual) faces a choice between two or more alternatives, she will select the alternative that gives the highest utility (McFadden, 2000). If the difference in the expected net payoffs for the two technology regimes are represented by π as shown in equation 1, then a household will adopt the protected technology if $\pi > 0$ and vice versa (Hardle, 1990).

$$(TB^{PFT} - TC^{PFT}) - (TB^{OFS} - TC^{OFS}) = \pi \qquad (2)$$

Where π is a latent variable that is explained by the difference in payoffs associated with use of the protected farming. The specification in equation (2) implies that factors that raise π will enhance adoption of PFT and vice versa. The empirical modelling of a farmer's choice of production can be represented by a binary variable (D) such that:

$$D_i = \begin{cases} 1 \text{ if } \pi_i = \pi_i + \varepsilon = (TB^{PFT} - TC^{PFT}) \\ \qquad\qquad\qquad - (TB^{OFS} - TC^{OFS}) \geq 0 \\ 0 \text{ otherwise} \end{cases} \quad (3)$$

Where ε is the standard error term. Equation (3) can be estimated using the binary regression approach once one identifies the factors likely to influence π (Hensher & Johnson, 1981). The magnitude π is assumed to be highly heterogeneous and household specific depending on various household contextual factors such as gender and income, differential access to markets, transaction costs, liquidity constraints, and information asymmetries (Poole, 2017). The empirical form of equation 3 which was estimated is shown in equation 4:

$$D_i = \Phi\left(\beta_0 + \sum_j^k \beta_j Z_{ji}\right) + \varepsilon \quad (4)$$

Where, Φ is the standard normal cumulative density function and Z_i is a vector of characteristics that are hypothesized to affect the choice of a tomato production technology and included various household specific attributes such as; age of household head, sex of the household head, education and access to credit (Annex 1). Equation 4 was estimated using the probit model based on the distributional assumptions about the error term (Hausman & Wise, 1978).

3 Results

3.1 Descriptive statistics

The results of the descriptive analysis summarised in Table 1 showed that adopters of PFT were slightly older (45.3 years) compared to non-adopters (39.8 years; $p < 0.05$). The results also showed that majority of the adopting households were male-headed (77.4 %) and more educated. The education level of the household's head which was expressed in terms of years of schooling was significantly different between adopters and non-adopters. It was also observed that adopting households had a significantly higher amount of annual household income (US$ 5548.4) than the non-adopting households (US$ 2898.2).

The average distance to an all-weather road was 0.4 km suggesting that households had relatively good access to input and output markets. However, PFT requires specialized type of inputs that are unlikely to be found in local markets. Thus, in addition to distance to an all-weather road, additional variables of distances to input and output markets were included in the study. The distance to input markets was on average 6.5 km compared to an average of 5.4 km for output markets. The study also found that the amount of credit accessed by adopters was significantly higher (US$ 150) compared to non-adopters (US$ 31) suggesting that access to credit would be an important factor influencing PFT adoption.

While the average experience in tomato farming in the sample was four years, there were significant differences between adopters who had less experience (2 years) compared to non-adopters (4.8 years). The adopting households had significantly larger portions of land (3.96 ha) than the non-adopting households (0.59 ha). Interestingly, there were significant differences between adopters and non-adopters regarding land tenure (Z=4.3). All adopters (100%) owned the plots they used for tomato farming compared to non-adopters (57.5 %). Overall, the result of the descriptive analysis showed that there were significant differences between adopters and non-adopters with regard to a number of variables which therefore qualified the data set for use in the regression model.

3.2 Determinants of PFT adoption

Table 2 presents the results of the econometric analysis of the determinants of adoption of PFT. The dependent variable takes a value of unity if a farmer used PFT and zero otherwise. Because of the binary nature of the dependent variable, a standard probit approach has been used for the estimation. Robust standard errors were estimated to account for possible heteroskedasticity and reported coefficients are marginal effects of the probit estimation. The factors included in the model are household demographic and social economic characteristics, farm characteristics and institutional variables. The results showed that age of a farmer, experience, educational level, household size, income, access to input markets, credit and extension services contributed significantly to the probability of PFT adoption.

The age of the farmer had a positive and significant marginal coefficient indicating that older household heads are more likely to adopt PFT for tomato farming. In addition to age of the farmer, the study included the farmer's experience in the formulation as a possible covariate of PFT adoption. This was considered plausible in accounting for the joint influence or interaction of the two variables since age and experience may go in opposite directions. The coefficient of the quadratic term for experience was significant at five percent implying existence of non-linearity in the relationship between experiences and adoption of PFT in tomato farming.

Consistent with many adoption studies, education – increase in years of education by one year increases the likelihood of adoption by 6.1 %. The education level of house-

Table 1: *Descriptive statistics of variables used in the Probit Model*

	N= 104		N= 73	N= 31	
Variable	*overall mean*	*Std Dev*	*non-adopters*	*adopters*	*t score*
Age of household head (years)	41.40	11.35	39.77	45.26	2.30***
Female headed (%)	38.46		45.20	22.60	
Male headed (%)	61.54		54.80	77.40	2.17***
Education of household head (years)	9.88	4.53	8.93	12.10	3.42***
Household size	4.28	1.72	4.22	4.42	0.54
Distance to an all-weather road (km)	0.40	0.48	0.44	0.29	1.47
Distance to input market (km)	6.46	5.88	5.06	9.74	3.97***
Distance to output market (km)	5.43	8.93	5.26	5.84	-0.30
Amount of credit obtained (KES)	6653.85	21256.50	3109.59	15000.00	2.69***
Approximate US$ equivalent	66.5	212.5	31	150	
Access to credit (%, Yes =1)	13.50		11.00	19.40	1.15
Access to extension (%, Yes=1)	29.81		32.90	22.60	2.05***
Experience producing tomato (years)	4.00	2.82	4.82	2.06	5.09***
Farm size (ha)	1.59	1.88	0.59	3.96	14.60***
Tenure (% Yes =1	70.20		57.50	100.00	4.33***
Labour structure (Family=1)	55.80		57.50	51.60	0.56
Household income (KES)	368817.30	242095.40	289821.90	554838.70	5.88***
Approximate US$ equivalent	3688	2420	2898	5548	

The asterisks denote significance *** at 1%, ** at 5% and * at 10 %; KES: Kenyan Shilling – 1000 KES = 10 US $.

Table 2: *Marginal effects of the factors determining adoption of protected farming technologies (PFT) .*

Variables	*Marginal effects*	*Std. Err.*	*Z*	*P>z*
Age of head of household	0.011**	0.004	2.53	0.049
Gender of head of household	0.015	0.007	2.2	0.145
Experience in tomato production	0.023	0.013	1.72	0.177
Square of experience	-0.089**	0.036	-2.46	0.034
Education of household head	0.061**	0.023	2.64	0.019
Household size	0.010**	0.004	2.91	0.019
Household income	0.006***	0.003	2.06	0.04
Distance to all weather road	-0.052	0.073	-0.72	0.605
Access to input markets	0.086**	0.035	2.45	0.024
Access to credit	0.015**	0.006	2.52	0.012
land tenure	0.018	0.010	1.88	0.187
Access to extension	-0.027*	0.015	1.85	0.084

*The asterisks denote significance***at 1%, **at 5% and*at 10 %)

hold head was used as proxy for human capital. This is because education enhances the ability of farmers to acquire, synthesize, and respond to information, thereby increasing the probability of adoption of an innovation. The results revealed that larger households were more likely to adopt PFT, attributed to the fact that household size increased the availability of family labour which reduced the need for hiring labour for transportation, handling and supervision of sales, and hence a rise in the propensity to adopt PFT. On income, it was hypothesized that household income was a good measure of farm capital and therefore should had a strong correlation with adoption of technology for agricultural intensification. The results showed that a unit increase in household income would increase the likelihood of greenhouse adoption by 0.6%. The importance of access to well-functioning markets for agricultural development has been extensively highlighted in literature. The results of the probit model showed that the coefficient of distance to input markets was significant at 5%. The magnitude of the coefficient was 0.0861 which implied that an increase in the distance to the input markets reduced the likelihood of adoption of PFT by 8.6 %. The results also revealed that increase in the amount of credit would increase the likelihood of PFT adoption. However, access to government extension services had a negative effect on adoption. FGDs showed that adopting farmers relied more on greenhouse suppliers for their extension needs than government agencies.

4 Discussion

The discussion focuses on two specific objectives raised at the outset of the paper – the level and determinants of adoption of protected farming technology among smallholder tomato farming in Kenya. The study found that only three out of 10 tomato farmers adopted PFT in tomato farming. These results are consistent with previous studies which show that adoption of protected farming technology in Kenya (Geoffrey *et al.*, 2014; Omoro *et al.*, 2015) and generally in Africa (Nordey *et al.*, 2017) is low. The results of the descriptive analysis showed that there were significant differences between adopting farmers and non-adopting farmers with regard to personal characteristics, farm and institutional characteristics. Adopting households were more likely to be male-headed, higher in years of tomato farming experience, incomes, land sizes, and have more secure land tenure arrangements. These results are not surprising considering that greenhouse farming is a capital-intensive undertaking which typically implies need for working capital to acquire necessary inputs (Geoffrey *et al.*, 2014; Nordey *et al.*, 2017). The Retail price for the greenhouses in Kenya is 2,500 USD and 1,500 USD for the metal and wooden greenhouse respectively (Van der Spijk, 2018). While open-field farmers on average produce 2.3 kilos per square meter per year, farmers producing in a greenhouse yield 16.1 kilos on average (Van der Spijk, 2018). The difference of 13.8 kg m^{-2} shows significant productivity differentials between the two systems.

As expected, age of the farmer was positively associated with adoption of PFT. This finding is consistent with Sitomwe *et al.* (2016) who found higher levels of adoption for improved pigeon pea varieties among older farmers and particularly those with access to credit. Contrary to the findings in this paper, Czaja *et al.* (2006) found that older farmers were reluctant to take up new technologies and hence age negatively influenced technology adoption. As observed by Adesina & Forson (1995), the expected result of age is an empirical question, because in some cases, older farmers may have more experience in farming and are better able to assess the characteristics of modern technology than younger farmers, and therefore are better able to judge the usefulness of the technology. In this study, the quadratic term of experience showed a negative influence on adoption of PFT implying existence of non-linearity in the relationship between experiences in tomato farming and adoption of PFT in tomato farming. Previous studies have shown that experience positively influences the decision to adopt agricultural technologies (Chima, 2015; Chirwa, 2005; Rahman 2008).

While gender did not have a significant influence on adoption of PFT, various studies have identified it as an important determinant of agricultural technology adoption among smallholder farmers in developing countries (see for example, Ogada *et al.*, 2014; Kimaru-Muchai *et al.*, 2020). This may be because women face resource constraints which limit their technology adoption (Ogada *et al.*, 2014). Recent literature argues that while gender has an inconsistent association with adoption, policy makers may consider evaluation of adoption for gender-based subpopulations because it can influence other factors with consistent influence on adoption such as information access (Llewellyn & Brendan, 2020). In the study, the education level had a positive association with adoption of PFT among tomato farmers suggesting that enhancing human capital can promote uptake of improved production technologies. This finding is consistent with Rahman (2008) who also found that both the educational level of the farmers and the farming experience had important influence on the decision to adopt diversified cropping systems in Bangladesh. The results also show that household income, as expected, increased the likelihood of greenhouse adoption. Household income is a good measure of farm capital and therefore should have a strong correlation with adoption of technology for agricultural intensification (Ogada *et al.*, 2014).

The importance of access to well-functioning markets for agricultural development has been extensively highlighted in literature. This study considered proximity to a paved road and distance to markets as proxies for access to markets. Proximity is important since households located nearer to input and output markets are expected to have higher access to financial institutions and income-generating facilities (medium size enterprises and off-farm employment) that can enable them to buy inputs in a timely manner than households in remote places (Fafchamps & Shilpi, 2005). Therefore, as expected, proximity to input markets was positively associated with adoption of PFT. The finding is consistent with other authors (e.g. Omiti *et al.*, 2009; Fafchamps & Minten, 2012; Aker & Fafchamps 2015; Mmbando *et al.*, 2015) who showed that transaction costs have an important influence on farmers' decision to adopt technology. The results however showed that the influence of distance to output markets was not important. This could be explained by the fact that most farmers in Kiambu County sold their tomatoes at the farm gate to middlemen who transported these to urban markets in Kenya's capital city Nairobi. Additionally, Kiambu's proximity to Nairobi means that farmers in the County face less constrains in selling tomato compared to their counterparts in far flung locations.

The results revealed that increases in credit amount would increase the likelihood of PFT adoption consistent with economic constrain paradigm of adoption (Sitomwe *et al.*, 2016). This is consistent with Dillon (2017), Burke *et al.* (2018) and Melkani *et al.* (2019) who argue that in the presence of liquidity constraints, asset-poor households may be dissuaded from entering into high-value agricultural activities due to lack of enough capital (and they did not have access to credit) or capacity to cope with market risks. This could explain why most open field tomato farmers considered greenhouse farming technology as being too expensive and a risky investment. To reduce their income risk, rural households may enter into low-risk, low-return activities. Similarly, FGDs indicated that there were perceptions that OFS tomatoes were morphologically different in terms of fruit weight, shape, skin texture, dry matter and succulence – compared to those produced through PTF[4]. As a result of these perceptions, consumer acceptance of tomatoes produced in greenhouses is low. A similar perception has been reported by Van der Spijk (2018) associated with debates around genetically modified foods (GMOs). Consumers in Kenya have been reported to have low acceptance to GMOs mainly due to food safety concerns (Kimenju *et al.*, 2005).

Access to extension has the potential to minimize the risks by reducing information asymmetries especially for resource poor farmers (see for example, Sitomwe *et al.*, 2016). However, access to government extension services had a negative effect on adoption. The result could be explained by an observed tendency of adopting farmers to rely more on greenhouse suppliers for their extension needs than government agencies. Additionally, the findings would be explained by the presence of multiple extension providers, apart from the government extension system given that the study area is currently characterised by pluralistic extension systems (Ateka *et al.*, 2019).

Overall, the results of this study indicate that farmers with higher incomes and education attainment and with better access to markets and credit are more likely to adopt PFT. These findings suggest need for interventions to enhance uptake of PFT among resource constrained farmers. Other studies have shown that supporting farmers in groups can enhance adoption of greenhouse technologies among resource poor farmers (Omoro *et al.*, 2015; Van der Spijk, 2018).

[4]While morphological variability between OFS and PFT produced tomatoes was not empirically examined, a number of key informants opined that such differences relate to the management practices and the planted varieties.

5 Conclusions

Protected farming has the potential to help farmers adapt to climate change through higher yields and enabling an all–year–round production. Despite this potential, and promotional efforts by government and other stakeholders, the adoption levels of PFT in the study area is low. This paper characterised smallholder tomato farmers and assessed the determinants of adoption for the greenhouse technology in Kiambu, Kenya. The results showed that only three in 10 farmers had adopted PFT in their tomato enterprises, implying that there is a significant potential for increasing the adoption rate of PFT. The study found significant differences in key demographic and household characteristics that have an implication on adoption. Adopters were statistically different from non-adopters on key variables including; age, gender, education, income, land tenure arrangements, farm size and access to extension.

The results of the probit model showed that age of the farmer, farmers' experience and education are the important socioeconomic variables influencing the adoption of PFT. The influence of these variables was positive which indicates that supporting the accumulation of human capital among smallholder households would enhance adoption of PFT. In addition, household income was found to have a positive influence on adoption. Since the initial cost outlay for greenhouse technology is high, it might be worthwhile for government and other organisations to organise farmers into groups and support them to access the technology. The findings further showed that access to credit and input markets are the important institutional variables influencing PFT adoption. These findings point to the importance of improving farmer's access to financial and input markets as a strategy for enhancing the adoption of PFT. While extension is an important institutional factor that enhances farmers' knowledge and experience and subsequently reduce information asymmetries, our probit model showed that it did not positively influence adoption decisions. Overall, the results of the present study suggest that an integrated promotional strategy that accounts for household heterogeneities and focuses on institutional arrangements that support the accumulation of human and financial capital would enhance PFT adoption.

Acknowledgements

The study acknowledges the Regional Universities Forum for Capacity Building in Agriculture (RUFORUM) through an institutional grant to Jomo Kenyatta University of Agriculture and Technology for funding the study. Special appreciation also goes to the Department of Agriculture in Kiambu County for their support.

Conflict of interest

The authors declare that they have no conflict of interest.

References

Adesina, A. A., & Baidu-Forson, J. (1995). Farmers perception and adoption of new agricultural technology: Evidence from analysis in Burkina Faso and Guinea, West Africa. *Agricultural Economics*, 13, 1–9.

Agriculture and Food Authority (2018). The validated horticulture data report (2016-2017). Available online at: http://kilimodata.developlocal.org/dataset/3534b0b9-e49e-4c72-a90a-e423844a83a2/resource/c7758a80-9102-481e-a6c2-fa983081221d/download/horticulture-validated-data-2016-2017.pdf. Last accessed 17.12.2020.

Aker, J., & Fafchamps, M. (2015). Mobile phone coverage and producer markets: Evidence from West Africa. *World Bank Economic Review*, 29 (2), 262–292.

Ateka, J., Onono-Okelo, P. A., & Etyang, M. (2019). Does participation in farmer field school extension program improve crop yields? Evidence from smallholder tea production systems in Kenya. *International Journal of Agricultural Management and Development*, 9 (4), 409–423.

Baliyan, S. P. (2014). Improving sustainable vegetable production and income through net shading: A Case Study of Botswana. *Journal of Agriculture and Sustainability*, 5(1), 70–103.

Bseiso, A., Abele, B., Ferguson, S., Lusch, P., & Mehta, K. (2015). A decision support tool for greenhouse farmers in low-resource settings. Paper presented at the 2015 IEEE Global Humanitarian Technology Conference (GHTC).

Burke, W., Myers, R., & Jayne, T. (2015). A triple-hurdle model of production and market participation in Kenya's dairy market. *American Journal of Agricultural Economic*, 97, (4), 1227–1246.

Chima C. D. (2015). *Socio-economic determinants of modern agricultural technology adoption in multiple food crops and its impact on productivity and food availability at the farm-level: A case study from South-eastern Nigeria*. PhD Thesis, University of Plymouth. 355 p.

Chirwa, E. W. (2005). Adoption of fertilizer and hybrid seeds by smallholders maize farmers in southern Malawi. *Development Southern Africa*, 22 (1), 1–12.

Chuma, T., Mudhara, M., & Govereh, J. (2020). The effects of grain storage technologies on maize marketing behaviour of smallholder farmers in Zimbabwe. *Journal of Agriculture and Rural Development in the Tropics and Subtropics*, 121 (1), 1–12.

Connell, S. O., Rivard, C., Peet, M., Harlow, C., & Louws, F. (2012). High tunnel and field production of organic heirloom tomatoes: Yield, fruit quality, disease, and microclimate. *Hortscience*, 47(9), 1283–1290.

County Government of Kiambu (2018). County Integrated Development Plan (2018-2022). County Government of Kiambu. http://Www.Kiambu.Go.Ke/Departments/Images/YASC/CIDP_2018_2022.PdfLastaccessed26.3.2020

Czaja, S. J., Charness, N., Fisk, A. D., Hertzog, C., Nair, S. N., Rogers, W. A., & Sharit, J. (2006). Factors predicting the use of technology: findings from the Center for Research and Education on Aging and Technology Enhancement (CREATE). *Psychology and aging*, 21(2), 333–352.

de Janvry, A., Fafchamps, M., & Sadoulet, E. (1991). Peasant household behaviour with missing markets: Some paradoxes explained. *Economic Journal*, 101 (409), 1400–1417.

Dillon, B., & Dambro, C. (2017). How competitive are crop markets in Sub-Saharan Africa? *American Journal of Agricultural Economics* 99 (5), 1344–1361.

Fafchamps M., & Shilpi, F. (2005). Cities and Specialisation: Evidence from South Asia, *Economic Journal*, 115, (503), 477–504

Fafchamps, M., & Minten, B. (2012). Impact of SMS-based agricultural information on Indian farmers. *World Bank Economic Review*, 26 (3), 383–414.

FAO (2013a). Good Agricultural Practices for greenhouse vegetable crops Principles for Mediterranean climate areas. Food and Agriculture Organisation, Rome.

FAO (2013b). Climate-smart agriculture sourcebook. Rome, Food and Agriculture Organisation, Rome. http://www.fao.org/3/a-i3325e.pdfLastaccessed26.3.2020

Feder, G., Just, R. E., & Zilberman, D. (1985). Adoption of agricultural innovations in developing countries: A survey. Econ. Dev. *Cultural Change*, 33 (2), 255–298.

Fernández, J. A., Orsini, F., Baeza, E., Oztekin, G. B., Muñoz, P., Contreras, J., & Montero, J. I. (2018). Current trends in protected cultivation in Mediterranean climates. *European Journal Horticultural Science*, 83 (5), 294–305.

García-Martínez, M-C., Balasch Parisi, S., Fernández-Zamudio, M-A., & Caballero Villar, P. (2010). Trends in the adoption of greenhouse technology in Mediterranean horticultural farms. *New Medit*, 3, 47–55.

Geoffrey, S. K., Hillary, N. K., Antony, K. M., Mariam, M., & Mary, M. C. (2014). Challenges and strategies to improve tomato competitiveness along the tomato value chain in Kenya. *International Journal of Business and Management* 9, 205–212.

Guodaar, L. (2015). *Effects of climate variability on tomato crop production in the Offinso North District of Ashanti region.* MPhil. Thesis, Kwame Nkrumah University of Science and Technology, Ghana.

Hardle, W. (1990). *Applied Nonparametric Regression*. New York: Cambridge University Press.

Hausman, J. A., & Wise, D. A. (1978). A Conditional Probit Model for Qualitative Choice: Discrete Decisions Recognizing lnterdependence and Heterogeneous Preferences, *Econometrica*, 46, 403–426.

Hensher, D. A., & Johnson, L. W. (1981). *Applied Discrete-Choice Modeling.* London: CroomHelm.

Hilmi, M. (2016). Developing greener food value chains: environmentally friendly tomato post-harvest operations in four cities. *Food chain*, 6 (1), 22–33

Johnson, G. I., Weinberger, K., & Wu, M. H. (2008). The vegetable industry in tropical Asia: An overview of production and trade, with a focus on Thailand. (Maureen Mecozzi, Ed.) (Exploratio). Shanhua, Tainan: AVRDC Publication. https://www.academia.edu/6143243/The_Vegetable_Industry_in_Tropical_Asia_ThailandLastaccessed4.4.2020

Justus, F., & Yu, D. (2014). Spatial Distribution of Greenhouse Commercial Horticulture in Kenya and the Role of Demographic, Infrastructure and Topo-Edaphic Factors. *ISPRS Int. J. Geo-Inf.*, 3(1), 274–296.

Karuku, G., Kimenju, W. & Verplancke, H. (2016). Farmers' perspectiveson factors limiting tomato production and yields in Kabete, Kiambu County, Kenya. *East African Agricultural and Forestry Journal*, 82(1), 70–89.

Kimaru-Muchai S. W., Ngetich F. K., Baaru, M., & Mucheru-Muna, M. W. (2020). Adoption and utilisation of Zai pits for improved farm productivity in drier upper Eastern Kenya. *Journal of Agriculture and Rural Development in the Tropics and Subtropics*, 121(1), 13–22.

Kimenju, S. C., Groote, H. D., Karugia, J., Mbogoh, S. & Poland, D. (2005). Consumer awareness and attitudes toward GM foods in Kenya. *African Journal of Biotechnology*, 4(10), 1066–1075.

Llewellyn, R. S., & Brown, B. (2020). Predicting adoption of innovations by farmers: What is different in smallholder agriculture? *Applied Economic Perspectives and Policy*, 42(1), 100–112.

Mariyono J., Kuntariningsih, A., Dewi, H. A., Latifah, E., Daroini, P. B., Negoro, A. A., Afari-Sefa, V., & Luther, G. (2017). Pathway analysis of vegetable farming commercialization. *Economic Journal of Emerging Markets*, 9(2), 115–124.

McFadden, D. (2000). *Economics of choices.* Nobel prize lecture, December 8 2000. https://www.nobelprize.org/uploads/2018/06/mcfadden-lecture.pdf Last accessed 26.5.2020.

Melkani, A., Mason, N., Mather, D., & Chisanga, B. (2019). Smallholder maize market Participation and choice of marketing channel in the presence of liquidity constraints: Evidence from Zambia. Feed the Future Innovation Lab for Food Security Policy Research Papers 161. https://www.canr.msu.edu/fsp/publications/policy-research-briefs/FSP_Policy_Brief_108ac.pdfLastaccessed30.3.2020

Mithöfer, D., Nang'ole, E., & Asfaw, S. (2008). Smallholder access to the export market: the case of vegetables in Kenya. *Outlook on Agriculture*, 37, 203–211.

Mmbando, F., Wale, E., & Baiyegunhi, L. (2015). Determinants of smallholder farmers' participation in maize and pigeon pea markets in Tanzania. *Agrekon*, 54, (1), 96–119.

Muñoz, P., Antón, A., Nuñez, M., Paranjpe, A., Ariño, J., Castells, X., Montero, J., & Rieradevall, J. (2007). Comparing the environmental impacts of greenhouse versus open-field tomato production in the Mediterranean region. International Symposium on High Technology for Greenhouse System Management. *Greensy*, 801, 1591–1596.

National Agriculture and Livestock Extension Programme NALEP (2011). A guide to effective extension methods for different situations, Nairobi, Kenya. Pages 1-8.

Nordey, T., Basset-Mens, C., De Bon, H., Martin, T., Déletré, E., Simon, S., & Malézieux, E. (2017). Protected cultivation of vegetable crops in sub-Saharan Africa: limits and prospects for smallholders. *A review of Agronomy for Sustainable Development*, 37 (53).

Ochilo, W., Nyamasyo G., Kilalo, D., Otieno, W., Otipa, M., Chegea, F., Karanja, T., & Lingeera, E. (2019). Characteristics and production constraints of smallholder tomato production in Kenya. *Scientific African*, 2, 1–10.

Odame, H., Musyoka, P., & Kere, J. (2009). Kenya: Maize, tomato, and dairy. Agribusiness and innovation systems in Africa, 89. Washington D.C, The World Bank Institute.

Ogada M. J., Mwabu, G., & Muchai, D. (2014). Farm technology adoption in Kenya: a simultaneous estimation of inorganic fertilizer and improved maize variety adoption decisions. *Agricultural and Food Economics*, 2 (12).

Omiti, J. M., Otieno, D. J., Nyanamba, T. O., & McCullough, E. (2009). Factors influencing the intensity of market participation by smallholder farmers: A Case study of rural and peri-urban areas of Kenya. *African Journal of agricultural and Resource Economics*, 3 (1), 58–82.

Omoro, P. A., Shitandi, A., Aming'a, N. N., & Basweti, E. (2015). Assessing the extension staff farm visits frequency effect on greenhouse technology performance in small scale farms in Gusii Highlands, Kenya. *Open Access Library Journal*, 2(2), 1–10.

Panwar, N. L., Kothari, S., & Kaushik, S. C. (2014). Cost-benefit and systems analysis of passively ventilated solar greenhouses for food production in arid and semi-arid regions. *Environment Systems and Decisions*, 34(1), 160–167.

Poole, N. (2017). *Smallholder agriculture and market participation*, Rugby, UK: Practical Action Publishing http://www.fao.org/3/a-i7841e.pdf.

Rahman, S., (2008). Determinants of crop choices by Bangladeshi farmers: A bivariate probit analysis. *Asian Journal of Agriculture and Development*, 5 (1), 29–42.

Republic of Kenya, (2014). Kenya National Health and Demographic Survey. Kenya National Bureau of Statistics. Available at: http://statistics.knbs.or.ke/nada/index.php/catalog/74

Research Solutions Africa (2015). Report of a study on fresh vegetables market in Kenya.

Sanzua, L. J., Saha H. M, & Mwafaida, J. (2018). Status of Greenhouse Farming in the Coastal Humid Climatic Region of Kenya. *Universal Journal of Agricultural Research* 6(5), 165–172.

Sitomwe, F., Asfaw S., & Abate, T. (2016). Determinants of agricultural technology adoption under partial population awareness: the case of pigeonpea in Malawi. *Agricultural and Food Economics*, 4 (7).

USAID (2012). Kenya Horticulture Competitiveness Project (KHCP) Kenya's Competitive Position in Horticulture: Progress Report. United States Agency for International Development.

Van der Spijk, C. A. (2018). *Greenhouse technology adoption among small and medium-scale tomato farmers in Kenya.* MSc Thesis, Wageningen University & Research. 71 p.