Makerere University Journal of Agricultural and Environmental Sciences
Vol. 13. pp. 1 - 20, 2024
© Makerere University 2024
pISSN 1563-3721
eISSN: 2958-4795

This article is licensed under a Creative Commons license, Attribution 4.0 International (CC BY 4.0)

Farmers' knowledge, perception, and willingness to pay for post-harvest disinfestation treatment technology for mango: A case of Makueni and Machakos districts, Kenya

Turinawe, A. [1*], Ndlela, S.[2], Wambui Muriithi, B.[2] and Abuelgasim Mohamed, S.[2]

[1]Department of Agribusiness and Natural Resource Economics,
College of Agricultural and Environmental Sciences, Makerere University,
P.O. Box 7062, Kampala, Uganda
[2] International Centre of Insect Physiology and Ecology (ICIPE),
P.O. Box 30772-00100, Nairobi, Kenya

*Corresponding author: aaturinawe@gmail.com

Abstract

Insect pest and disease damage contribute about 52% of the fruits losses in Kenya. The Hot Water Disinfestation Treatment (HWDT) technology can reduce post-harvest losses for mango and improve access to export markets. We investigate the willingness to adopt and pay for the HWDT technology by mango farmers and traders and determine the profitability of the mango production enterprise with the introduction of the technology. Data were collected from 83 mango farmers and 40 traders in Machakos and Makueni sub-counties of Kenya. Contingent valuation methods and the probit regression model were employed in data analysis. Results showed that mango production is profitable, with profits being potentially higher at bigger scales of production. To promote adoption, implementation programs should consider group formation, gender, experience, and scale of operation of the farmers and traders. Implementations, therefore, should take into account the inherent differences among the production and marketing participants.

Key words: Kenya, Machakos, Makueni, mango, Post-Harvest Disinfestation Treatment Technology, willingness to adopt, willingness to pay

Introduction

Post-harvest losses present a threat to food security and nutrition, profitable agriculture, and general livelihood improvement of farmers in developing countries (Affognon *et al.*, 2015). Thus, reducing postharvest losses is an emerging priority for investment in agriculture. It is estimated that to eliminate hunger by 2050 in SSA, 47% of investments for this purpose should be directed to the post-harvest sector.

Like other countries in sub-Saharan Africa, Kenya loses about 40% of its produced food to insect pests, diseases, and postharvest handling. The losses in the horticultural sector alone are estimated at 50% with most of the losses taking place at the production, handling and storage stages of the value chain (Ridolfi *et al.*, 2018). In the fruits sub-sector, postharvest losses are estimated at 40%–50% of the total harvest (Government of Kenya, GoK, 2010; Affognon *et al.*, 2015).

The horticulture sub-sector in Kenya has increasingly formed a significant part of Kenya's agricultural sector, as a major source of income, employment, food, and export earnings. It contributes about 33% of the agricultural GDP and 38% of export earnings (HCD, 2013). The horticulture sub-sector is considered a lucrative opportunity for Kenyan farmers as well as the value chain participants. The cultivated area of horticultural crops is steadily increasing, gradually replacing traditional crops (HCD, 2017).

Fruits are among the most highly performing horticultural crops in Kenya, together with cut flowers and vegetables (Match Maker Associates, 2017). Demand for fruits is increasing, and there are matching efforts in production to satisfy the demand. A recent increase in the volume of fresh horticultural exports has been attributed to an increase in fresh fruit exports (HCD, 2017). Between 2011 and 2015, fresh fruit exports increased by 70.5% from 27,100MT to 46,200MT (HCD, 2015, 2016). Mango is ranked the second most valuable fruit after bananas, contributing about 21% of the total value of fruits annually between 2015 and 2017 (HCD, 2016, 2017), and 19.4% of total fruit exports between 2015 and 2016 (HCD, 2015, 2016).

While the production of mango has been steadily increasing, the potential production is yet to be achieved (HCD, 2017). High post-harvest losses significantly reduce the quantity of produce available for processing and export (Gitonga *et al*., 2010; USAID-KHP, 2015; Muriithi *et al*., 2016). About 52% of the loss is attributed to insect pest and disease damage, while the rest is caused by the small size of the mango fruits, immature harvesting, mechanical damage during harvesting, over-ripening and poor markets (Gitonga *et al.*, 2010; Ndaka *et al.*, 2012). One of the most devastating insect pests are the tephritid fruit flies (particularly, *Bactorocera dorsalis* (Hendel)). The pest directly reduces the yield and quality of mango but is also classified as an A1 quarantine pest, thus restricting trade and access to regional and international export markets. Therefore, the fruit fly is a major threat to the livelihoods of the mango growers, especially women who represent the majority of the farming community in Kenya and SSA in general (Lutomia *et al.*, 2019).

In a bid to improve farm-level productivity as well as facilitate access to diversified markets, the International Centre of Insect Physiology and Ecology (ICIPE), through public-private partnerships (PPP), has disseminated pre-harvest integrated pest management (IPM) technologies targeting the tephritid fruit flies (Ekesi, 2016; Muriithi *et al.*, 2016). However, pre-harvest management techniques seldom give 100% freedom from infestation by fruit flies (Ndlela *et al.*, 2021). Thus, post-harvest techniques such as fumigation, irradiation, controlled atmosphere storage, cold treatment and heat-regulated post-harvest treatment are available for use in disinfesting fruit. The post-harvest treatment provides quarantine assurance to importing, countries that commodities are free from devastating quarantine pests such as *B. dorsalis* among others. Hot Water Disinfestation Treatment (HWDT) has been touted as an economically viable option for disinfesting mangoes against *B. dorsalis* and to this effect, protocols have been developed for adoption by the horticulture sector (Ocitti *et al.*, 2021; Mwando *et al.*, 2021). Preparations are at an advanced stage to establish the first HWDT facility in Kenya.

Like other new technologies and innovations in agriculture, future adoption rates of the HWDT are expected to be determined by various factors including economic feasibility as well as farmer and farm characteristics. Preliminary studies on willingness to adopt and pay for HWDT, are therefore necessary to guide efforts towards improving future adoption and sustainability. This study focused on the post-harvest HWDT for mango and aimed to (i) determine the willingness of mango farmers and traders to adopt and pay for the post-harvest disinfestation treatment technology, and (ii) Assess the profitability of the mango production enterprise with HWDT treatment technology.

Materials and methods

The study employed contingent valuation methods to assess farmers' willingness to adopt and pay for the HWDT technology. In addition, the probit regression model was used to determine factors that influence potential adoption and willingness to pay for the HWDT technology for mango, while gross margin analysis was used to estimate the profitability of the mango production enterprises when using the HWDT technology.

Data sources

The data utilized in this study was obtained from mango farmers and traders from Makueni and Machakos counties of Kenya. The two counties are the largest mango-producing counties in Kenya (Onyimbo *et al.*, 2022). Farmers in these areas face high pests-related pre- and post-harvest losses. Muthini (2015) estimated the post-harvest loss of mango in Makueni County to be about 30% of the total harvest.

From each of the two counties, one sub-county was purposively chosen, based on the number of mango growers, namely Mwala Sub-county in Machakos County and Kibwezi East Sub-county in Makueni County. At the Sub-county level, lists of mango farmers were generated: For Mwala Sub-county, the primary list (sampling frame) was obtained from a database of a previous study by ICIPE, on mango and citrus (Midingoyi *et al.*, 2019). The previous project had conducted a census of all mango and citrus growers up to the village level in the sub-county, with the help of front-line agriculture extension officers. For Kibwezi East Sub-county, the list of mango farmers was obtained from the agricultural officers in charge of the sub-county. From these lists, a total of 42 mango-growing households were randomly chosen from each of the sub-counties, making a total of 84 mango farmers. Due to missing data and the quality of responses, one observation was dropped, thus data from a sample of 83 farmers was utilized in the analysis.

For the traders, lists with mango traders' contacts were obtained from multiple sources, including farmers who provided lists of the traders who purchase mango from their farms; the Horticultural Crops Directorate offices (HCD) in Kibwezi; key informants (district agricultural officers); and references from mango traders. From the obtained lists, a sample of 40 traders was randomly sampled.

For both mango farmers' and traders' surveys, data collection was done using semi-structured questionnaires. Face-to-face interviews were conducted with farmers. Due to the diversity of traders in terms of location, interviews were conducted by telephone. Traders were contacted before the interview, and their consent was sought after explaining the details of the study. For those who consented to give an interview, appointments were arranged for the telephone interviews, based on convenience for traders.

Data analysis methods

Determining the Willingness to adopt and pay for the post-harvest disinfestation treatment technology

The Contingent valuation (CV) method is one of the methods used to calculate values for products or services in which there are no clear market prices, and where revealed preference approaches are not feasible (Asindu, 2019). The Contingent valuation method (also called the stated preference method) has its foundations in utility theory. An individual/unit investigated attaches monetary values to items or services. The value attached to this will depend on how utility is expected from an item or service (Carson and Haneman, 2005). This method was deemed suitable for this study because data on the use of the HWDT technology was not available, as the technology is not in use yet, and responses of the farmers would solely have to be based on perceived preference and expected utility to decide on willingness to pay for and adopt the technology. This approach has also been used by other studies to elicit willingness to adopt and pay for different technologies and services (Nyangau *et al.*, 2022).

To elicit information on the willingness to adopt and pay for the hot water disinfestation treatment technology from respondents, the open-ended format of eliciting responses was used (Carson and Haneman, 2005; Hoyos and Mariel, 2010; Ziolkowska and Peterson, 2017). Respondents were first asked about their awareness of the HWDT technology. Irrespective of the response, details of the hot water disinfestation treatment technology were explained to them. This involved describing the technology, its effectiveness, and potential benefits in terms of post-harvest loss reduction and access to previously inaccessible markets due to quarantine policies.

After a thorough explanation and discussion about the HWDT technology, farmers were allowed to ask questions and clarifications before being asked whether they would be willing to adopt such a technology for the treatment of their mangoes. The farmers who responded in the affirmative, were then asked whether they would be willing to pay for the use of the HWDT technology. Then those that were willing to pay, were asked to state the minimum and maximum amount of money they would be willing to pay for a kg of their mangoes to be processed using the technology once it is introduced.

Modeling determinants of farmers' willingness to adopt and pay for the HWT technology

It was assumed that a typical household maximizes the expected utility when choosing to adopt the HWDT technology and when choosing to pay for it. The expected utility maximization framework is assumed to represent investment and production decisions made under uncertainty (Kassie and Holden, 2006). However, the utility is not observed, and what is observed is the household's choice of technology. This is a dichotomous choice where a farmer either chooses to take up new technology or continues using the traditionally used methods and is normally analyzed by Binary choice models (Verbeek, 2003). The models describe the probability that technology will be adopted. The main methods that have been used in adoption studies include the logit, the tobit, and the probit (Greene*,* 2003).

The logistic regression model was used to determine the factors influencing willingness to adopt the HWDT technology and the factors influencing willingness to pay for the technology. Let U_i^* be an unobserved continuous variable, which is the expected utility of the individual farmers from the adoption of/payment for the HWDT technology. Instead of observing utility, we observe its dichotomous realization, the adoption/payment status, where $Y_i = 1$ if $U_i^* > 0$ and $Y_i = 0$ if $U_i^* \leq 0$. In the logistic regression, the outcome variable $Y_i (i = 1,2 \ldots n)$ follows a Bernoulli probability function that takes on the value 1 with probability π_1 and 0 with probability 1- π_1. Then π_1 varies over the observations as an inverse logistic function of a vector x_1, which includes a constant and k-1 explanatory variables (King and Zeng, 2001). Following King and Zeng (2001), Y Bernoulli ($Y_i l \pi_1$)

$$\pi_i = \frac{1}{1+e^{-X_i\beta}} \quad \text{(1)}$$

We then relate the true proportion p of adopters the HWDT technology to the value of a certain explanatory variable that explains adoption and non-adoption.

$$Y = \log it(p) = \ln \frac{p}{1-p} = \beta_0 + \beta_i \mathrm{x}_i + e \quad \text{(2)}$$

Where e is the variability not explained by the model, and X, are explanatory variables.

The parameters are estimated by maximum likelihood, with the likelihood function formed by assuming independence over the observations:

$L(\beta \mid Y) = \Pi_{i=1}^{n} \pi_i^{Y_i} (1-\pi_i)^{1-Y_i}$. If we take logs and use equation 1,

$$\ln \ \mathrm{L}(\beta|Y) = \sum_{\{Y_i=1\}} \ln(\pi_i) + \sum_{\{Y_i=0\}} \ln(1-\pi_i) = -\sum_{i=1}^{n} \ln(1+e^{(1-2Y_i)\mathrm{X}_i\beta}) \quad \text{(3)}$$

Maximum-likelihood logit analysis then works by finding the value of β that gives the maximum value of this function, which we label β.

Variables in the logistic regression model

The independent variables included in the logistic regression model include social, economic, and institutional factors. Analysis was done at the household level. The choice of variables was influenced by variables from related literature on the adoption of agricultural technologies (Ogada *et al.,* 2014;Acheampong, 2015; Turinawe *et al.,* 2015; Simtowe *et al.,* 2016; Mesele *et al.,* 2022; Oluwamayokun *et al.,* 2022). Specifically, the independent variables used in this study include: Age of the farmer (years), percentage of male mango farmers, education of the farmer (years in formal school), farmer's experience in farming (years), farmer's experience in mango production (years), household size, dependency ratio, membership to farmer group by the farmer, distance from home to the nearest all-weather road (Km), average of the total area (acres) owned, proportion of owned land under mango production, number of mango productive trees, whether farmer received training on mango production (yes/no), and percentage contribution of mango income to annual crop income.

The logistic regression model was run twice; first, the dependent variable *Y*, represented a dichotomous variable on whether the farmer was willing to adopt the HWT technology or not. Second, the dichotomous dependent variable was whether the farmer would be willing to pay for their mango to undergo the hot water treatment technology or not.

Profitability analysis of the mango production enterprises with and without the HWDT technology

Technology adoption efforts are correlated with perceived financial gains associated with technology use. For technologies to be successfully and sustainably adopted, the benefits on the part of adopters have to outweigh the costs of adoption and use of the technologies.

To estimate the potential effect of the introduction of the HWDT technology on profitability, we used the gross margin analysis method, and compared two scenarios. The first scenario is the estimation of the gross margins of the mango production enterprises, under the current production and trade conditions (using the collected data). The second scenario is the one where the HWT technology has been introduced and is in use. A major assumption in this second (adoption) scenario is that irrespective of whether the HWDT technology is adopted by farmers or traders, the benefits will trickle down to the farmers. To create the second scenario, the following assumptions were made, based on data collected from both farmers and traders (Table 1).

Gross Margin (GM) per unit is commonly defined as the difference between Gross Return (GR) and Total Variable Cost (TVC) (Kay and Edwards, 1994). Gross

Table 1. Assumptions used to create the scenario for the effects of the introduction of HWDT on farm-level profitability

Assumption	Explanation	Data source
Increase the market for mango	The reduced post-harvest losses and the ability of the traders to handle larger quantities of mango. Markets that were previously closed to trade due to the quarantine regulation are expected to be available, further fueling the demand for more mango	Traders: The additional quantity of mango traders are willing to purchase if the HWDT service is available to increase the shelf life of the mango
Higher scales of production for mango at the farm level	Due to increased demand farmers would be willing to allocate more of their land to mango production.	Farmers: Additional Amount of land the farmers are willing to allocate to mango production

We used these assumptions to estimate the potential profitability of the mango production enterprise for farmers after the HWDT technology has been introduced as compared to the scenario without the HWDT.

Return is calculated by multiplying yield by the price of the product, whereas Total Variable Cost is the summation of all variable costs involved in the production. The gross margin was calculated as:

$$GM = TR - TVC \quad (4)$$

Where: GM_i = Gross margin (KShs. Acre^{-1} year^{-1})
TR_i = Average total returns (KShs. Acre^{-1} year^{-1})
TVC_i = variable cost (KShs. Acre-1 year-1)

A positive (negative) gross margin indicates that the costs of production are less than (exceed) returns.

Results and discussion

Socio-economic characteristics of respondents

Table 2 presents a summary of the selected socio-economic characteristics of the entire sample. The majority of the interviewed farmers are small-scale, harvesting about 12 tons of mango per annum. Farmers owned 7 acres of land on average, with

Table 2. Socio-economic characteristics of respondents

Variables	Pooled sample (n=83)	Willingness to Adopt HWT sample (n=82)			Willingness to pay HWT sample (66)		
	Mean / %	No (n=14)	Yes (n=68)	t-test/ Chi2	No (n=7)	Yes (n=59)	t-test/Chi2
Age of the farmer (Years)	60.5 (12.95)	63.07 (8.92)	60.25 (13.61)	0.74	60.61 (14.29)	60.43 (6.63)	0.03
% of male mango farmers	78.31	78.57	77.94	0.00	9.80	90.20	0.15
Education of the farmer (years in formal school)	8.37 (4.62)	7.07 (4.36)	8.59 (4.67)	-1.12	8.14 (4.92)	8.54 (7.28)	-0.21
Farmer's experience in farming	29 (12.60)	34.29 (12.38)	28.04 (12.52)	1.70*	29.29 (8.36)	28 (13.16)	0.25
Farmer's experience in mango production (years)	15.06 (8.66)	17.79 (9.70)	14.44 (8.45)	1.32	18.71 (13.10)	14.03 (7.78)	1.39
Household size	4.90 (2.39)	4.71 (1.64)	4.90 (2.52)	-0.26	3.43 (1.90)	5.05 (2.56)	-1.62
Dependency ratio	0.38 (0.27)	0.34 (0.26)	0.39 (0.27)	-0.69	0.23 (0.24)	0.41 (0.28)	-1.66
Membership to farmer group by the farmer (1/0)	59.76 (n=82)	30.77	66.18	5.73*	11.0	89.0	0.08
Distance from home to the nearest all-weather road (Km)	0.59 (1.10)	0.14 (0.27)	0.70 (1.19)	-1.73*	0.49 (0.68)	0.74 (1.25)	-0.51
Average of the total area (Acres) owned	7.74 (7.72)	9.77 (10.56)	7.35 (7.09)	1.06	4.36 (2.29)	7.19 (6.16)	-1.20
Proportion of owned land under mango production	0.34 (0.25) (n=82)	0.29 (0.27)	0.35 (0.24)	-0.93	0.50 (0.24)	0.33 (0.238)	1.77*
Number of mango productive trees	111.31 (115.32) (n=81)	152.36 (113.61)	103.14 (115.48)	1.45	103.71 (117.28)	103.12 (117.30)	0.013

Table 2. Contd.

Variables	Pooled sample (n=83)	Willingness to Adopt HWT sample (n=82)			Willingness to pay HWT sample (66)		
	Mean / %	No (n=14)	Yes(n=68)	t-test/ Chi2	No (n=7)	Yes (n=59)	t-test/Chi2
Farmer received training on mango production (0/1)	53.16 (n=79)	30.77	56.92	2.97*	11.11	88.9	0.00
% of the contribution of mango income to annual crop income	41.77 (22.49)	45 (24.18)	41.43 (22.27)	0.54	51.43 (33.38)	40.29 (34.36)	1.24

Figures in parentheses are standard deviations. * indicate significance level at 10%. respectively

about 32% of that land allocated to mango production. The farmers have been engaged in mango production for an average of 15 years, and their farms are fairly established, with an average number of trees per farmer at 139. Eighty-one per cent of the mango trees owned were in a productive stage. Results suggest that farmers are increasing acreage under mango, with most of them having both productive and non-productive young trees.

About 73% of the traders interviewed were operating in Nairobi city. The rest were operating in the counties of Meru, Kiambu, Makueni, Mombasa, Machakos, and Tharaka in 11 sub-counties. Twenty-nine percent of the traders interviewed were exporters and 68% were wholesalers, with 26% doing both retail and wholesale (Table 3).

Potential adoption of the hot water disinfestation treatment for mango

Willingness to adopt the hot water disinfestation treatment technology

Seventy and 39% of farmers and traders, respectively, mentioned that they would adopt the technology as soon as it was available, while 12% and 18%, respectively, would adopt the HWDT technology at a later stage (Fig. 1). However, the proportion of those who would not adopt the technology was also quite high, especially for traders (42.1%). These results suggest that although initial adoption rates are promising, more work is needed to ensure higher adoption rates.

Table 3. Socio-Economic characteristics of mango traders

Characteristic	Mean (Percentage) (n=38)
Area of operation: Percentage operating in Nairobi	73.68
% of exporters (*vs* domestic traders)	28.95
% of wholesalers (*vs* retail traders)	68.42
% of those doing both retail and wholesale	26.32
Experience in trading agricultural produce (years)	15.22
Experience in trading mango (years)	14.37
Estimated percentage of exported mango (n=27)	30.2
% of income from mango trade (n=20)	54.76
% of traders whose sole source of income is mango trade	42.86

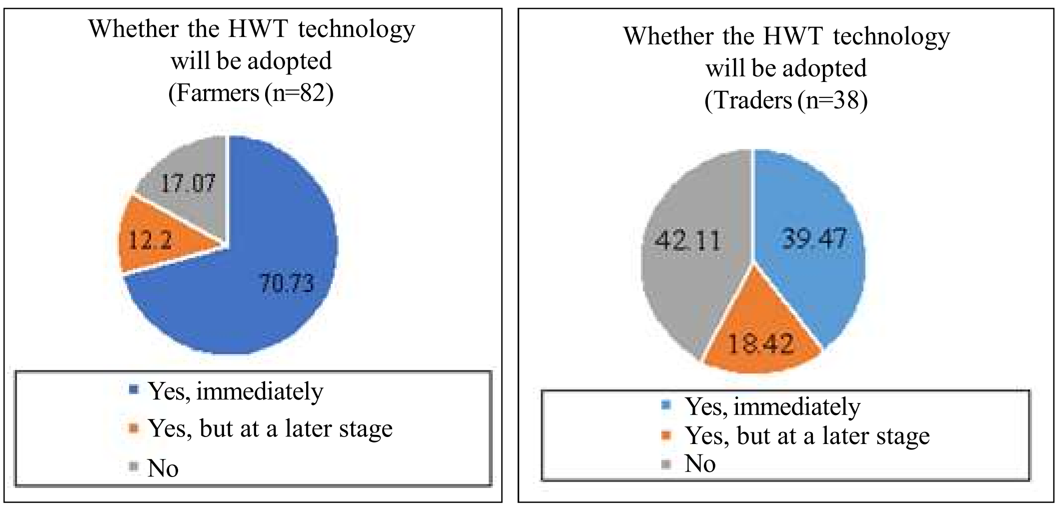

Figure 1. Adoption potential of hot water post-harvest disinfestation treatment technologies.

Willingness to pay for the hot water disinfestation treatment technology

For both traders and farmers, over 80%of those who were willing to adopt the technology were also willing to pay for it (Table 4). Over 68% of the traders were willing to handle larger quantities of produce if the market and higher shelf life are assured. Nearly 90% of the farmers reported willingness to pay to use the HW/DT technology, while slightly over 80% of the traders were willing to pay to use the technology (Table 4). Both traders and farmers are willing to pay an additional price of about 3KShs per Kg of mango to be treated. Compared to the improved varieties, both farmers and traders were willing to pay less (less than 0.4 KShs per Kg) for the use of the HWDT on local mango varieties. These results suggest that the adoption of the HWT for local mango varieties may not take off due to the low value and demand of the variety.

Table 4. Willingness to pay for produce to undergo HWT technology

	Farmers	Traders
% of respondents willing to pay to use the HWT technology (Farmers n=66; Traders, n=24)	89.4	83.3
Minimum price respondents are willing to pay Per Kg for improved variety (KSHS) (Farmers, n=51; Traders, n=18)	2.1	2.3
Maximum price respondents are willing to pay Per Kg for improved variety (KShs) (Farmers, n=50; Traders, n=18)	3.9	4.0
Minimum price respondents are willing to pay per Kg for local variety (KShs) (Farmers, n=29; Traders, n=17)	0.2	0.1
Maximum price respondents are willing to pay Per Kg for local variety (KShs) (Farmers, n=29; Traders, n=17)	0.5	0.1
% of respondents willing to allocate additional area/land to mango production immediately (n=57)	73.7	
% of respondents willing to allocate additional area/land to mango production at a later stage (n=57)	7.0	
Amount of additional land that can be allocated to mango production (acres) (n=48)	1.5	
% of respondents willing to increase traded quantities of mango (n=38)		68.4
Estimated percentage increase in quantity exported (n=28)		16.6
Estimated percentage increase in domestic quantities of mango traded (n=27)		18.3
% of respondents willing to purchase hot water treatment machinery for their own use at all costs (n=38)		7.9
% of respondents willing to purchase hot water treatment machinery for their own use depending on affordability costs (n=38)		44.7

Determinants of farmers' willingness to adopt and pay for the HWT technology
Results on factors that influence whether farmers would be willing to adopt the technology once it is introduced, or whether they would be willing to pay to use the technology are presented in Table 5. Results indicate that the age of the farmer and distance from home to the nearest all-weather road (Km) influence both the willingness to adopt (WTA) and willingness to pay (WTP) for the hot water treatment technology. For both WTA ($P<0.1$) and WTP ($P<0.01$), the age of the farmer negatively influences the decisions. However, the squared value of age has a positive influence on both

Table 5. Determinants of Farmers' willingness to adopt and pay for the HWT technology

Independent variables	Willingness to Adopt HWT Technology Coefficient (std. error)	Willingness to pay for HWT Technology Coefficient (std. Error)
Age of the farmer (years)	-0.785* (0.439)	-2.682***(1.04)
Age of the Farmer (squared)	0.006* (0.004)	0.022** (0.009)
The farmer is male (1/0)	-2.460**(1.247)	2.751(1.734)
Education (years in formal school)	0.264** (0.130)	0.020(0.200)
Experience in mango production (years)	-0.180 (0.21)	0.901** (0.369)
Experience in mango production (years) (squared)	0.003(0.005)	-0.023** (0.009)
Dependency ratio	0.196 (1.813)	-3.341(2.34)
Membership to farmer group (1/0)	2.063** (0.965)	-2.53(1.7)
Distance from home to the nearest all-weather road (Km)	2.526* (1.478)	0.924** (0.426)
Size of land (Acres) owned	-0.079** (0.040)	-
Proportion of land owned under mango cultivation	-	-6.176* (3.38)
Farmer received training on mango (0/1) production	0.393 (1.068)	2.049(1.504)
% of the contribution of mango income to annual crop income	-0.019 (0.023)	-0.043*(0.025)
Constant	26.379** (13.117)	79.080** (33.702)
Chi2	22.800	31.333***
Pseudo R^2	0.358	0.446
n	77	63

Figures in parentheses are standard errors. ***, ** and * indicate significance level at 1%, 5% and 10%, respectively

WTA ($P<0.1$) and WTP ($P<0.05$). These results suggest that younger farmers are neither likely to adopt nor be willing to pay for the HWT technology. However, the older the farmer, the more likely they are to adopt and pay for the technology. Results further indicate that farmers who are located far away from an all-weather road are both more likely to adopt ($P<0.1$) and pay ($P<0.05$) for the HWT technology. This finding is contrary to the findings of some adoption studies (e.g. Turinawe *et al.*, 2014), which commonly indicate that the farmers who adopt are normally those located near infrastructures such as roads and input and output markets. Farmers that are located far away from roads and markets, typically sell their produce at cheaper prices. Its is likely that those located far away consider the HWDT technology to be an opportunity to get better prices for their mangoes.

The likelihood of adopting the HWDT technology is significantly lower (P<0.05) when the farmer is male compared to when they are female. This finding is unexpected and counter intuitive. Studies (such as Barungi *et al.,* 2013) have found that adoption of agricultural technologies is more likely to take place with male farmers and male household heads, due to comparatively better access to resources that facilitate adoption such as labour and capital. Educated farmers are more likely to be willing to adopt hot water treatment technology than the less educated (P<0.05). Adoption is associated with the availability of knowledge, and the ability of the recipient to digest the knowledge and put it into use. Education, therefore, facilitates this process.

Relatedly, membership to a farmers' group was found to positively (P<0.05) influence the willingness to adopt the HWDT technology. Farmer groups are some of the key fora and quick pathways through which agricultural technologies can be disseminated. It is therefore expected that farmers who are organized in groups have faster access to agricultural technologies as well as the information necessary to encourage adoption. Earlier, Sidibe (2005) found that adoption of coil conservation technologies was more likely for farmers who were in groups.

The size of land owned is negatively associated with willingness to adopt the HWDT technology (P<0.05). The larger the size of land owned, the less likely a farmer is to adopt the technology. Land ownership is normally taken as a sign that farmer resources are required in agricultural investments, including technologies. Therefore, the negative sign on the size of land owned was unexpected.

Further, on the part of the willingness to pay for HWT Technology and influencing factors, results in Table 5 indicate that years of experience in mango production are positively associated with willingness to pay for the HWDT technology (P<0.05). Farmers with years of moderate experience in mango production are likely to be willing to pay for the technology. However, results indicate that as the years of experience increase, the influence of years of experience on willingness to pay for the technology turns negative (P<0.05). This means that farmers who have been doing mango production for a long time are not likely to be willing to pay for the technology, although experience is a key factor in willingness to pay for the technology.

Results further suggest that farmers having a big proportion of land covered by mango production are less likely to be willing to pay for the technology. This is related to the finding that farmers whose income is comprised of a high percentage coming from mango production are not likely to be willing to pay for this technology. In this context, it is possible that the new technology is seen as a source of risk for the farmers, yet the stakes are high for their livelihoods as they largely depend on mango production.

Profitability of mango production and Potential profitability after the introduction of the hot water Disinfestation Treatment technology

Gross margins analysis results for the mango farmers are presented in Table 6. In addition, results based on the approximation of potential profits for farmers after the introduction of the hot water treatment technology are presented in the same table. Estimated results of the potential profitability were based on adjustment of the following variables: 1) Gross production per year was estimated by increasing production using the percentage by which farmers are willing to increase land under mango; 2) Mango production per acre was estimated by dividing the quantity generated in 1) with the total new acreage. Total new acreage was generated as the sum of the land size under mango by the time of the study, plus the additional land size which farmers were willing to allocate to mango production. 3) The same price for mango as elicited from the farmers was used since it was assumed that the purchase price for mango would not change. 4) Production costs included all the costs involved in maintaining and producing mango including all agrochemicals and labor. The simulated gross margins after adoption, also included costs required to establish a mango plantation on the additional acreage that farmers were willing to establish mango on.

Generally, the results indicate that the mango production business is profitable for the farmers. A farmer can get 81,982.57 KShs per acre per year. However, the data from the farm shows that the majority (44.7%) of the farmers are operating mango production at a small scale of less than an acre. This can be seen from the gross margins that are elicited based on actual production, where they are seen to be lower than those of one acre. Comparatively, results indicate higher margins for the simulated case of potential profitability for the mango farmers after the introduction of the HWDT technology: Farmers would get positive margins after the introduction of the technology. Irrespective of whether it is the farmers or traders who use the HWDT technology, farmers benefit through increased production and sales as a result of increased demand from traders. It's also important to note that the margins based on total acreage for the post-HWDT technology introduction case are higher than the estimated margins based on actual production. This is an indicator that mango farmers could increase their gross margins further, by increasing their scale of production. With the seemingly potential increase in demand, this is a plausible possibility for farmers. It is also important to note that in both cases the gross margins reported are a possibly lower estimate of the actual scenario because of farmers in the sample who have negative margins. Potentially the profits of the farmers could be higher than the presented figures if all farmers operate above break-even levels.

Table 6. Comparative gross margins for two scenarios: Current mango production, and post-HWT technology introduction

Net investment requirement (Outflows)	Current mango production (BAU) (n=82)	After the introduction of the HWT technology (n=48)
Production (Kgs)		
Gross production (Kg) per year	12,329.52 (33,820.28)	102,225.4 (593,583.2)
Mango production per acre (Kg) per year	23,879.3 (147,171.3)	(35,029.98) (19,0418.4)
Price (Kshs)		
Price per unit (Kg)	2.812 (2.088)	2.812 (2.088)
Revenues (Kshs)		
Total revenue based on total harvest/ year	45,969.09 (139,930.3)	487,374.6 (301,1642)
Total revenue per acre/year	100450.3 (743160.1)	498,068.8 (3,029,691)
Costs related variables (Kshs)		
Total costs of production incurred/farmer	34,073.37 (66,877.87)	66,138.42 (111581.2)
Average costs of production/acre	18,335.5 (22,675.66)	21,608.63 (27492.72)
Costs of establishment on additional land	-	34,288.96 (53,751.99)
Cost of establishing mango on the additional land/acre	-	27785.96 (26367.35)
Gross margins (Kshs)		
Gross Margin for total production	11,895.72 (146,122.6)	397,641.4 (2,968,260)
Gross margin/acre	81,982.57 (730,468.5)	116,588.4 (956,327)

Conclusion

Mango production is a profitable venture for farmers, and profits are potentially higher at bigger scales of production. However, this will only be possible if there is a ready market for the produce. The hot water disinfestation treatment technology can facilitate access to such markets by allowing access to previously inaccessible markets due to quarantine restrictions. HWDT technology facilitates the treatment of fruits to the required standards.

It is clear from the results that farmers are willing to adopt the HWDT technology and there is willingness to pay by a majority. However, given that the number of those who are willing to adopt is slightly higher than that of those willing to pay, this implies that cost implications for using the technology may affect the adoption rate.

There are several factors to take into account as the technology is rolled out. These factors would facilitate the fast diffusion of the technology and thus the spread of its positive effects. These include taking into account the role of groups in the dissemination of the technologies, as well as the differences in socio-economic characteristics, notably, gender, education, experience, and scale of operation.

It is noted that there are inherent limitations that come with the use of small samples, particularly in a quantitative analysis such as this one. While our findings provide very valuable insights, a small sample size may not fully capture the complexity and variability within the population of interest. The results should therefore be interpreted with this in mind, as they may lightly under- or over-estimate the variables of interest.

Acknowledgements

The authors gratefully acknowledge the financial support for this research by the following organizations and agencies: the Bioinnovate Africa Programme (BA-C1-2017-06_*icipe*.); Germany Agency For International Cooperation (GIZ) (Grant Number Grant number/agreement number: 1206), Government of Kenya (GoK) and European Union (EU) (Grant Number Grant number/agreement number: 1161); the Swedish International Development Cooperation Agency (Sida); the Swiss Agency for Development and Cooperation (SDC); the Australian Centre for International Agricultural Research (ACIAR); the Norwegian Agency for Development Cooperation (Norad); the German Federal Ministry for Economic Cooperation and Development (BMZ); and the Government of the Republic of Kenya. The views expressed herein do not necessarily reflect the official opinion of the donors.

References

Acheampong, P. P. 2015. Economic Analysis of farmers' preferences for cassava variety traits: Implications for breeding and technology adoption in Ghana . Thesis., Kwame Nkrumah University of Science and Technology, Ghana. DOI: 10.13140/RG.2.1.4382.5366

Affognon, H., Mutungi, C., Sanginga, P. and Borgemeistera, C. A. 2015. Unpacking postharvest losses in Sub-Saharan Africa: A Meta-Analysis. World Development, 66, pp. 49–68, 2015 http://dx.doi.org/10.1016/j.worlddev.2014.08.002

Asindu, M. 2019. Demand and acceptability of sweetpotato silage based diet as pig feed by smallholder pig farmers in Uganda: A case of Kamuli and Masaka districts. MSc. Makerere University, Uganda.

Barungi, M., Ng'ong'ola, D. H. Edriss, A., Mugisha, J., Waithaka, M. and Tukahirwa, J. 2013. Factors influencing the adoption of soil erosion control technologies by farmers along the slopes of Mt. Elgon in Eastern Uganda. *Journal of Sustainable Development* 6(2). doi:10.5539/jsd.v6n2p9.

Carson, R.T. and Hanemann, W. M. 2005. Contingent valuation. K.-G. Mäler and J.R. Vincent (eds.) Handbook of Environmental Economics, Vol 2. DOI: 10.1016/S1574-0099(05)02017-6

Ekesi, S., De Meyer, M., Samira, A. M., Virgilio, M., and Borgemeister, C. 2016. Taxonomy, ecology, and management of native and exotic fruit fly species in Africa. *Annual Review of Entomology* 61:219-238. https://doi.org/10.1146/annurev-ento-010715-023603

Greene, W.H. 2003. Econometric Analysis. 5th Edition. Prentice Hall, Pearson Education, Inc., Upper Saddle River, New Jersey, 07458

Kenya Horticultural Crop S Directorate. 2015. Agriculture and Food Authority-Validated Report 2015-2016

Horticultural Crops Directorate and AFA (Agriculture and Food Authority). 2017. Horticulture. Validated data report 2016-2017.

Hoyos, D. and Mariel, P. 2010. Contingent valuation: Past, present and future. Prague Economic Papers, (4):329-343. DOI: 10.18267/j.pep.380

Kassie, M. and Holden, S. T. 2006. Parametric and non-parametric estimation of soil conservation impact on productivity in the northwestern Ethiopian highlands. Contributed paper presented at the international Association of Agricultural Economists Conference, Gold Coast, Australia. August 12-18, 2006.

Kay, R. D. and Edwards, W. M. 1994. *Farm Management*, 3rd edition. McGraw-Hill, Inc., New York.

King, G. and Zeng, L. 2001. Logistic regression in rare events data. *Society for Political Methodology*. Pp. 137-164. *https://gking.harvard.edu/files/0s.pdf*

Lutomia, C. K., Obare, G. A., Kariuki, I. M. and Muricho, G. S. 2019. Determinants of gender differences in household food security perceptions in the Western and Eastern regions of Kenya. *Cogent food & Agriculture* 5(1):1694755.

Match Maker Associates. 2017. Horticulture study Phase 1: Mapping of production of fruits and Vegetables in Kenya. Final report. Study commissioned by the Embassy of the Kingdom of the Netherlands.

Mesele, B. Z., Fikire, A. H. and Meshesha G. B. 2022. Determinants of multiple agricultural technology adoption: evidence from rural Amhara region, Ethiopia, Cogent Economics & Finance, 10(1):2058189, DOI:10.1080/23322039.2022.2058189

Midingoyi, S.G., Kassie, M., Muriithi, B., Diiro, G. and Ekesi, S. 2018. Do farmers and the environment benefit from adopting integrated pest management practices? Evidence from Kenya. *Journal of Agricultural Economics* 70 (2):452–470. doi: 10.1111/1477-9552.12306Ó2018

Muriithi, B. W., Affognon, H. D., Diiro, G. M., Kingoria, S. W., Tanga, C. M., Nderitu, P. W., Samira, A. M. and Ekesi, S. 2016. Impact assessment of Integrated Pest Management (IPM) strategy for suppression of mango-infesting fruit flies in Kenya. *Crop Protection* 81:20-29. https://doi.org/10.1016/j.cropro.2015.11.014

Mwando, N. L., Ndlela, S., Meyhöfer, R., Subramanian, S. and Mohamed, S. A. 2021. Hot water treatment for post-harvest disinfestation of Bactrocera dorsalis (Diptera: Tephritidae) and its effect on cv. tommy atkins mango. *Insects* 12(12): 1070.

Muthini, N. D. 2015. An assessment of mango farmers' choice of marketing channels in Makueni, Kenya. Master Thesis, University of Nairobi, Kenya (No. 634-2016-41489).

Ndaka, D., Macharia, I., Mutungi, C., and Affognon, H. 2012. Postharvest losses in Africa–Analytical review and synthesis: the case of Kenya. International Center for Insect Physiology and Ecology, Nairobi, Kenya.

Ndlela, S., Mwando, N. L., Samira, A. and Mohamed, S. A. 2021. Advances in postharvest disinfestation of fruits and vegetables using hot water treatment technology–updates from Africa. Postharvest Technology–Recent Advances, New Perspectives and Applications.

Nyangau, P., Muriithi, B., Diiro, G. Diiro, , Akutse, K.S. and Subramanian, S. 2022. Farmers' knowledge and management practices of cereal, legume and vegetable insect pests, and willingness to pay for biopesticides. *International Journal of Pest Management* 68:204-216. doi: 10.1080/09670874.2020.1817621

Ocitti, P., Ndlela, S., Akol, A. M., Muyinza, H. and Mohamed, S. A. 2021. Non-chemical post-harvest disinfestation of Bactrocera dorsalis (Hendel)(Diptera: Tephritidae) in Tommy Atkins mango using hot-water immersion treatment. *African Entomology* 29 (1):238-247.

Ogada, M.J., Mwabu, G. and Muchai, D. 2014. Farm technology adoption in Kenya: a simultaneous estimation of inorganic fertilizer and improved maize variety adoption decisions. Agric Econ 2, (12). https://doi.org/10.1186/s40100-014-0012-3

Oluwamayokun, A. F., Ariyawardana, A. and Ammar, A. A. 2022. Factors influencing technology adoption among smallholder farmers: a systematic review in Africa. *Journal of Agriculture and Rural Development in the Tropics and Subtropics* 123(1):13-30. DOI: 10.17170/kobra-202201195569.

Onyimbo, S. W., Ayuya, O. I., and Macharia, A. M. 2022. Determinization of the duration that farmers take to adopt integrated pest management strategy for suppression of mango fruit flies in Kenya. Rigorous Journal of Agricultural Sciences, 1(1), 26-33.

Ridolfi, C., Hoffmann, V. and Baral, S. 2018. Post-harvest losses in fruits and vegetables: The Kenyan context. International Food Policy Research Institute (IFPRI). http://ebrary.ifpri.org/cdm/ref/collection/p15738coll2/id/132325)

Sidibe, A. 2005. Farm-level adoption of soil and water conservation techniques in northern Burkina Faso. *Agricultural Water Management* 71: 211–224.

Simtowe, F., Asfaw, S. and Abate, T. 2016. Determinants of agricultural technology adoption under partial population awareness: the case of pigeonpea in Malawi. Agric Econ 4, (7). https://doi.org/10.1186/s40100-016-0051-z

Turinawe, A., Mugisha, J. and Drake, L. 2015. Soil and water conservation agriculture in subsistence systems: Determinants of adoption in South-western Uganda. *Journal of Soil and Water Conservation* 70(2):133-142. Doi: 10.2489/jswc.70.2.133

Turinawe, A., Drake, L. and Mugisha, J. 2014. Adoption intensity of soil and water conservation technologies: a case of Southwestern Uganda. *Environment, Development and Sustainability* DOI 10.1007/s10668-014-9570-5

Verbeek, M. 2003. A Guide to Modern Econometrics. John Wiley & Sons Ltd, England.

Ziolkowska, J. R. and Peterson, J.M. 2017. Competition for water resources: Experiences and management approaches in the US and Europe. Elsevier. Radarweg 29, PO Box 211, 1000 AE Amsterdam, Netherlands; The Boulevard, Langford Lane, Kidlington, Oxford OX5 1GB, United Kingdom; 50 Hampshire Street, 5th Floor, Cambridge, MA 02139, United States. ISBN 978-0-12-803237-4 https://doi.org/10.1016/C2014-0-03820-8