Journal of Agriculture and Rural Development in the Tropics and Subtropics
Vol. 121 No. 2 (2020) 219–231

https://doi.org/10.17170/kobra-202010191970 ISSN: 2363-6033 (online); 1612-9830 (print) – website: www.jarts.info

Are there gender differences in access to and demand for East Coast fever vaccine? Empirical evidence from rural smallholder dairy farmers in Kenya

Humphrey Jumba [a,b,*], Henry Kiara [a], George Owuor [b], Nils Teufel [a]

[a] *International Livestock Research Institute (ILRI), Nairobi, Kenya*
[b] *Egerton University, Department of Agricultural Economics and Agribusiness Management, Kenya*

Abstract

Women lag in the adoption of agricultural innovations compared to men, mainly due to gender inequalities in access to complementary inputs, capital, and knowledge/information. The Infection-and-Treatment-Method (ITM) is considered a safe and effective method of controlling East Coast fever. However, since its commercialisation in Kenya differences in demand for this vaccine among smallholder men and women dairy cattle keepers have not been assessed. Using a sample of 448 respondents, we used an Average-Treatment-Effect framework to estimate ITM adoption rates under awareness constraints and the determinants of adoption among smallholder male-headed (MHHs) and female-headed (FHHs) households. We found some difference in ITM awareness between MHHs (57 per cent) and FHHs (46 per cent). However, gender adoption gaps in the actual and potential adoption rates were considerable, with actual adoption rates of 41 per cent and potential adoption rate of 62 per cent among MHHs, compared to 19 per cent actual and 31 per cent potential adoption for FHHs. The smaller adoption gap for FHHs indicates that only increasing awareness amongst FHHs will not reduce inequities. ITM adoption in both household headships was mainly determined by education, extension interventions, access to financial services, and social capital. In addition to this, ITM adoption in FHHs was positively influenced by age, land-size, and group membership. To realise adoption beyond the current potential and to reduce inequities at the scale-up stage, gender-specific interventions targeting resource-poor women cattle keepers would be effective, in addition to ensuring that women have access to extension and financial services.

Keywords: Gender, East Coast fever, infection and treatment method, adoption, awareness, Kenya

1 Introduction

Low cattle productivity remains a major cause of poverty and food insecurity in Africa, particularly for the resource-constrained smallholder rural poor farmers who depend on livestock as the primary source of livelihood and of which a large proportion are women. In sub-Saharan Africa (SSA), cattle production is constrained by tick-borne-diseases (TBDs), with East Coast fever (ECF) being of great economic significance in Eastern and Southern Africa (Gachohi *et al.*, 2011). ECF causes high levels of cattle mortality and morbidity, and its control results in high costs due to frequent dipping or spraying of animals with acaricides to rid them of ticks and for treating sick animals. The effects of ECF are especially damaging among resource-constrained smallholder cattle keepers (Minjauw & McLeod, 2003). According to recent estimates, nearly 60 per cent (about 75 million) cattle in the Eastern and Southern Africa are at high risk of contracting ECF, with mortality rates in untreated immature animals under pastoral systems estimated to be more than 80 per cent (Di Giulio *et al.*, 2003).

The Infection-and-Treatment-Method (ITM) developed by a group of international agricultural research institutes based at the East African Veterinary Research Organisation, Muguga is considered a safe and effective approach towards ECF control among smallholder cattle keepers (Radley *et al.*, 1975; Patel *et al.*, 2016). The use of the ITM vaccine has shown positive results among vaccinated immature cattle in pastoral systems where it led to a reduction in the

* Corresponding author – H.Jumba@cgiar.org

Published online: 3 November 2020 – Received: 1 April 2019 – Accepted: 21 August 2020

cattle death rate due to ECF from over 20 per cent to less than 2 per cent (Homewood *et al.*, 2006). In addition, ECF vaccination has helped smallholder farmers to save on time and costs incurred in vector control, enabling them to diversify their income base (Homewood *et al.*, 2006; Jumba *et al.*, 2020). Various studies indicate that increased income in households adopting ITM vaccine has improved several livelihood indicators, as shown in increases in investment in farm enterprises, educating children of both genders and having enough milk for domestic consumption (Homewood *et al.*, 2006; Marsh *et al.*, 2016; Jumba *et al.*, 2020).

Since commercialisation and subsequent dissemination of the ITM vaccine in Kenya in 2012, differences in adoption patterns among men and women cattle keepers have remained unclear. Yet such insights would be important for an effective up-scaling plan, as shown below, especially as around 30 per cent of rural households in Kenya are headed by women (United Nations, 2017). Previous research efforts have mainly focused on the production of the ITM vaccine and its efficacy (Mbassa *et al.*, 1998; Maloo *et al.*, 2001; Patel *et al.*, 2016; Perry, 2016; Patel *et al.*, 2019, to name a few). Although a few studies have investigated adoption and impact determinants of the ITM vaccine (Homewood *et al.*, 2006; Karanja-Lumumba *et al.*, 2015; Marsh *et al.*, 2016), these studies have not considered household gender characteristics, hence failing to address the gender dynamics surrounding the adoption of the vaccine.

Considering a household as a genderless unit of analysis does not provide enough information to understand and better promote the adoption of the ITM vaccine. Although an earlier study highlighted major obstacles to ITM vaccine adoption among men and women smallholder cattle keepers (Jumba *et al.*, 2020), it did not provide empirical evidence of how the influence of various social, cultural, and institutional factors on ITM's adoption differs between genders. Therefore, using survey data from rural Kenya, this study aims to address the following research questions:

1. How big are the differences in ITM vaccine awareness and adoption between smallholder dairy farming households headed by men and by women?

2. What are the factors contributing to these differences?

An improved understanding of gender-disaggregated barriers to ITM awareness and adoption will guide policymakers and researchers in designing effective strategies for disseminating and further scaling the ITM vaccine among smallholder cattle keepers.

2 Materials and methods

2.1 Study area, data, and sampling

This study was conducted in Uasin Gishu County in Kenya (Figure 1) in June 2016, four years after the commercialization and dissemination of the ITM vaccine in Kenya. Uasin Gishu has a high concentration of intensified dairy production (Kibiego *et al.* 2015) and has been the site for various support activities and studies regarding the diffusion and adoption of dairy-related technologies, including the ITM vaccine (Rademaker *et al.*, 2016; Shelburne *et al.*, 2017). While different roles of men and women in dairy production have been highlighted, with men assuming a stronger role in animal health management (Wafula, 2014; Tavenner *et al.*, 2018), this has not been extended to an analysis of how this affects the adoption of animal health innovations.

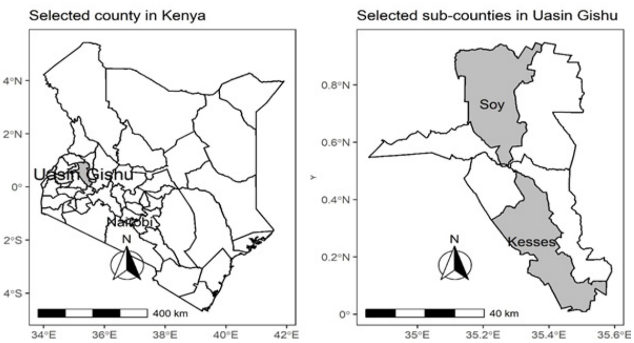

Fig. 1: *Map of the study area.*
Source: *Created by authors based on GADM v3.6*

The study focused on farmers who had vaccinated at least part of their cattle stock against ECF (adopters) and those who were yet to vaccinate (non-adopters). The primary farming system is mixed crop-livestock smallholder farming, where keeping cattle is integrated with crop production. Farmers use intensive or semi-intensive systems and keep improved cattle breeds for milk production.

We used a multi-stage sampling method to select potential respondents. The first stage involved a purposive selection of Soy and Kesses sub-counties, where farmers primarily depend on cattle for their livelihood. In the second stage, veterinary officers from the Kenya Dairy Farmers Federation and county government agricultural extension officers helped in undertaking a census of all dairy cattle keepers in the two sub-counties. This resulted in a list of 2,750 cattle keepers, with an emphasis on active members of milk cooling plant co-operatives in the area, who had an active interest in dairy development. A total of 298 respondents were randomly selected from the male-headed households (MHHs) in the list, while all 150 female-headed households (FHHs) were included. This resulted in a total sample of 448 households. We made phone calls in advance to book for the interview schedule with the respective farmers; this helped to improve the response rate.

We used a team of trained enumerators who fluently spoke the local language (Kalenjin) to collect data using a pretested structured questionnaire. The survey referred to the two agricultural production seasons during 2015/2016 and focused on household socio-economic characteristics, farm characteristics and institutional aspects, and the respondent's knowledge/awareness of the ITM vaccine.

2.2 Gender and the adoption of agricultural innovations

Evidence from previous studies shows that despite the critical role of agricultural innovations in improving the welfare of smallholder farmers, women lag in adoption compared to men (Doss & Morris, 2001; Phiri *et al*., 2004; Peterman *et al*., 2010). In fact, men dominate all three critical stages of adopting agricultural innovations: awareness, tryout, and continuous adoption (Theis *et al*., 2018). This has been attributed to several different factors. Amongst these, inadequate awareness or knowledge among women farmers regarding agricultural innovations, poor infrastructure and constrained access to complementary inputs and resources have been mentioned most frequently (Doss & Morris, 2001; Njuki *et al*., 2014; Galiè *et al*., 2015; Theis *et al*., 2018). These are presented in greater detail in the following.

The level of knowledge regarding agricultural technology generally enhances the acceptance, initial adoption, and the extent of adoption. Targeted farmers who are aware of farming innovations are in a better position to gather additional information concerning technologies' attributes, an act that guides them in deciding on whether to uptake it or not (Diagne & Demont, 2007; Simtowe *et al*., 2016; Theis *et al*., 2018; Simtowe *et al*., 2019). Gender differences in knowledge levels are often attributed to differing literacy levels among men and women, where in most cases, women are less educated than men (Doss & Morris, 2001; Quisumbing & Pandolfelli, 2010). Several adoption studies attribute this effect to the limited capability of less-educated household decision-makers in interpreting the information presented to them during training or available from visual and print media platforms (Deere & Doss, 2006; Wanyama *et al*., 2013). In addition, cultural barriers, especially in more remote rural African settings, may restrict women from accessing extension services or attending training programs regarding farming innovations promoted to improve their livelihoods (Quisumbing & Pandolfelli, 2010; Ragasa, 2012).

Active participation in social group activities has been documented to assist both men and women in acquiring knowledge from extension service providers and in sharing information among themselves (Galiè *et al*., 2017). In some cases, social groups can also assist in overcoming resource constraints when it comes to paying for agricultural innovations, especially for women who are constrained in controlling household resources. Through groups, women can mobilize agricultural resources among themselves and pay for agricultural innovations, thus overcoming restricting social inequities based on cultural and social norms (Doss *et al*., 2003; Meinzen-Dick *et al*., 2011). Poor infrastructure contributes negatively to the adoption of agricultural technologies, as it might hinder access to extension services or required inputs (Mutua *et al*., 2019; Waithanji *et al*., 2019; Jumba *et al*., 2020). This situation might be more limiting for women who are unable to travel far, as they are constrained by domestic chores and cultural barriers curtailing their movement (Quisumbing & Pandolfelli, 2010).

Finally, access to both physical and financial assets is considered vital by various adoption studies, as farmers use them to pay for the innovation expenses (Doss *et al*., 2008). However, a lack of appropriate institutions and policies limits the access of women farmers to credit and other government support, especially as most household resources eligible to be used as collateral are within the men's domain of control (Quisumbing & Pandolfelli, 2010; Njuki *et al*., 2014). Hence, when it comes to experimenting with or adopting agricultural technologies that require payments or productive resources, men often have an advantage.

2.3 Analytical framework

This study is guided by the Average-Treatment-Effect (ATE) approach (Diagne, 2006; Diagne & Demont, 2007) to determine actual and potential adoption for the ITM vaccine among MHHs and FHHs. The ATE estimation framework helps to control for biases that might result from a non-random distribution of information and self-selection by farmers into training activities (Diagne & Demont, 2007; Simtowe *et al*., 2019). This makes it relevant for this study because not all cattle keepers have been made aware of the ITM vaccine since its commercialisation and dissemination in Kenya, and it is not clear whether the aware farmers are otherwise similar to those not aware of the ITM vaccine. Classical approaches generally investigate the adoption of agricultural innovations with little or no consideration of awareness constraints and self-selection problems (e.g., Probit, Logit, Tobit, and two-stage selection models, among many more). The usefulness of the ATE framework has been demonstrated by a number of agricultural innovation adoption studies (Diagne & Demont, 2007; Dandedjrohoun *et al.*, 2012; Kabunga *et al.*, 2012; Simtowe *et al.*, 2019, 2016).

Outlining the theoretical structure of the ATE framework, we assume that y_1 is the potential adoption outcome for an individual when aware (w_1) of the ITM vaccine, while y_0 it is the adoption outcome otherwise (w_0). Therefore, the treatment effect for an individual $_i$ is the difference in y_{i1} and y_{i0}. This can be estimated at the population level by determining the mean difference ($E(y_1 - y_0)$)), which is commonly referred to as population adoption rate, and corresponds to the Average-Treatment-Effect (ATE) familiar from impact assessment studies (Wooldridge, 2002). However, since technology awareness is a necessary pre-condition for adoption to take place (Simtowe *et al.*, 2016, 2019; Theis *et al.*, 2018), then $y_0 = 0$ for those individuals who are not aware of the ITM vaccine. Therefore, individual $_i$ possible adoption outcomes can be expressed as y_{i1}, and Ey_1 for population adoption outcome.

Considering the sub-sample that is aware of the ITM vaccine, the sub-population mean adoption outcome is given based on the awareness condition, such that (Ey_1/w_1), which corresponds to the ATE on the treated (ATE_1). For the non-aware sub-sample, the mean sub-population adoption outcome is expressed as Ey_0/w_0, which represents the ATE on the untreated (ATE_0). Noting that $y_0 = 0$, the two expressions can be reduced to $y = w_1 y_1$, suggesting that the ITM vaccine actual/observed adoption outcome is determined condition to its awareness, commonly referred to as the joint awareness and adoption parameter (JEA) (Diagne, 2006; Diagne & Demont, 2007).

According to the ATE framework, ATE measures the potential population adoption outcome while the JEA measures the actual observed adoption outcome of the given population (Diagne, 2006; Diagne & Demont, 2007; Simtowe *et al.*, 2016). In addition, the ATE framework enables the computation of the adoption gap (GAP), which is the difference between ATE and JEA ($GAP = E(y) - E(y_1)$). The adoption GAP helps to estimate the untapped ITM vaccine adoption potential due to awareness constraints.

We computed the ATE parameters using a parametric estimation procedure (see Diagne & Demont, 2007), which was informed by the Conditional Independence (CI) assumptions (Imbens & Wooldridge, 2009). The ITM vaccine adoption rates were computed using vectors of observable covariates from a random sample of the targeted population, as specified in equation 1 below.

$$(y_i, w_i, x_i, z_i) \;\; i = 1, 2, ...n \tag{1}$$

Where: y_1 = the potential ITM vaccine adoption outcome; w_1 = the condition for ITM vaccine awareness; x_1 = the vector of observable covariates which determines the likelihood of potential adoption of ITM vaccine, and z_1 = the vector of covariate which determine awareness of ITM vaccine. We estimated ATE across the pooled sample (both aware and non-aware population), while ATE_1 and ATE_0 were estimated for aware and non-aware sub-population, respectively, as shown in equations 2, 3, and 4.

$$A\hat{T}E = \frac{1}{n}\sum_{i=1}^{n} g(x_i\hat{\beta}) \tag{2}$$

$$A\hat{T}E_1 = \frac{1}{n_e}\sum_{i=1}^{n} w_i g(x_i\hat{\beta}) \tag{3}$$

$$A\hat{T}E_0 = \frac{1}{n - n_e}\sum_{i=1}^{n}(1 - w_i) g(x_i\hat{\beta}) \tag{4}$$

Where n = the total sample size, n_e = the treated sample, g = a function of covariates, x = observable covariates, w = ITM vaccine awareness condition, and β = coefficient, which were estimated using Maximum Likelihood Estimation. We further estimated a probit model to determine the factors influencing joint awareness and the adoption of the ITM vaccine when the awareness constraint is controlled.

3 Results

3.1 Descriptive statistics

Table 1 presents summary statistics of the variables of interest. Out of the surveyed households, 67 per cent were MHHs, while 33 per cent were FHHs. With respect to ITM vaccine adoption, 41 per cent of the respondents in MHHs were ITM adopters, while among FHHs, 19 per cent had adopted ITM. In both household headships, adopters of ITM vaccine had a significantly higher level of formal education and larger households than non-adopters. The latter would suggest a higher active family labour force among ITM adopters compared to non-adopters.

Regarding the age of the household head, there was a statistically significant difference between ITM adopters compared to non-adopters. In MHHs, ITM adopters were younger (average age of 44 years) than non-adopters (average age of 46 years), while in FHHs adopters were older (average age of 48years) compared to non-adopters (average age of 45 years). There was a significant difference regarding the primary income source of household heads, with 66 per cent and 80 per cent of ITM adopters in MHHs and FHHs, respectively, considering farming as their primary source

Table 1: *Descriptive statistics of variables used in econometric analysis.*

	MHHs				FHHs			
variables	*Non-Adopter (n=175)*	*Adopter (n=123)*	*Z-test*	*Chi² test*	*Non-Adopter (n=121)*	*Adopter (n=29)*	*Z-test*	*Chi² test*
Household demographics								
Age of the household head (years)	46.44	43.58	3.10**		44.93	48.17	-2.72**	
Education level (schooling years)	10.15	12.05	-5.94***		9.64	11.26	-3.50**	
Household size (adult equivalent)	4.10	4.38	-1.85*		3.75	4.66	-3.84**	
Primary occupation of household head (1=farming; 0=off-farm)	52.57	65.85		5.23 **	36.67	80.00		3.03**
Household wealth and farm characteristics								
Cattle herd size (TLU)	4.46	7.06	-2.65**		3.13	5.13	-3.57**	
Land size (hectares)	1.36	1.50	-1.57		1.12	1.55	-4.14**	
Primary cattle feeding system (1=zero-grazing; 0=open grazing or mixed feeding)	41.14	47.97		1.37	9.92	10.34		0.01
Cattle breed kept (1=exotic; 0=local)	95.43	98.37		8.65	96.55	98.35		0.38
Primary vector control method (1=private spraying; 0=communal dipping/spraying)	42.39	56.14		35.82**	39.32	58.79		21.22***
Access to services								
Access to extension services (1=yes)	38.29	98.37		4.41***	21.49	79.31		6.08***
Access to drinking water (walking distance in minutes)	2.67	3.01	-1.51		3.06	3.00	0.11	
Social-group membership (1=yes)	66.86	85.37		13.02***	47.93	93.10		19.44***
Credit access (1=yes)	43.39	73.98		27.37***	34.71	65.52		9.20***

Male-headed (MHHs) and female headed (FHHs) households.
*, **, *** = significant at 10 per cent, 5 per cent and 1 per cent level, respectively.
The adult labour equivalent was calculated based on OECD scale. TLU: Tropical Livestock Units
The results for categorical variables are given in proportions (percentages) with reference to the sample size (n).

of income. This result differed to those of non-adopters who primarily engaged in off-farm income-generating activities. In terms of resource endowments, the results demonstrate significant differences between ITM adopters and non-adopters. In both household headships, adopters had larger herds, as measured in Tropical Livestock Units (TLU), compared to non-adopters. The average herd size in MHHs was 7 TLU for adopters and 4 TLU for the non-adopters, while for FHHs; the average herd size for adopters was 5 TLU and 3 TLU for non-adopters. The difference in the size of land under farming was significant only in FHHs, as the adopters had an average land size of 1.55 hectares compared to 1.12 hectares for the non-adopters.

In both household headships, no significant difference between ITM adopters and non-adopters could be detected in the number cattle of exotic breeds, which could be explained by the generally high population of improved cattle in the region, kept for intensified milk production. Private spraying was the primary method of vector control among ITM adopters compared to non-adopters, who mostly used communal dipping/spraying facilities. This is a sign of higher wealth among adopters compared to non-adopters, as they were able to purchase spraying facilities and acaricides, an act that might be too expensive for many smallholder farmers.

Regarding cattle feeding systems, zero-grazing was the main practice of adopters, while the primary methods of cattle feeding among non-adopters were open grazing and mixed feeding. This surprising given that animals raised in open grazing systems are at a higher risk of being infected by ECF (Gachohi *et al.*, 2012). However, this could be because farmers who practice zero-grazing seem to be wealthier; this system requires a high level of external inputs, including bought-in feeds, and significant expenditure on livestock and veterinary services compared to other cattle production systems. In both household headships, ITM adopters had more access to livestock extension services compared to non-adopters. In MHHs, 98 per cent of the ITM adopters had access to livestock extension services within the study period compared to 38 per cent for the non-adopters. While for FHHs, 79 per cent of ITM adopters had accessed extension services compared to 21 per cent of non-adopters. This is an indication that in both household types, ITM adopters were more exposed to agricultural information compared to non-adopters.

In both MHHs and FHHs, the proportion of households' key decision-makers belonging to a livestock-related social group was considerably higher among ITM adopters than among non-adopters. In MHHs, 85 per cent of the household heads belonged to social groups linked to livestock, compared to 67 per cent for non-adopters. Similarly, in FHHs, 93 per cent of the household heads belonged to livestock linked social groups compared to 48 per cent for non-adopters. It appears that social groups help in the dissemination of information and even in resource mobilization when it comes to the adoption of agricultural technologies. Finally, a significantly higher proportion of ITM adopters in both household headships had access to credit compared to non-adopters. In FHHs, 66 per cent of the respondents had accessed credit, cash or in-kind, compared to 35 per cent of non-adopters. For the MHHs, 74 per cent had access to financial support compared to 44 per cent for non-adopters.

3.2 Actual and potential adoption rates of ITM vaccine by gender

Table 2 presents the results on ITM awareness, adoption rates, and adoption gaps by gender. The estimates for both MHHs and FHHs were significantly different from zero at 1 per cent level. Results reveal that 53 per cent of the pooled sample was aware of the ITM vaccine. In terms of household headship, 57 per cent and 46 per cent of MHHs and FHHs, respectively, were aware of the ITM vaccine, suggesting greater level of ITM vaccine awareness among MHHs. A similar trend was observed for the actual adoption rates (JEA): there was a higher (41 per cent) adoption among MHHs as compared to FHHs (19 per cent). These results imply that not all the cattle keepers who had ITM knowledge adopted it and that the difference was especially pronounced in FHHs. Hence, a need for further investigation on factors influencing the adoption of the ITM vaccine when the awareness constraint is controlled.

Gender differences were further witnessed in the estimated potential demand for the ITM vaccine; 62 per cent of MHHs were likely to adopt ITM vaccine by relaxing the awareness constraint compared to 31 per cent of FHHs. These results project a potential adoption gap of 21 per cent for MHHs but only 12 per cent for FHHs. These results show that without channelling more efforts in gender-responsive awareness and adoption support interventions at the scale-up stage, it will be difficult to achieve gender equity in regard to the adoption of ITM. Similar results are presented for the case of ATE_1 and ATE_0, where around 72 per cent and 42 per cent of MHHs and FHHs, respectively, are estimated to have adopted ITM vaccine in ITM vaccine aware villages; while 48 per cent and 22 per cent are estimated to be potential adopters in the non-aware villages (ATE_0).

3.3 Determinants of ITM adoption among MHHs and FHHs

Table 3 presents results on the determinants of ITM adoption by household headship when awareness is controlled. The goodness of fit estimate reveals that the models have good explanatory power. The explanatory variables used in the regressions explained 45 per cent, 43 per cent, and 39 per cent of the variation in the dependent variables for the case of pooled sample, FHHs, and MHHs, respectively. In the pooled model, the gender variable had a significant (5 per cent level) and a positive influence on the adoption of the ITM vaccine. This result was expected as men and women have shown to differ when it comes to the adoption of agricultural technologies, with women lagging in most of the cases.

Considering the pooled and the separate models, most of the variables were significant and had the expected signs. The education level of the household head strongly influenced the probability of adopting the ITM vaccine in both household headships and for the pooled sample. These results indicate the importance of education in access to information and the adoption of agricultural innovations. The pooled sample and for MHHs, age of the household heads had a negative and significant association with the adoption of ITM vaccine, suggesting that ITM vaccine was more likely to be adopted by younger household heads as compared to older ones. Surprisingly, this was contrary to FHHs, as the age of the household head significantly and positively influenced the probability of adopting the ITM vaccine. Older household heads in FHHs were more likely to adopt the ITM vaccine than young ones.

The active labour force (adult equivalent) returned significant positive coefficients in FHHs only. Household heads that considered farming as primary occupation were more likely to take up ITM. This was significant in the pooled sample, as well as in MHHs and FHHs.

Farm size under production positively influenced the probability of adopting the ITM vaccine; however, this was only significant in FHHs. Cattle herd size, tropical livestock units, positively and significantly influenced the probability of ITM adoption in both the pooled sample and household headships. This could be a sign of wealth difference between ITM adopters as compared to non-adopters.

Active membership in social groups related to agricultural production was also positive and significant in all the

Table 2: *Adoption of Infection-and-Treatment-Method (ITM) by gender.*

	MHHs		FHHs		Pooled sample	
Adoption estimator	*Parameters*	*S.E.*	*Parameters*	*S.E.*	*Parameters*	*S.E.*
Potential adoption rates in the whole population of interest (ATE):	0.616***	0.032	0.314***	0.044	0.528***	0.025
Potential adoption rates among ITM vaccine aware population (ATE_1):	0.720***	0. 026	0.422***	0.031	0.635***	0.022
Potential adoption rates among ITM vaccine non-aware population (ATE_0):	0.478***	0. 042	0.223***	0.064	0.406***	0.031
Observed ITM vaccine adoption rates (JEA):	0.411***	0.015	0.194***	0.014	0.339***	0.012
Adoption gap (GAP): GAP=ATE-JEA	-0.205***	0.018	-0.120***	0.034	-0.190***	0.014
Population Selection Bias (PSB):	0.103***	0.010	0.107***	0.029	0.106***	0.008
Total number of observations	298		150		448	
Number of household heads aware of ITM	170		69		239	
Number of household heads adopted ITM	123		29		152	

Male-headed (MHHs) and female headed (FHHs) households.
** = significant at 1 per cent level; S.E =Robust Standard Errors

Table 3: *Determinants of Infection-and-Treatment-Method (ITM) adoption among male-headed (MHH) and female-headed (FHH) households.*

Variables	MHHs		FHHs		Pooled sample	
Explanatory variables	*Coef.*	*S.E.*	*Coef.*	*S.E.*	*Coef.*	*S.E.*
Household characteristics						
Gender of the household head (1=male)					3.679**	1.112
Age (years)	-0.023*	0.012	0.011**	0.061	-0.010*	0.011
Education level (years)	0.206***	0.037	0.037***	0.140	0.184***	0.035
Household size (adult equivalent)	0.149	0.069	0.071*	0.028	0.287	0.109
Primary occupation (1=farming)	1.140**	0.508	0.045*	0.150	0.772**	0.253
Household wealth and farm characteristics						
Land-size (hectares)	0.449	0.059	0.022**	0.073	0.364**	0.073
Cattle herd size (TLU)	0.173*	0.077	0.035**	0.035	0.195**	0.075
Breed- type (1=exotic)	0.654	0.341	0.015	0.083	0.521	0.538
Feeding- systems zero-grazing (1=yes)	-0.197	0.290	-0.141	0.105	-0.425	0.259
Main method of vector control (1 = spraying)	0.387	0.049	0.298	0.144	0.368	0.252
Institutional characteristics						
Group membership (1=yes)	0.740**	0.036	0.196***	0.075	1.628***	0.286
Credit access (1=yes)	1.079**	0.029	0.136**	0.080	0.584***	0.349
Access to extension services (1=yes)	1.627***	0.011	0.047**	0.088	1.619**	0.582
Access to fresh water (walking time in minutes)	0.099	0.082	0. 016	0.214	0.061	0.073
Interactions of gender with other variables						
Land size and gender of household head					-0.340**	0.140
Household size and gender of household head					-0.376**	0.167
Credit access and gender of household head					0.169	0.392
Group membership and gender of household head					-0.825*	0.495
Constant	-7.138	1.531	-4.318	1.285	-10.071	1.450
Number of observations	168		69		239	
Pseudo R^2	0.386		0.539		0.458	
Prob> Chi^2	0.000		0.000		0.000	

***; **; * = significant at 1 per cent level, 5 per cent and 10 per cent, respectively; S. E= Robust standard errors models; most likely attributed to the social capital gain through group networking. Access to livestock-related training significantly and positively influenced the probability of adopting the ITM vaccine. Access to credit returned positive and expected coefficients, which were significant in the three models, suggesting that access to credit relaxes the financial constraint cattle keepers' face in purchasing the ITM vaccines and paying for its services.

In order to assess further the contribution of the significant factors to ITM adoption identified in the gender-specific models, interaction terms of the most relevant factors were introduced in the pooled sample model. As expected, the factors representing resource endowment showed a significant interaction with gender, indicating that the effect of resource constraints differs significantly between the two headships. The adoption of ITM is significantly affected by resource constraints in FHHs, but this does not apply to MHHs. While the model shows no interaction of gender with credit access – the effect of credit on adoption does not differ between headships – a significant negative interaction is shown for group membership, indicating that group membership has a stronger effect in FHHs than in MHHs.

4 Discussion

The results demonstrate that there is great potential for increasing ITM adoption among smallholder dairy farmers in Kenya. This is revealed through the significant adoption gaps in both household headships. The results also demonstrate that ITM awareness and even more so adoption rates are lower among FHHs compared to MHHs. The adoption of the ITM vaccine can be attributed to several factors, some of which have similar effects in MHHs and FHHs while others differ, as discussed below. The fact that formal education level of the household head, allowing farmers to more efficiently acquire knowledge, had a significant and positive association with ITM adoption in both household headships resonates well with those of (Karanja-Lumumba *et al.*, 2015), where highly educated farmers embraced ECF immunization as they understood its effectiveness in the control of ECF as compared to the conventional methods like use of acaricides.

The age of the household head (seen as a proxy for cattle keeping experience) negatively influenced the probability of adopting ITM vaccine in MHHs. This result might be attributed to the conservative nature of older farmers, where mostly they tend to retain their conventional methods of ECF control (dipping and spraying using acaricides). Besides, this could be because older farmers experience higher information search costs regarding agricultural innovations compared to younger farmers (Simtowe *et al.*, 2016); hence, they might lack information regarding ECF vaccination. This result contradicts those of (Karanja-Lumumba *et al.*, 2015), where older farmers were more likely to vaccinate against ECF as from experience; they clearly understood the shocks resulting from the disease. Interestingly, the age of the household head significantly and positively influenced ITM adoption among the FHHs. This could be due to the fact that although older people incur higher information search costs regarding agricultural innovations, once they overcome these barriers, they may be more likely to adopt because they have a higher resource endowment compared to young farmers, and these are especially constraining for female farmers.

The household size (active labour force) within the studied households was positively and significantly correlated with ITM adoption in FHHs only, although their average household size was similar to the MHHs. This might be due to differences in household composition, masked by the weighted aggregation of household members. Practising farming as the primary source of income had a significant and positive association with ITM adoption in both household headships. These results suggest that farming increased the chance or the interest of household heads to interact with extension services providers, hence gaining more knowledge regarding ITM technology. This finding differs from those of previous adoption studies which note that participation in off-farm income-generating activities increases chances of adopting agricultural innovations, as the farmers take advantage of the extra cash from off-farm businesses to pay for the agricultural innovation inputs or services (Homewood *et al.*, 2006; Obisesan, 2014; Karanja-Lumumba *et al.*, 2015). Land size had a significant positive association with ITM in FHHs only. A possible explanation is that female farmers with more land under farming have a more diverse income base. This allows them to channel income from other agriculture enterprises to ECF immunization. That this is relevant only for FHHs might be linked to their greater difficulties in accessing financial resources. However, these results differ from those of ECF vaccination among pastoralists in Tanzania, where there was no link between ECF vaccination and income diversification (Homewood *et al.*, 2006).

Herd size (TLU) had a positive and significant influence on the probability of ITM adoption in both household headships. Three possible reasons might explain this result: First, larger cattle herds are a measure of household wealth; it is easier for financially stable families to pay for ECF immunization services. Similar findings were reported in previous studies, in which wealthier farmers are more likely to pay for agricultural innovations compared to poor farmers (Homewood *et al.*, 2006; Waithanji *et al.*, 2019; Jumba *et al.*, 2020). Secondly, livestock keepers with relatively larger herd size may feel more vulnerable to shocks resulting from diseases like ECF or environmental calamities. Therefore, such farmers are incentivised to protect their livestock against risk through adopting novel agricultural innovations, such as index-based livestock insurance (Amare *et al.*, 2019). Thirdly, owning large herd size could be an indicator of entrepreneurship. Such farmers would tend to adopt agricultural innovations that can improve their livestock productivity. Similar findings were reported for the case of vaccination against Newcastle disease in Tanzania, where farmers with larger flock sizes were more likely to vaccinate since they were more commercially oriented (Campbell *et al.*, 2018).

Cattle keepers of both headships who had accessed extension services and those who had attended field days, host demonstrations or trials were more likely to adopt the ITM vaccine. These findings highlight the considerable role played by the extension agents in creating awareness about agricultural innovations. Regular contacts with the extension agents enhance farmers' knowledge and equips them with new techniques of managing agricultural production (Mugisha *et al.*, 2005; Heffernan *et al.*, 2008; Quisumbing & Pandolfelli, 2010; Suvedi *et al.*, 2017).

Social group membership also had a positive influence on the adoption of the ITM vaccine in both household headships. Participation in group activities implied higher social capital that improved individual ability to access knowledge on ITM. However, the potential benefits of social groups seem to be more significant among women, as indicated by the interaction term in the pooled model. These households also face constraints in resources, information and traditional gender roles when it comes to the uptake of livestock vaccines. Groups may help overcome these constraints by creating a forum for interaction and sharing of information regarding innovations (Heffernan *et al.*, 2008; Quisumbing & Pandolfelli, 2010; Galiè *et al.*, 2017; Mutua *et al.*, 2019; Jumba *et al.*, 2020). Social groups also help cattle keepers mobilise cattle for ECF vaccination, as it is easier through groups to meet the required 40 head of cattle per batch, which is often reported to be a considerable constraint to ITM uptake (Jumba *et al.*, 2020; Patel *et al.*, 2019). This finding differs from those of Heffernan *et al.* (2011), where community groups, particularly those related to livestock keeping, did not affect the uptake of livestock vaccine.

Access to credit had a positive and significant influence on ITM adoption in both household headships as it helps farmers pay for innovation expenses with minimal difficulties. Studies have shown that, the more farmers have access to finance sources to help them with liquidity, the more likely they can pay for inputs and expenses incurred during the adoption of innovations (Mendola, 2007; Justus *et al.*, 2013; Simtowe *et al.*, 2016). This is an outcome that reflects the vital role played by institutional factors in promoting agricultural research and development plans. Despite the general assumption that women face greater constraints in accessing credit, the pooled model does not indicate that the effect of access to credit on ITM adoption differs between headships.

5 Summary and conclusions

The study is based on cross-sectional data collected from rural smallholder dairy cattle keepers in Kenya. Despite the potential of ITM in reducing shocks due to ECF, adoption rates are still low overall and especially amongst women. This is confirmed by a statistically significant gender difference in ITM adoption, with higher actual and potential adoption rates among MHHs compared to FHHs. However, the ATE estimates also reveal a considerably lower adoption gap in FHHs, half the gap in MHHs, implying that improving only awareness in FHHs would not help in increasing adoption rates to levels found in MHHs.

After controlling for ITM vaccine awareness, in both MHHs and FHHs, household heads with higher education and higher social capital regarding active participation in social groups, access to extension services and credit, and having farming as primary occupation resulted in an increased probability of ITM adoption. Among FHHs, the age of the household head, land size, and household active labour force also significantly increased the probability of ITM adoption. Group membership appeared to have an especially strong effect in FHHs. The findings from this study have relevant policy implications regarding the awareness and adoption of this innovation and agricultural innovations in general. While strengthening publicity campaigns can support all farmers in their awareness of relevant innovations, more strategic targeting FHHs is required to close the gender gap in awareness. Crucially though, extension and promotion efforts must consider the specific constraints of women to increase their adoption of innovations substantially. For ITM, this includes recognition that more efforts should be directed towards alleviating resource limitations and supporting group formation.

While the results of this work are significant, the study has some limitations. Firstly, the study was restricted to only intensive dairy systems, leaving out other cattle rearing systems in Kenya. Secondly, the data is based on a small sample. Therefore, the results should be interpreted with caution when generalising to a larger population. Future research should analyse a more substantial sample and also include other cattle production systems, both in Kenya and in other regions where ECF is endemic.

Acknowledgements

The authors wish to thank the International Livestock Research Institute (ILRI) for financial and technical support, particularly Dr. Isabelle Baltenweck. We would also like to thank lecturers in the Department of Agricultural Economics and Agribusiness Management, Egerton University, Kenya, for their valuable support during the design of this study. Our thanks go to the editor and the anonymous reviewer for their constructive comments on the earlier draft of this article, as well as smallholder livestock keepers for their co-operation during data collection.

Funding source

The study was funded by the Livestock & Fish CRP through ILRI, now Livestock CRP (http://www.cgiar.org/about-us/our-funders). ILRI thanks all donors and organizations that globally supported its work through their contributions to the CGIAR System.

Conflict of interest

The authors declare no conflict of interest.

References

Amare, A., Simane, B., Nyangaga, J., Defisa, A., Hamza, D., & Gurmessa, B. (2019). Index-based livestock insurance to manage climate risks in Borena zone of southern Oromia, Ethiopia. *Climate Risk Management*, 25, 100191. https://doi.org/10.1016/j.crm.2019.100191.

Campbell, Z. A., Marsh, T. L., Mpolya, E. A., Thumbi, S. M., & Palmer, G. H. (2018). Newcastle disease vaccine adoption by smallholder households in Tanzania: Identifying determinants and barriers. *PLoS ONE*, 13(10), 1–16. https://doi.org/10.1371/journal.pone.0206058.

Dandedjrohoun, L., Diagne, A., Biaou, G., N'Cho, S., & Midingoyi, S.-K. (2012). Determinants of diffusion and adoption of improved technology for rice parboiling in Benin. *Review of Agricultural and Environmental Studies*, 93(12), 171–191. https://doi.org/10.22004/ag.econ.188224.

Deere, C. D., & Doss, C. R. (2006). Gender and the distribution of wealth in developing countries. UNU-WIDER, Helsinki Finland.

Di Giulio, G., Lynen, G., & Medley, G. (2003). Characterization of theileriosis in pastoral production systems in Northern Tanzania. Proceedings of the 10^{th}, International Symposium on Veterinary Epidemiology and Economics. International Society for Veterinary Epidemiology and Economics, Vina del Mar, Chile.

Diagne, A. (2006). Diffusion and adoption of NERICA rice varieties in Côte d'Iviore. *Developing Economies*, 44(2), 208–231. https://doi.org/10.1111/j.1746-1049.2006.00014.x.

Diagne, A., & Demont, M. (2007). Taking a new look at empirical models of adoption: Average treatment effect estimation of adoption rates and their determinants. *Agricultural Economics*, 37, 201–210. https://doi.org/10.1111/j.1574-0862.2007.00266.x.

Doss, C. R., Grown, C., & Deere, C. D. (2008). Gender and Asset Ownership: A Guide to Collecting Individual-Level Data. The World Bank, Washington D.C., USA.

Doss, C. R., & Morris, M. L. (2001). How does gender affect the adoption of agricultural innovations? The case of improved maize technology in Ghana. *Agricultural Economics*, 25(1), 27–39. https://doi.org/10.1016/S0169-5150(00)00096-7.

Doss, C. R., Mwangi, W., Verkuijl, H., & De Groote, H. (2003). Adoption of Maize and Wheat Technologies in Eastern Africa: A Synthesis of the Findings of 22 Case Studies. CIMMYT, Mexico DF, Mexico.

Gachohi, J., Skilton, R., Hansen, F., Ngumi, P., & Kitala, P. (2012). Epidemiology of East Coast fever (Theileria parva infection) in Kenya: Past, present and the future. *Parasites and Vectors*, 5(1), 194–207. http://www.parasitesandvectors.com/content/5/1/194.

Galiè, A., Distefano, F., Kangogo, D., Mattioli, R. C., Wieland, B., & Baltenweck, I. (2017). Gendered Perspectives on Smallholder Cattle Production and Health Management in Three Sites in Tanzania. *Journal of Gender, Agriculture and Food Security*, 2(3), 43–65. https://doi.org/10.19268/JGAFS.232017.3.

Galiè, A., Jiggins, J., Struik, P. C., Grando, S., & Ceccarelli, S. (2017). Women's empowerment through seed improvement and seed governance: Evidence from participatory barley breeding in pre-war Syria. *NJAS - Wageningen Journal of Life Sciences*, 81, 1–8. https://doi.org/10.1016/j.njas.2017.01.002.

Galiè, A., Mulema, A., Mora Benard, M. A., Onzere, S. N., & Colverson, K. E. (2015). Exploring gender perceptions of resource ownership and their implications for food security among rural livestock owners in Tanzania, Ethiopia, and Nicaragua. *Agriculture & Food Security*, 4(1), 1–14. https://doi.org/10.1186/s40066-015-0021-9.

Heffernan, C., Thomson, K., & Nielsen, L. (2008). Livestock vaccine adoption among poor farmers in Bolivia: Remembering innovation diffusion theory. *Vaccine*, 26(19), 2433–2442. https://doi.org/10.1016/j.vaccine.2008.02.045.

Heffernan, C., Thomson, K., & Nielsen, L. (2011). Caste, livelihoods and livestock: An exploration of the uptake of livestock vaccination adoption among poor farmers in India. *Journal of International Development*, 23(1), 103–118. https://doi.org/10.1002/jid.1643.

Homewood, K., Trench, P., Randall, S., Lynen, G., & Bishop, B. (2006). Livestock health and socio-economic impacts of a veterinary intervention in Maasailand: Infection-and-treatment vaccine against East Coast fever. *Agricultural Systems*, 89(2–3), 248–271. https://doi.org/10.1016/j.agsy.2005.09.004.

Imbens, G. W., & Wooldridge, J. M. (2009). Recent developments in the econometrics of program evaluation. *Journal of Economic Literature*, 47(1), 5–86. https://doi.org/10.1257/jel.47.1.5.

Jumba, H., Teufel, N., Baltenweck, I., Haan, N. de, Kiara, H., & Owuor, G. (2020). Use of the infection and treatment method in the control of East Coast fever in Kenya: does gender matter for adoption and impact? *Gender, Technology and Development*, 1–17. https://doi.org/10.1080/09718524.2020.1829359.

Justus, O., Owuor, G., & Bebe, B. O. (2013). Management practices and challenges in smallholder indigenous chicken production in western Kenya. *Journal of Agriculture and Rural Development in the Tropics and Subtropics*, 114(1), 51–58. urn:nbn:de:hebis:34-2013030542607.

Kabunga, N., Dubois, T., & Qaim, M. (2012). Heterogeneous information exposure and technology adoption: The case of tissue culture bananas in Kenya. *Agricultural Economics*, 43, 473–486. https://doi.org/10.1111/j.1574-0862.2012.00597.x.

Karanja-Lumumba, T., Mugambi, J., & Wesonga, F. (2015). Adoption of East Coast Fever Vaccine among Smallholder Dairy Farmers in Kenya: The Case of North Rift Kenya. *East African Agricultural and Forestry Journal*, 81(1), 34–39. https://doi.org/10.1080/00128325.2015.1040646.

Kibiego, M. B., Lagat, J. K., & Bebe, B. O. (2015). Competitiveness of Smallholder Milk Production Systems in Uasin Gishu County of Kenya. *Journal of Economics and Sustainable Development*, 6(10), 39–46.

Maloo, S. H., Rowlands, G. J., Thorpe, W., Gettinby, G., & Perry, B. D. (2001). A longitudinal study of disease incidence and case-fatality on smallholder dairy farms in coastal Kenya. *Prev Vet Med*, 52, 17–29. https://doi.org/10.1016/S0167-5877(01)00235-5.

Marsh, T. L., Yoder, J., Deboch, T., McElwain, T. F., & Palmer, G. H. (2016). Livestock vaccinations translate into increased human capital and school attendance by girls. *Science Advances*, 12, 1–7. https://doi.org/10.1126/sciadv.1601410.

Mbassa, G. K., Kweka, L. E., & Dulla, P. N. (1998). Immunization against east coast fever in field cattle with low infectivity Theileria parva stabilate - Preliminary assessment. *Veterinary Parasitology*, 77(1), 41–48. https://doi.org/10.1016/s0304-4017(97)00138-6.

Meinzen-Dick, R., Johnson, N., Quisumbing A., Njuki, J., Behrman, J., Rubin, D., Peterman, A., & Waithanji, E. (2011). Gender , Assets , and Agricultural Development Programs: A Conceptual Framework. IFPRI, Washington DC, USA.

Mendola, M. (2007). Agricultural technology adoption and poverty reduction: A propensity-score matching analysis for rural Bangladesh. *Food Policy*, 32(3), 372–393. https://doi.org/10.1016/j.foodpol.2006.07.003.

Minjauw, B., & McLeod, A. (2003). Tick-Borne Diseases and Poverty: The Impact of Ticks and Tick-Borne Diseases on the Livelihoods of Small-Scale and Marginal Livestock Owners in India and Eastern and Southern Africa. Centre for Tropical Veterinary Medicine, University of Edinburgh, Edinburgh, UK.

Mugisha, A., McLeod, a, Percy, R., & Kyewalabye, E. (2005). Strategies, effectiveness and rationale of vector-borne disease control in the pastoralist system of south-western Uganda. *Tropical Animal Health and Production*, 37(6), 479–489. https://doi.org/10.1007/s11250-005-2174-1.

Mutua, E., De Haan, N., Tumusiime, D., Jost, C., & Bett, B. (2019). A qualitative study on gendered barriers to livestock vaccine uptake in kenya and uganda and their implications on rift valley fever control. *Vaccines*, 7(3), 86. https://doi.org/10.3390/vaccines7030086.

Njuki, J., Waithanji, E., Sakwa, B., Kariuki, J., Mukewa, E., & Ngige, J. (2014). Can Market-Based Approaches to Technology Development and Dissemination Benefit Women Smallholder Farmers? A Qualitative Assessment of Gender Dynamics in the Ownership, Purchase, and Use of Irrigation Pumps in Kenya and Tanzania. IFPRI, Washington D.C., USA.

Obisesan, A. (2014). Gender Differences in Technology Adoption and Welfare Impact Among Nigerian Farming Households. Department of Agricultural Economics, University of Ibadan, Ibadan, Nigeria.

Patel, E., Mwaura, S., Di Giulio, G., Cook, E. A. J., Lynen, G., & Toye, P. (2019). Infection and treatment method (ITM) vaccine against East Coast fever: Reducing the number of doses per straw for use in smallholder dairy herds by thawing, diluting and refreezing already packaged vaccine. *BMC Veterinary Research*, 15(46), 1–6. https://doi.org/10.1186/s12917-019-1787-y.

Patel, E., Mwaura, S., Kiara, H., Morzaria, S., Peters, A., & Toye, P. (2016). Production and dose determination of the Infection and Treatment Method (ITM) Muguga cocktail vaccine used to control East Coast fever in cattle. *Ticks and Tick-Borne Diseases*, 7(2), 306–314. https://doi.org/10.1016/j.ttbdis.2015.11.006.

Perry, B. D. (2016). The control of East Coast fever of cattle by live parasite vaccination: A science-to-impact narrative. *One Health*, 2, 103–114. https://doi.org/10.1016/j.onehlt.2016.07.002.

Peterman, A., Quisumbing, A., Behrman, J., & Nkonya, E. (2010). Understanding Gender Differences in Agricultural Productivity in Uganda and Nigeria. IFPRI, Washington D.C., USA.

Phiri, D., Franzel, S., Mafongoya, P., Jere, I., Katanga, R., & Phiri, S. (2004). Who is using the new technology? The association of wealth status and gender with the planting of improved tree fallows in Eastern Province, Zambia. *Agricultural Systems*, 79(2), 131–144. https://doi.org/10.1016/S0308-521X(03)00055-6.

Quisumbing, A. R., & Pandolfelli, L. (2010). Promising Approaches to Address the Needs of Poor Female Farmers: Resources, Constraints, and Interventions. *World Development*, 38(4), 581–592. https://doi.org/10.1016/j.worlddev.2009.10.006.

Rademaker, C. J., Omedo Bebe, B., van der Lee, J., Kilelu, C., & Tonui, C. (2016). Sustainable Growth of the Kenyan Dairy Sector: A Quick Scan of Robustness, Reliability and Resilience. WUR, Wageningen, The Netherlands.

Radley, D. E., Brown, C. G. D., Cunningham, M. P., Kimber, C. D., Musisi, F. L., Payne, R. C., Purnell, R. E., Stagg, S. M., & Young, A. S. 1975. East coast fever: 3. Chemoprophylactic immunization of cattle using oxytetracycline and a combination of theilerial strains. *Veterinary Parasitology*, 1(1), 51–60. https://doi.org/10.1016/0304-4017(75)90007-2.

Ragasa, C. (2012). Gender and Institutional Dimensions of Agricultural Technology Adoption: A Review of Literature and Synthesis of 35 Case Studies. International Association of Agricultural Economists (IAAE); 2012 Conference, August 18-24, 2012, Foz Do Iguaçu, Brazil.

Shelburne, I., Lawver, D. E., Fraze, S., Ulmer, J., Stephenson, C., & Magogo, J. (2017). Adoptive Behaviors of Farmers After Training and their Subsequent Diffusive Behaviors in Uasin Gishu County, Kenya. *Journal of International Agricultural and Extension Education*, 24(1), 74–89. https://doi.org/10.5191/jiaee.2016.24108.

Simtowe, 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), 1–21. https://doi.org/10.1186/s40100-016-0051-z.

Simtowe, F., Marenya, P., Amondo, E., Worku, M., Rahut, D. B., & Erenstein, O. (2019). Heterogeneous seed access and information exposure: implications for the adoption of drought-tolerant maize varieties in Uganda. *Agricultural and Food Economics*, 7(15), 1–23. https://doi.org/10.1186/s40100-019-0135-7.

Suvedi, M., Ghimire, R., & Kaplowitz, M. (2017). Farmers' participation in extension programs and technology adoption in rural Nepal: a logistic regression analysis. *Journal of Agricultural Education and Extension*, 23(4), 351–371. https://doi.org/10.1080/1389224X.2017.1323653.

Tavenner, K., Fraval, S., Omondi, I., & Crane, T. A. (2018). Gendered reporting of household dynamics in the Kenyan dairy sector: trends and implications for low emissions dairy development. *Gender, Technology and Development*, 22(1), 1–19. https://doi.org/10.1080/09718524.2018.1449488.

Theis, S., Lefore, N., Meinzen-Dick, R., & Bryan, E. (2018). What happens after technology adoption? Gendered aspects of small-scale irrigation technologies in Ethiopia, Ghana, and Tanzania. *Agriculture and Human Values*, 35, 671–684. https://doi.org/10.1007/s10460-018-9862-8.

United Nations, D. of E. and S. A. (2017). Household Size and Composition Around the World 2017. United Nations, Department of Economic and Social Affairs, New York, USA.

Wafula, I. N. (2014). Gender roles in a dairy value chain in Uasin Gishu County, Kenya. University of Nairobi, Nairobi, Kenya.

Waithanji, E., Mtimet, N., & Muindi, P. (2019). Contagious Bovine Pleuropneumonia Vaccine Delivery and Adoption by Women and Men in North-Eastern Kenya. *European Journal of Development Research*, 31(3), 364–387. https://doi.org/10.1057/s41287-018-0157-0.

Wanyama, R. N., Mshenga, P. M., Orr, A., Christie, M. E., & Simtowe, F. P. (2013). A Gendered Analysis of the Effect of Peanut Value Addition on Household Income in Rongo and Ndhiwa Districts of Kenya. 4th International Conference of the African Association of Agricultural Economists, September 22-25, 2013, Hammamet, Tunisia.

Wooldridge, J. M. (2002). Econometric Analysis of Cross Section and Panel Data. MIT Press, Cambridge (Mass.), USA.