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FOOD SCIENCE & TECHNOLOGY | RESEARCH ARTICLE

Determinants of fish farmers' awareness of insect-based aquafeeds in Kenya; the case of black soldier fly larvae meal

Kevin Okoth Ouko[1]*, Jimmy Brian Mboya[2,3], Kevin Odhiambo Obiero[2], Erick Ochieng Ogello[3], Adrian Wekulo Mukhebi[3], Mavindu Muthoka[3] and Jonathan Mbonge Munguti[4]

Abstract: It is evident from scientific studies that black soldier fly larvae can replace the widely used fishmeal, which is costly and unsustainable for smallholder farmers, in aquafeeds. The purpose of this study was to evaluate the factors t influencing fish farmers' awareness of use of black soldier fly larvae meal as an ingredient in fish feeds. The effect of farmers' socioeconomic status and aquaculture practices on their awarenessabout black soldier fly larvae based aquafeeds was examined using a binary logit regression model. The regression analysis results revealed that fish farming experience (β = 0.327; *p* = 0.001), distance to feed sources (β = 0.009; *p* = 0.034), farmers' income (β = −0.505; *p* = 0.008) and knowledge about the components of existing feed (β = 2.667; *p* = 0.004) significantly influenced the farmers' awareness about black soldier fly larvae meal. The results suggest that communication and farmer education are key in improving the farmers' awareness about novel fish feed ingredients. Therefore, there is need for both public and private institutions to improve awareness creation through local print and electronic media to enhance fish farmers' awareness of insect-based aquafeeds.

Subjects: Agricultural Economics; Aquaculture; Fisheries & Related Industries

Keywords: black soldier fly; farmers' awareness; logit regression; aquafeeds; aquaculture; Kenya

1. Introduction

Due to the increasing demand for fish and fish products as an alternative source of animal protein brought on by the constantly growing human population, aquaculture has experienced a remarkable expansion in the recent decades (FAO, 2020). The aquafeed industry should continue to expand in order to meet the projected increase in fish demand (Liland et al., 2017). In aquafeed, fishmeal and plant-based meals such as soybeans are the main sources of protein (FAO, 2013). Whereas fishmeal is costly and unsustainable for smallholder farmers, plant proteins can impact negatively on the nutritional quality of some farmed fish e (Craig & Kuhn, 2017; Popoff et al., 2017). Owing to the pressure on land and water-use by agriculture, and depleted fish resources due to overfishing, there is an urgent need to explore alternative sustainable feed diet which is nutritive and ecologically friendly for sustainable commercial fish production. . In order to achieve this, insects have been promoted as a beneficial source of fat and protein for fish diets.

Lately, research on the use of insect meal (IM) in aquafeeds has developed rapidly in the last years, leading to an increased number of scientific contributions on this topic recently (Borgogno et al., 2017; Magalhães et al., 2017; Nairuti et al., 2022). Insects are naturally used as food in aquaculture because many fish species feed on them, but their impact on domestic fish production is still minimal (Govorushko, 2019). According to Sánchez-Muros et al. (2014), about 20% of the estimated one million insect species have been recognized and characterized, demonstrating the diversity and possibility that these components should be employed in place of fishmeal (2014). Insect meals can now be used in aquafeed after the European Commission has abolished the restriction on the use of processed animal proteins (PAPs) derived from insects in fish feed (van der Fels-Klerx et al., 2018). The regulation outlines the seven permitted insect species—the banded cricket (*Gryllodes sigillatus*), house cricket (*Acheta domesticus*), yellow mealworm (*Tenebrio molitor*), common housefly (HF), *Musca domestica*, lesser mealworm (*Alphitobius diaperinus*), and field cricket (*Gryllus assimilis*)—as well as the permitted rearing substrates that insects can be grown on (Gasco et al., 2020; Madau et al., 2020). In particular, the black soldier fly larvae (BSFL) has a great opportunity of effectively converting organic matter into high-value fat and protein. The BSFLis resilient to climate change, rich in protein and calcium, cultivated using bio-waste, therefore, helps to conserve the environment, emits less greenhouse gases, and are easy to collect, and therefore require minimal labour during harvesting (Cai et al., 2018; Newton et al., 2008).

The global production of insects for the food and feed industries has grown dramatically in recent years (Madau et al., 2020). The current increase in funding for research and innovation initiatives and the rise in peer-reviewed publications are evidence that insect study is spreading globally. The Journal of Insects as Food and Feed was established in 2015 as a result of the expanding interest in this topic. Consequently, Kenya is one of the countries where the culture of rearing insects is emerging (Gahukar, 2011; Kelemu et al., 2015; Ssepuuya et al., 2017). The country also supports the insect farming business by introducing standards for the use of dried insect products in compounded animal feed (Chia et al., 2020; Vernooij & Veldkamp, 2018). The standards and guidelines are provided by the Kenya Bureau of Standards, outlining the specific nutritional requirements for insect products, their microbiological requirements, limits on heavy metals and pesticide residues in insect products, aflatoxins, and packaging and labelling requirements (Ke, 2016). The regulation permits that insect products may be produced from black soldier fly larvae and pupae (*Hermetia illucens*); crickets adults and nymphs (family Gryllidae); blowfly/Housefly larvae and pupae (Calliphoridae/Muscidae); grasshopper adults and nymphs (sub-order Caelifera); silkworm pupae (*Bombyx* spp.); mealworm larvae and pupae (*Tenebrio* spp); termite adults (Termitidae); Lake fly adult larvae and pupae (Chironomidae, Chaoboridae, Ephemeroptera), cockroach adult and nymph (Blattellidae), among others (Ke, 2016).

Farmers ought to be aware of the employment of insects in the formulation of fish feeds in order to increase fish productivity while lowering production costs. Without awareness raised by trained public extension agents and other credible service providers, farmers rely on information from their input suppliers, which may be inaccurate information (Ullah et al., 2022). A better understanding of the factors influencing farmer awareness is necessary to formulate appropriate agricultural policies and programs that would aid in improving yields and returns in aquaculture. Numerous studies have recognised the significance of farmers' understanding of alternative technology and methods in increasing agricultural productivity in Kenya (Halloran et al., 2021; Jogo et al., 2011; Muatha et al., 2017). Most studies on determinants of farmers' awareness in the country have only been done on, among others, climate change (Ajuang et al., 2016; Gichangi & Gatheru, 2018; Jairo & E, 2019), banana farming (Jogo et al., 2011), and cricket farming (Halloran et al., 2021). However, scanty information exists regarding the drivers of farmers' awareness on use of BSFL as feed in aquaculture. This paper focuses on determinants of awareness of BSFL-based feed in aquaculture. Improving the adoption process requires focusing on those factors that can raise awareness of and adoption of BSFL in aquafeed. As a result, this will ease the pressure now placed on conventional feed resources and bring insight on Kenya's aquafeed value chain.

2. Methodology

2.1. Study area

A cross-sectional survey was conducted in three selected riparian counties of Lake Victoria, Kenya. Cage farming is currently practised in five riparian counties, including Migori, Siaya, Homa Bay, Busia, and Kisumu counties, according to Opiyo et al. (2018). The counties of Kisumu, Siaya, and

Homa Bay were purposively chosen for the study because they had the highest number of Nile tilapia farmers engaged in both pond and cage fish farming. Kisumu county has the most ponds and aquaculture-related operations, whereas Siaya and Homa Bay counties have the most fish cages (representing 85% and 13% of the 3,696 fish cages in Lake Victoria, Kenya, respectively) (Orina et al., 2018). The main species cultured in fish cages is Nile tilapia due to high consumer preference, its fast growth rate, tolerance to crowded conditions and high market value (Charles et al., 2007; Munguti et al., 2014; Obiero et al., 2014).

2.2. Sampling procedure

A two-stage sampling technique was adopted. The highest fish-producing counties in the riparian counties around Kenya's Lake Victoria were purposively selected in the first stage. The counties of Siaya, Kisumu, and Homa Bay were specifically chosen for this study because they have the highest number of fish farmers, both pond farmers and cage farmers (Munguti et al., 2014; Orina et al., 2018). The second stage involved the selection of pond and cage farmers. In the selection of pond farmers for the study, systematic random sampling was applied. This involved using farmers' lists provided by the Sub-County Fisheries Officers in each county. The names of the fish ponds farmers were chosen at an interval in which all the three counties namely Siaya, Kisumu and Homabay were considered Established fish farmers who had been actively involved in fish farming for more than two years were taken into account since they were perceived to have more information on the role of feeds in fish farming . This was also used to reduce the population heterogeneity and increase the efficiency of the estimates. Systematic sampling was also used to select cage farmers in Siaya, Kisumu and Homabay Counties based on the cage locations along Lake Victoria Beaches.

2.3. Data collection

A semi-structured questionnaire was used to collect the data through face-to-face interviews. In contrast to other techniques like mail and telephone surveys, which have the issue of a high non-response rate, face-to-face interviews offer the benefit of allowing for quick follow-up and clarifications (Hussain et al., 2013; Mackenzie & Knipe, 2006).The interviews were conducted only after consent forms had been signed, indicating the participants willingness to be part of the study. The structured questionnaire comprised two sections namely socio-demographic characteristics, awareness about BSFL in aquaculture.

2.4. Conceptual framework and variables

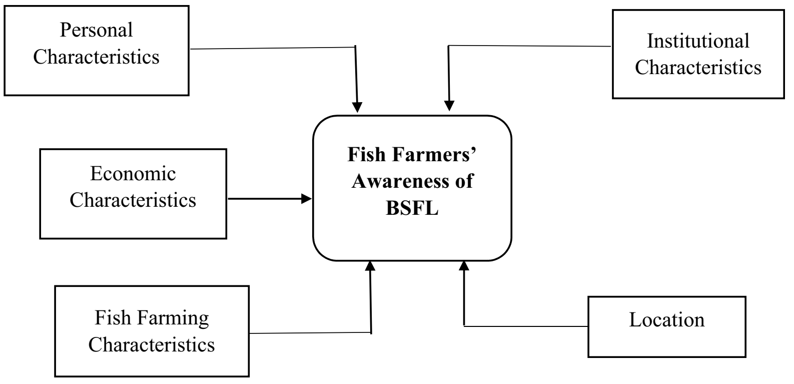
In the present study, fish farmers' awareness a BSFL is predicted to be influenced by several factors. These include, personal characteristics, economic characteristics, fish farming characteristics, institutional characteristics and location (Figure 1).

Age, gender, marital status, education, and fish farming experience are all taken into account as personal characteristics in this study. Access to credit and the average income from fish farming are economic characteristics. There are three variables of fish farming characteristics: number of ponds/cages, distance to feed source and knowledge about existing feed components. Access to extension services and membership to fish farmer groups represents institutional characteristics. The location consists of the three counties; Siaya, Kisumu and Homa Bay.

2.5. Empirical framework

Logistic regression can be seen as a method that is comparable to multiple linear regression. However, it considers the fact that the dependent variable is categorical (Pituch & Stevens, 2020). When the dependent variable is binary, there are several fundamental problems with using a linear regression model, including the error term's non-normality, heteroscedasticity, the possibility that the outcome would not fall within the range of 0 to 1, and generally low coefficient of determination (Gujarati, 2003). The estimate will always fall between the logical limits of 0 and 1, as per the logit and probit models. Therefore, a binary logit regression model was applied to examine how various factors affect fish farmers' awareness of BSFL. The logit regression model was chosen since numerous studies have shown that it may be used to examine farmer awareness (Muatha et al.,

Figure 1. Conceptual framework of fish farmers' awareness of BSFL.



2017; Mustafa et al., 2019; Obi-Egbedi et al., 2020; Ullah et al., 2022). The probit model does not perform better in practical research than the logistic distribution due to the computational difficulties caused by the lack of a closed form for the normal cumulative density function, which the probit model is based on (Ai & Norton, 2003). The current study's dependent variable was the farmers' awareness of or unawareness of BSFL, with a value of 1 (if the farmer is aware of BSFL) and 0 (if the farmer is not aware of BSFL). The independent variables and their values are shown in Table 1. The response variable (awareness of BSFL) is predicted by this model using the independent variables. The relationships were evaluated at $p < 0.05$ statistical significance level.

The possibility that the farmer is aware of BSFL is predicted by odds ($Y = 1$); that is, the ratio of the probability that $Y = 1$ to the probability that $Y \neq 1$, as shown in equation (1);

$$Odd\ Y = P(Y = 1)/(1 - P(Y = 1)) \tag{1}$$

The binary logit regression model is presented in equation (2).

The logit (Y) is given by the natural log of odds;

$$ln\{\frac{p(Yi = 1)}{1 - p(Yi = 1)}\} = logOdds = Logit(Y) \tag{2}$$

This can be expanded as in equation 3;

$$Logit(Y) = \propto + \sum \beta 1X1 + \sum \beta 2X2 + \ldots + \sum \beta nXn + \varepsilon i \tag{3}$$

Where Y = dependent variable (awareness) with 1= aware and 0= not aware;

$\propto$ = intercept

εi= error term

$\beta 1, \ldots, \beta n$= coefficients of the independent variables

$X1, \ldots, Xn$= the independent variables

$p(Yi = 1)$= probability of awareness of BSFL

$1 - p(Yi = 1)$= probability of unawareness of BSFL

and ln= natural log

Table 1. Description of variables used in the binary logit regression model

Variables	Type	Description	Value
Dependent Variable			
Awareness of BSFL (Y)	Dummy	Farmer is aware or unaware of BSFL	1 if aware, 0 if not aware
Independent Variables			
Age (X_1)	Continuous	Age of the farmer	Years
Gender (X_2)	Dummy	Gender of the farmer	1 if male, 0 if female
Education level (X_3)	Categorical	Highest level of education of the farmer	1 if primary level, 0, otherwise
Extension access (X_4)	Dummy	Whether the farmer has accessed extension services related to BSFL	1 if accessed 0 if not accessed
Number of ponds/cages (X_5)	Continuous	Total number of cages or ponds owned by the farmer	Number
Farming experience (X_6)	Continuous	Number of years the farmer has practiced fish farming	Years
Group membership (X_7)	Dummy	Farmer's membership to a fish farmers group	1 if a member 0 if not a member
Credit access (X_8)	Dummy	Farmer's access to credit for fish farming activities	1 if accessed, 0 if not accessed
County (X_9)	Categorical	County in which the farmer practices fish farming	1 if Siaya, 0 otherwise
Distance to feed source (X_{10})	Continuous	Distance to input market (source of feed)	Kilometers
Knowledge of existing feed (X_{11})	Dummy	Farmer's knowledge of the components of the existing feed	1 if knowledgeable, 0 if not knowledgeable
Average income (X_{12})	Continuous	Average Income from fish farming	Ksh
Marital status (X_{13})	Categorical	Marital status of the fish farmer	1 if married, 0 otherwise

Marginal effects were estimated to quantify the immediate effects of changes in the explanatory factors on the predicted likelihood of awareness while holding the other explanatory variables constant.

2.6. Test for multicollinearity

The variance inflation factor (VIF) computation was used as a multicollinearity test to ensure that the independent variables in the model had no correlation at all. According to Gujarati (2003), VIF is determined using the method shown in equation 4 and demonstrates how an estimator's variance is inflated when there is multicollinearity;

$$VIF = \frac{1}{1 - R_i^2} \quad (4)$$

where R_i^2 is the R^2 of the regression with the i^{th} independent variable as a dependent variable. The results of the VIF are presented in Table 2.

The average VIF was 1.52. The explanatory variables had a VIF ranging from 1.16 to 2.13. The VIF of the independent variables was below 5. . None of the independent variables was found to have a significant correlation, suggesting no problem of multicollinearity.

Table 2. Variance inflation factor results		
Variable	**VIF**	**1/VIF**
logAverageIncome	2.13	0.4695
Group membership	2.05	0.4878
Distance to feed source	1.93	0.5181
Credit access	1.88	0.5319
Age	1.51	0.6623
Knowledge of existing feed	1.46	0.6849
County	1.37	0.7299
Marital status	1.36	0.7353
Gender	1.32	0.7576
Extension access	1.24	0.8065
Number of ponds/cages owned	1.2	0.8333
Education level	1.18	0.8475
Farming experience	1.16	0.8621
Mean VIF	**1.52**	

3. Results

3.1. Descriptive statistics

Table 3 displays the sociodemographic characteristics of the farmers. Pond farmers made up 53.54% of all respondents. Most of the respondents were males, representing about 74% of the farmers. Majority of the respondents were married (91.94%), with most of them having attained secondary education (52.13%). About 94% of the respondents practiced commercial fish farming.

3.2. Fish farmers' awareness and use of insect-based feeds (IBFs)

About 46% of the respondents were aware that IBFs are used in aquaculture and most of the respondents (86.3%) were not aware of BSFL. The majority of the respondents (61.2%) had received information about IBFs from the government.

Regarding the use of IBFs in aquaculture, 68.2% had not used IBFs in aquaculture. On the other hand, 7.1% were not sure whether they had used or not used IBFs in aquaculture. Figure 2 shows the various insects which have been used by the farmers to either directly feed their fish or include in their fish feeds. Generally, out of the sampled respondents, 17.5% reported to have used termites, 4.3% had used common housefly and 0.9% had used mealworms. Only 1.9% reported to have used black soldier fly larvae.

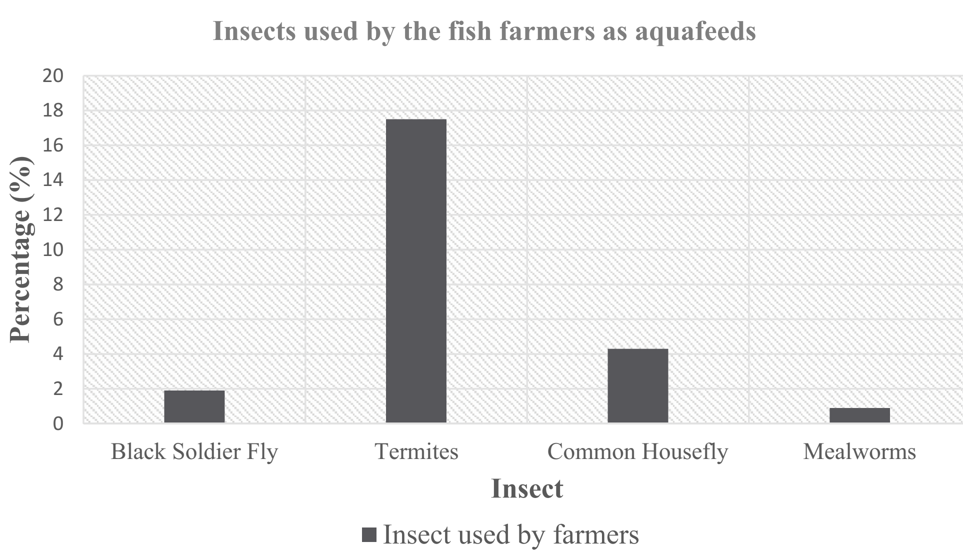
3.3. Factors affecting fish farmers' awareness of BSFL

Table 4 displays the results of the binary logit regression model for the key elements affecting fish farmers' awareness of BSFL. The chi-square value ($\chi 2$) of the model was 40.70, and the log likelihood ratio was −54.4179. The Pseudo R^2 value was 0.2722, meaning that the fourteen variables shown in table 1 explain around 27.22% of the farmers' awareness of BSFL; in other words, the model accounts for 27.22% of the available data. The results show a positive and significant coefficient of fish farming experience on awareness of BSFL ($\beta = 0.327$; $p = 0.001$), distance to feed source on awareness of BSFL ($\beta = 0.009$; $p = 0.034$), and knowledge about the components of the existing feed on awareness ($\beta = 2.667$; $p = 0.004$). However, the coefficient of average income earned from fish farming on awareness of BSFL was negative but significant ($\beta = -0.505$; $p = 0.008$).

Table 3. Socio-demographic characteristics of the fish farmers

Characteristic	Frequency	Percent
Farmer type		
Pond farmer	113	53.54
Cage farmer	98	46.46
Gender		
Female	55	26.07
Male	156	73.93
Education level		
Primary level	40	18.96
Secondary level	110	52.13
Tertiary level	61	28.91
Marital status		
Single	16	7.58
Married	194	91.94
Others	1	0.47
Main Occupation		
Farming	114	54.03
Off-farm	65	30.81
Salaried	32	15.17
Type of farming		
Commercial	199	94.31
Subsistence	12	5.69

Figure 2. Insects used by the fish farmers as aquafeeds.



4. Discussion

The objective of this study was to understand the factors influencing fish farmers' awareness of BSFL based aquafeeds. Based on the descriptive statistics, majority of the respondents were pond farmers. These results are consistent with earlier research on aquaculture production in Kenya which have reported that the country's aquaculture is dominated by pond-based farming (Charo-Karisa et al., 2012; J. M. Munguti et al., 2014; J. Munguti et al., 2021; Mbugua, 2008). Most of the respondents were males, which can be attributed to the male dominance of the aquaculture

Table 4. Results of binary logistic regression model on fish farmers' awareness of BSFL

Determinant	Coefficient (β)	Std. Err.	z	P>z	dy/dx
County	−0.486	0.343	−1.41	0.157	−0.050
Gender	0.704	0.688	1.02	0.306	0.073
Age	0.027	0.025	1.07	0.287	0.003
Marital Status	−0.999	1.056	−0.95	0.344	−0.103
Education level	0.616	0.415	1.48	0.138	0.064
Farming Experience	0.327***	0.100	3.28	0.001	0.034
logAverageIncome	−0.505***	0.190	2.66	0.008	−0.052
Extension Access	−0.143	0.557	−0.26	0.797	−0.015
Credit Access	0.193	0.665	0.29	0.771	0.020
Group Membership	−1.231	0.918	−1.34	0.18	−0.127
No of Ponds/Cages owned	−0.008	0.012	−0.62	0.536	−0.001
DistFeedSource	0.009**	0.004	2.12	0.034	0.001
Knowledge of Existing Feed	2.667***	0.917348	2.91	0.004	0.280
_cons	−0.539	3.112217	−0.17	0.862	-
LRχ^2 = 40.70					
Prob>0.0001					
PseudoR^2 = 0.2722					
Log likelihood= −54.4179					

Note: ** and *** indicate statistical significance at $p < 0.05$ and $p < 0.01$ level of significance respectively.

sector, brought about by factors such as unbalanced gender norms, the high amounts of initial capital needed and the need for the uptake of novel technologies relating to its development, power relations and education (Githukia et al., 2020; Kruijssen et al., 2018). Similar to the majority of developing nations, gender norms in Kenya place restrictions on women's ability to control their income and benefits as well as their access to production resources like land (Ajuang et al., 2016). Additionally, they lack access to education and entrepreneurship training, which is linked to issues with mobility and gender inequality (Githukia et al., 2020). The findings also showed that most of the farmers practised commercial fish farming. Perhaps, the high number of commercial fish farms is due to the constant push for the commercialization of aquaculture in Kenya from both the government and private actors in the sector (Obiero et al., 2022; Obwanga et al., 2020; Odende et al., 2022).

Our findings reveal that most fish farmers were not aware of the use of BSFL in aquafeeds production and have not used it to feed fish as compared to other insects like termites which has been used by relatively more farmers. This finding is in accordance with previous findings that noted that termites are the other locally available insects mostly used as fish feed ingredients by fish farmers in Kenya (Opiyo et al., 2018). This can be attributed to the fact that IBFs are fairly a novel concept in Kenya and fish farmers have not been well informed on their potential significance in aquaculture, and this has been reported by various studies (Chia et al., 2019, 2020; Nairuti et al., 2022; Onsongo et al., 2018) revealing that the use of IBFs in animal feeds is still a new practice that is still under experimental and promotion stages. Similar results were documented by Adeoye et al. (2020) who found that majority of fish farmers are only aware of organic feeds of animal and plant sources such as silkworm, maggot, termites, earthworm, snail, tadpoles, jack beans, maize bran, rice bran, soybean meal and cottonseed meal as feed ingredients for fish production, and only a few people are aware of BSFL. However, the results are inconsistent with the findings of the study conducted by Rumbos et al. (2021), which showed that 80.7% of the participants were aware of the possibilities for insect-based aquafeeds in Greece.

According to our findings, most farmers get information about IBFs from the government, indicating the importance of government research institutions and extension services in dispensing information on new technologies and practices to farmers. These results are similar to those of . Obiero et al. (2019) and Ulhaq et al. (2022) that reported that most small-scale fish farmers get technical aquaculture information from the government.

The awareness of BSFL is influenced by various aspects. This study examined how these independent variables affected fish farmers' awareness of BSFL. The findings of the regression model reveal a low R^2 value that may warrant low goodness of fit. However, this is attributed to the field of study according to Chabris et al. (2008), which justifies that any field of study that deals with humans may have a low R^2 as humans are simply harder to predict than the physical processes. King (1986) adds that inferences are drawn based on the significant coefficients regardless of the value, thus a low R^2 does not always indicate that the model is not well-fit.

The current study revealed that if farmers attain one more year of farming experience, the probability of being aware of BSFL increases, as shown by the positive coefficient value. These findings based on experience level concur with other studies that have reported that farming experience impacts the level of farmers' awareness (Chia et al., 2020; Mustafa et al., 2019). They go on to say that having more farming experience makes farmers more aware and able to embrace better farming practices. Mustafa et al. (2019) reported that farmers' experience has a positive and significant impact on farmers' awareness of climate change. Ullah et al. (2022) also reported that farmers' experience has a positive impact on their awareness of agricultural practices recommended through extension.

The current study's findings also showed a positive relationship between the distance to the feed source and awareness of BSFL, demonstrating that as the distance to the feed source increases, so does the likelihood of being aware of BSFL, as indicated by the positive value of the coefficient. This suggests that the likelihood that a farmer will be aware of the usage of BSFL in feeds increases with distance from the feed source, such as the distance between farmers and feed millers and dealers. This can be linked to farmers looking for substitute feeds to save transportation costs and to increase their convenience. Since it affects the timely delivery of farm inputs and disposal of farm output, the distance between farmers and the feed source is a crucial determinant in their knowledge of and readiness to pay for IBFs (Chia et al., 2020; Chirwa, 2005; Mengistu et al., 2016). In the current study, the closeness of the feed traders to the farmers would determine how they influence the farmers who may buy other conventional feeds from them due to convenience.

The average income earned from fish farming negatively and significantly impacts the awareness of BSFL, implying that the probability of farmers' awareness of BSFL decreases with an increase in the farmers' income. These findings are contrary to the findings of Munyua and Stilwell (2010) who observed that small-scale farmers who have higher incomes have a better capability of being aware of new advancements in farming. Similar to this, Muatha et al. (2017) revealed that household income had a positive and substantial effect on farmers' knowledge in a research that intended to evaluate the factors of smallholder farmers' awareness of the devolution of agricultural extension by Kenyan farmers. The results of the current study may be explained by the fact that farmers with greater earnings can afford the traditional feeds and do not look for alternate diets for their fish as a result.

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The current study's results also revealed that knowledge about the components of the existing feed was found to positively and significantly influence the farmers' awareness of BSFL, indicating that the more the farmer is knowledgeable about existing fish feeds, the more their probability of being aware of BSFL as a potential component of aquafeeds. This is consistent with previous studies that have confirmed that a person's level of knowledge is critical in awareness of novel farming technologies and practices (McKitterick et al., 2016; Wood et al., 2014; Šūmane et al., 2018).

5. Conclusion and policy implications

The study was carried out to determine the determinants of fish farmers' awareness of BSFLs in aquaculture in Kenya. The empirical results show that the farmers' personal, economic and fish farming characteristics had a significant influence on their awareness of BSFL as an IBF in aquaculture. Fish farming experience, distance to feed sources, farmers' income and knowledge about components of existing feed significantly affected awareness of BSFL, suggesting that communication and education may be effective tools for improving awareness which can consequently improve social acceptance of BSFL in aquaculture.

Substantial extension services and investments are required to improve awareness along the value chain, improve the capacity and abilities of stakeholders, and influence farmers' choices as we move away from conventional feed sources like fishmeal and toward insect-based meals. Therefore, raising awareness is a critical point in trying to generate knowledge that may improve the adoption of BSFL in aquaculture production. Both public and private institutions could consider raising awareness through print and electronic media, especially the local radio stations and television channels, to improve fish farmers' awareness of using IBFs in fish farming.

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Disclosure statement
The authors affirm that they do not have any competing interests.

Ethical approval
The study was conducted within the scope of Jaramogi Oginga Odinga University of Science and Technology (JOOUST) ethical provisions, an academic institution mandated to conduct studies and abides by the its Research Policy and its Social Science Research Ethics.

Data availability statement
The data used in this publication, according to the authors' certification, was collected from the study and is only available upon request from the corresponding author.

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References

Adeoye, A. A., Akegbejo-Samsons, Y., Fawole, F. J., & Davies, S. J. (2020). Preliminary assessment of black soldier fly (Hermetia illucens) larval meal in the diet of African catfish (Clarias gariepinus): Impact on growth, body index, and hematological parameters. *Journal of the World Aquaculture Society*, *51*(4), 1024–1033. https://doi.org/10.1111/jwas.12691

Ai, C., & Norton, E. C. (2003). Interaction terms in logit and probit models. *Economics Letters*, *80*(1), 123–129. https://doi.org/10.1016/S0165-1765(03)00032-6

Ajuang, C. O., Abuom, P. O., Bosire, E. K., Dida, G. O., & Anyona, D. N. (2016). Determinants of climate change awareness level in upper Nyakach Division, Kisumu County, Kenya. *SpringerPlus*, *5*(1). https://doi.org/10.1186/s40064-016-2699-y

Borgogno, M., Dinnella, C., Iaconisi, V., Fusi, R., Scarpaleggia, C., Schiavone, A., Monteleone, E., Gasco, L., & Parisi, G. (2017). Inclusion of Hermetia illucens larvae meal on rainbow trout (Oncorhynchus mykiss) feed: Effect on sensory profile according to static and dynamic evaluations. *Journal of the Science of Food and Agriculture*, *97*(10), 3402–3411. https://doi.org/10.1002/jsfa.8191

Cai, M., Hu, R., Zhang, K., Ma, S., Zheng, L., Yu, Z., & Zhang, J. (2018). Resistance of black soldier fly (Diptera: Stratiomyidae) larvae to combined heavy metals and potential application in municipal sewage sludge treatment. *Environmental Science and Pollution Research*, *25*(2), 1559–1567. https://doi.org/10.1007/s11356-017-0541-x

Chabris, C. F., Laibson, D., Morris, C. L., Schuldt, J. P., & Taubinsky, D. (2008). Individual laboratory-measured discount rates predict field behavior. *Journal of Risk and Uncertainty*, *37*(2–3), 237–269. https://doi.org/10.1007/s11166-008-9053-x

Charles, N. C., Bowman, J. R., & Omolo, B. O. (2007). A New Guide to Fish Farming in Kenya.

Charo-Karisa, H., Gichuri, M. W., Nyonje, B., Opiyo, M., Mbugua, H., Ngugi, C., & Ntiba, J. M. (2012). The Role of Government in Promoting Commercial Aquaculture in Africa: Examples from East Africa. *Sixth Biennial Conference of the International Institute of Fisheries Economics*, 4(in 2009), 111.

Chia, S. Y., Macharia, J., Diiro, G. M., Kassie, M., Ekesi, S., van Loon, J. J. A., Dicke, M., Tanga, C. M., & Gao, Z. (2020). Smallholder farmers' knowledge and willingness to pay for insect-based feeds in Kenya. *PLoS One*, *15*(3), 1–25. https://doi.org/10.1371/journal.pone.0230552

Chia, S. Y., Tanga, C. M., Osuga, I. M., Alaru, A. O., Mwangi, D. M., Githinji, M., Subramanian, S., Fiaboe, K. K. M., Ekesi, S., Loon, J. J., Van, A., & Dicke, M. (2019). Meal on Growth Performance, Blood Profiles and Economics of Growing Pigs in Kenya. *Animals*, *9*(705), 1–19. https://doi.org/10.3390/ani9100705

Chirwa, E. W. (2005). Adoption of fertiliser and hybrid seeds by smallholder maize farmers in southern Malawi. *Development Southern Africa*, *22*(1), 1–12. https://doi.org/10.1080/03768350500044065

Craig, S., & Kuhn, D. D. (2017). Fish Feed. *Virginia Cooperative Extension, 420–256(UNESCO 2015)*, 420–256.

FAO. (2013). Global Aquaculture Production Statistics for the year 2011. *Fisheries and Aquaculture Development*, *2011*(March), 3. www.fao.org/fishery/topic/16140/en

FAO. (2020). The State of World Fisheries and Aquaculture 2020: Sustainability in Action. *Rome*, *32*(6), Sustainability in action. Rome.https://doi.org/10.4060/ca9229en

Gahukar, R. T. (2011). Entomophagy and human food security. *International Journal of Tropical Insect Science*, *31*(3), 129–144. https://doi.org/10.1017/S1742758411000257

Gasco, L., Acuti, G., Bani, P., Dalle Zotte, A., Danieli, P. P., De Angelis, A., Fortina, R., Marino, R., Parisi, G., Piccolo, G., Pinotti, L., Prandini, A., Schiavone, A., Terova, G., Tulli, F., & Roncarati, A. (2020). Insect and fish by-products as sustainable alternatives to conventional animal proteins in animal nutrition. *Italian Journal of Animal Science*, *19*(1), 360–372. https://doi.org/10.1080/1828051X.2020.1743209

Gichangi, E., & Gatheru, M. (2018). Farmers' awareness and perception of climate change and the various adaptation measures they employ in the semi-arid eastern Kenya. *Climate Change*, *4*(14), 112–122.

Githukia, C. M., Drexler, S. S., Obiero, K. O., Nyawanda, B. O., Odhiambo, J. A., Chesoli, J. W., & Manyala, J. O. (2020). Gender roles and constraints in the aquaculture value chain in Western Kenya. *African Journal of Agricultural Research*, *16*(5), 732–745. https://doi.org/10.5897/AJAR2020.14783

Govorushko, S. (2019). Global status of insects as food and feed source: A review. *Trends in Food Science & Technology*, *91*, 436–445. https://doi.org/10.1016/j.tifs.2019.07.032

Gujarati, D. N. (2003). *Basic Econometrics* (fourth ed.). McGraw-Hill. https://doi.org/10.1038/278097a0

Halloran, A., Ayieko, M., Oloo, J., Konyole, S. O., Alemu, M. H., & Roos, N. (2021). What determines farmers' awareness and interest in adopting cricket farming? A pilot study from Kenya. *International Journal of Tropical Insect Science*, *41*(3), 2149–2164. https://doi.org/10.1007/s42690-020-00333-2

Hussain, M. A., Elyas, T., & Nasseef, O. A. (2013). Research Paradigms: A Slippery Slope for Fresh Researchers. *Life Science Journal*, *10*(4), 81–109.

Jairo, M., & E, K. (2019). Climate Knowledge, Adaptation and Intensity of Adaptation Strategies among Farmers in the Slopes of Mount Kenya | Semantic Scholar. *Journal of Climatology and Weather Forecasting*. https://www.semanticscholar.org/paper/Climate-Knowledge%2C-Adaptation-and-Intensity-of-in-Jairo-Korir/274d891d84d095eb4c3cbd11ee4afbe6e56cabfa

Jogo, W., Karamura, E., Kubiriba, J., Tinzaara, W., Rietveld, A., Onyango, M., Odongo, M., International, B., & Box, P. O. (2011). Farmers ' awareness and application of banana Xanthomonas wilt control options: The case of Uganda and Kenya. *3*(11), 561–571.

Ke, B. S. (2016). Dried Insect products for compounding animal feeds - Specification. *Kenya Bureau of Standards, DKS 2711*, 1–7.

Kelemu, S., Niassy, S., Torto, B., Fiaboe, K., Affognon, H., Tonnang, H., Maniania, N. K., & Ekesi, S. (2015). African edible insects for food and feed: Inventory, diversity, commonalities and contribution to food security. *Journal of Insects as Food and Feed*, *1*(2), 103–119. https://doi.org/10.3920/JIFF2014.0016

King, G. (1986). How Not to Lie with Statistics: Avoiding Common Mistakes in Quantitative Political Science. *American Journal of Political Science*, *30*(3), 666. https://doi.org/10.2307/2111095

Kruijssen, F., McDougall, C. L., & van Asseldonk, I. J. M. (2018). Gender and aquaculture value chains: A review of key issues and implications for research. *Aquaculture*, *493*(September 2017), 328–337. https://doi.org/10.1016/j.aquaculture.2017.12.038

Liland, N. S., Biancarosa, I., Araujo, P., Biemans, D., Bruckner, C. G., Waagbø, R., Torstensen, B. E., Lock, E. J., & Wegener, C. (2017). Modulation of nutrient composition of black soldier fly (Hermetia illucens) larvae by feeding seaweed-enriched media. *PLoS One*, *12*(8), 1–23. https://doi.org/10.1371/journal.pone.0183188

Mackenzie, N., & Knipe, S. (2006). Research dilemmas: Paradigms, methods and methodology. *Issues in Educational Research*, *16*(2), 193–205. https://brainmass.com/file/125444/mackenzie.pdf%0Ahttp://msessd.ioe.edu.np/wp-content/uploads/2017/04/Handout4L4pages11-Research-Dilemmas-etc.pdf

Madau, F. A., Arru, B., Furesi, R., & Pulina, P. (2020). Insect farming for feed and food production from a circular business model perspective. *Sustainability (Switzerland)*, *12*(13), 5418. https://doi.org/10.3390/su12135418

Magalhães, R., Sánchez-López, A., Leal, R. S., Martínez-Llorens, S., Oliva-Teles, A., & Peres, H. (2017). Black soldier fly (Hermetia illucens) pre-pupae meal as a fish meal replacement in diets for European sea-bass (Dicentrarchus labrax). *Aquaculture*, *476*, 79–85. https://doi.org/10.1016/j.aquaculture.2017.04.021

Mbugua, H. M. (2008). Aquaculture in Kenya: Status, challenges and opportunities. *AquaDocs*.

McKitterick, L., Quinn, B., McAdam, R., & Dunn, A. (2016). Innovation networks and the institutional actor-producer relationship in rural areas: The context of artisan food production. *Journal of Rural Studies*, *48*, 41–52. https://doi.org/10.1016/j.jrurstud.2016.09.005

Mengistu, M. G., Simane, B., Eshete, G., & Workneh, T. S. (2016). Factors affecting households' decisions in biogas technology adoption, the case of Ofla and Mecha Districts, northern Ethiopia. *Renewable Energy*, *93*, 215–227. https://doi.org/10.1016/j.renene.2016.02.066

Muatha, I. T., Otieno, D. J., & Nyikal, R. A. (2017). Determinants of smallholder farmers ' awareness of agricultural extension devolution in Kenya. *African Journal of Agricultural Research*, *12*(51), 3549–3555. https://doi.org/10.5897/AJAR2017.12603

Munguti, J. M., Kim, J. D., & Ogello, E. O. (2014). An overview of Kenyan aquaculture: Current status, challenges, and opportunities for future development. *Fisheries and Aquatic Sciences*, *17*(1), 1–11. https://doi.org/10.5657/FAS.2014.0001

Munguti, J., Obiero, K., Orina, P., Mirera, D., Kyule, D., Mwaluma, J., Opiyo, M., Musa, S., Ochiewo, J., Njiru, J., Ogello, E., & Hagiwara, A. (2021). *State of Aquaculture Report 2021: Towards Nutrition Sensitive Fish Food Production Systems*. Techplus Media House.

Munyua, H., & Stilwell, C. (2010). A mixed qualitative-quantitative-participatory methodology: A study of the agricultural knowledge and information system (AKIS) of small □ scale farmers in Kirinyaga district, Kenya. *Library Management*, *31*(May), 5–18. https://doi.org/10.1108/01435121011013359

Mustafa, G., Latif, I. A., Bashir, M. K., Shamsudin, M. N., & Daud, W. M. N. W. (2019). Determinants of farmers' awareness of climate change. *Applied Environmental Education and Communication*, *18*(3), 219–233. https://doi.org/10.1080/1533015X.2018.1454358

Nairuti, R. N., Musyoka, S. N., Yegon, M. J., & Opiyo, M. A. (2022). Utilization of black soldier fly (Hermetia illucens linnaeus) larvae as a protein source for fish feed: A review. *Aquaculture Studies*, *22*(2). https://doi.org/10.4194/AQUAST697

Newton, G. L., Sheppard, D. C., & Burtle, G. J. (2008). Black soldier fly prepupae - a compelling alternative to fish meal and fish oil. Research summary of "Animal Manure and Waste Utilization, Treatment and Nuisance Avoidance for a Sustainable Agriculture". (Available at: http://www.extension.org/sites/defau. *The National Marine Fisheries Service*, 15.

Obi-Egbedi, O., Ogungbite, O., & Oluwatayo, I. (2020). Genetically Modified Crops' Technology and its Awareness among Smallholder Farmers in Nigeria. *Zeszyty Naukowe SGGW w Warszawie - Problemy Rolnictwa Światowego*, *20*(4), 58–67. https://doi.org/10.22630/prs.2020.20.4.22

Obiero, K., Brian Mboya, J., Okoth Ouko, K., & Okech, D. Economic feasibility of fish cage culture in Lake Victoria, Kenya. (2022). *Aquaculture, Fish and Fisheries*, *2*(6), 484–492. *July*. https://doi.org/10.1002/aff2.75

Obiero, K., Meulenbroek, P., Drexler, S., Dagne, A., Akoll, P., Odong, R., Kaunda-Arara, B., & Waidbacher, H. (2019). The contribution of fish to food and nutrition security in Eastern Africa: Emerging trends and future outlooks. *Sustainability (Switzerland)*, *11*(6), 1–15. https://doi.org/10.3390/su11061636

Obiero, K. O., Opiyo, M. A., Munguti, J. M., Orina, P. S., Kyule, D., Yongo, E., Githukia, C. M., Charo-Karisa, H., Opiyo, M. A., Munguti, J. M., & Charo-Karisa, H. (2014). Consumer preference and marketing of farmed Nile Tilapia (Oreochromis niloticus) and African Catfish (Clarias gariepinus. *Kenya: Case Study of Kirinyaga and Vihiga Counties Correspondence*, *1*(5), 67–76.

Obwanga, B., Soma, K., Ingasia Ayuya, O., Rurangwa, E., van Wonderen, D., Beekman, G., & Kilelu, C. (2020). Exploring enabling factors for commercializing the aquaculture sector in Kenya. *3R Kenya Research Report*, 1–55.

Odende, T., Ogello, E. O., Iteba, J. O., Owori, H., Outa, N., Obiero, K. O., Munguti, J. M., Kyule, D. N., Kimani, S., & Osia, M. M. (2022). Promoting Sustainable Smallholder Aquaculture Productivity Through Landscape and Seascape Aquapark Models: A Case Study of Busia County, Kenya. *Frontiers in Sustainable Food Systems*, *6*(June), 1–16. https://doi.org/10.3389/fsufs.2022.898044

Onsongo, V. O., Osuga, I. M., Gachuiri, C. K., Wachira, A. M., Miano, D. M., Tanga, C. M., Ekesi, S., Nakimbugwe, D., & Fiaboe, K. K. M. (2018). Insects for income generation through animal feed: Effect of dietary replacement of soybean and fish meal with black soldier fly meal on broiler growth and economic performance. *Journal of Economic Entomology*, *111*(4), 1966–1973. https://doi.org/10.1093/jee/toy118

Opiyo, M. A., Marijani, E., Muendo, P., Odede, R., Leschen, W., & Charo-Karisa, H. (2018). A review of aquaculture production and health management practices of farmed fish in Kenya. *International Journal of Veterinary Science and Medicine*, *6*(2), 141–148. https://doi.org/10.1016/j.ijvsm.2018.07.001

Orina, S., Ogello, E. O., Kembenya, E. M., & Muthoni, C. (2018). State of Cage Culture in Lake Victoria, Kenya. *1*(2019), 5–47.

Pituch, K. A., & Stevens, J. P. (2020). Binary Logistic Regression. *Applied Multivariate Statistics for the Social Sciences*, 454–490. https://doi.org/10.4324/9781315814919-16

Popoff, M., MacLeod, M., & Leschen, W. (2017). Attitudes towards the use of insect-derived materials 1 in Scottish salmon feeds. *Journal of Insects as Food and Feed*, *3*(2), 131–138. https://doi.org/10.3920/JIFF2016.0032

Rumbos, C. I., Mente, E., Karapanagiotidis, I. T., Vlontzos, G., & Athanassiou, C. G. (2021). Insect-Based Feed Ingredients for Aquaculture: A Case Study for Their Acceptance in Greece. *Insects*, *12*(7), 586. https://doi.org/10.3390/insects12070586

Sánchez-Muros, M. J., Barroso, F. G., & Manzano-Agugliaro, F. (2014). Insect meal as renewable source of food for animal feeding: A review. *Journal of Cleaner Production*, *65*, 16–27. https://doi.org/10.1016/j.jclepro.2013.11.068

Ssepuuya, G., Namulawa, V., Mbabazi, D., Mugerwa, S., Fuuna, P., Nampijja, Z., Ekesi, S., Fiaboe, K. K. M., & Nakimbugwe, D. (2017). Use of insects for fish and poultry compound feed in sub-Saharan Africa - a systematic review. *Journal of Insects as Food and Feed*, *3*(4), 289–302. https://doi.org/10.3920/JIFF2017.0007

Šūmane, S., Kunda, I., Knickel, K., Strauss, A., Tisenkopfs, T., des Ios Rios, I., Rivera, M., Chebach, T., & Ashkenazy, A. (2018). Local and farmers' knowledge matters! How integrating informal and formal knowledge enhances sustainable and resilient agriculture. *Journal of Rural Studies*, *59*, 232–241. https://doi.org/10.1016/j.jrurstud.2017.01.020

Ulhaq, I., Pham, N. T. A., Le, V., Pham, H. C., & Le, T. C. (2022). Factors influencing intention to adopt ICT among intensive shrimp farmers. *Aquaculture*, *547*(6), 519–532. https://doi.org/10.1016/j.aquaculture.2021.737407

Ullah, A., Saqib, S. E., & Kächele, H. (2022). Determinants of Farmers' Awareness and Adoption of Extension Recommended Wheat Varieties in the Rainfed Areas of Pakistan. *Sustainability (Switzerland)*, *14*(6), 1–18. https://doi.org/10.3390/su14063194

van der Fels-Klerx, H. J., Camenzuli, L., Belluco, S., Meijer, N., & Ricci, A. (2018). Food Safety Issues Related to Uses of Insects for Feeds and Foods. *Comprehensive Reviews in Food Science and Food Safety*, *17*(5), 1172–1183. https://doi.org/10.1111/1541-4337.12385

Vernooij, A. G., & Veldkamp, T. (2018). Insects for Africa; Developing business opportunities for insects in animal feed in Eastern Africa. *Wageningen Livestock Research, Report*, *1150*, 30. https://doi.org/10.18174/470617

Wood, B. A., Blair, H. T., Gray, D. I., Kemp, P. D., Kenyon, P. R., Morris, S. T., Sewell, A. M., & Amaral, L. A. N. (2014). Agricultural science in the wild: A social network analysis of farmer knowledge exchange. *PLoS One*, *9*(8), e105203. https://doi.org/10.1371/journal.pone.0105203