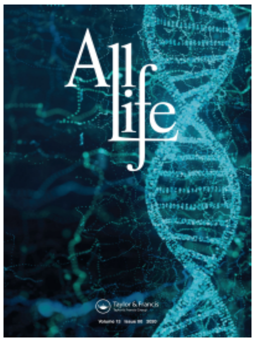

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Using technology acceptance model to understand fish farmers' intention to use black soldier fly larvae meal in Nile tilapia production in Kenya

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ABSTRACT

The purpose of this study was to identify the underlying socio-psychological factors that influence pond and cage farmers' intentions to adopt Black Soldier Fly Larvae (BSFL) in Kenya. Based on the Technology Acceptance Model (TAM), this study empirically investigated the relationship between TAM constructs, namely Perceived Ease of Use (PEOU), Perceived Usefulness (PU), Attitude towards Use (ATT), and Behavioral Intention (BI) to use BSFL. The study used a cross-sectional survey design to collect primary data from 211 randomly selected cage operators (98) and pond farmers (113) in Kenya's Siaya, Kisumu, and Homabay Counties. A structural equation model was employed to examine hypothesized paths in the uptake of BSFL meal with the aid of SmartPLS 3. The inner model path coefficients suggested that ATT had the strongest effect on farmers' intentions to adopt BSFL (0.411). Further, PU had a greater relative influence on intention to adopt BSFL than PEOU based on the model path coefficients of 0.319 and 0.178 respectively. This indicates that the more respondents believe BSFL is useful in their fish farm's production conditions, the more likely they are to adopt BSFL. Consequently, these findings have direct implications for policy development and the potential use of BSFL in aquaculture.

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Black soldier fly larvae; Nile tilapia; partial least squares; structural equation model; technology acceptance model

Introduction

Aquaculture continues to grow at a 5.8% annual rate in most regions of the world, owing to the industry's rapid expansion and intensification (FAO 2020). Aquaculture is thus the world's fastest-growing food-producing industry, driving local economies and employing many people in the Sub-Saharan Africa (SSA) region, including Kenya (Hasimuna et al. 2020). Aquaculture uptake has recently improved significantly in most African countries, though its full potential is still far from being realized. Despite the significant potential for aquaculture development, the majority of SSA countries (excluding Nigeria) continue to report low aquaculture production (Tran et al. 2019; Mmanda et al. 2020). In Kenya's inland areas, the main culture species is Nile tilapia (*Oreochromis niloticus*), though African catfish (*Clarias gariepinus*) is also produced to some extent (Opiyo et al. 2018). Tilapia is the preferred culture species due to its rapid growth, disease resistance, ability to withstand low dissolved oxygen (DO) levels, and ease of producing fingerlings in captivity (Githukia et al. 2015; Fitzsimmons 2016). The domestic market for Nile tilapia is also quite promising (Quagrainie et al. 2010).

The sustainable intensification of aquaculture output necessitates an increase in the supply and development of inputs, primarily feedstuff, as well as their formulations and optimization (Alhazzaa et al. 2019). The main bottlenecks in boosting aquaculture in Kenya have been identified as a lack of quality and affordable aquafeeds due to the high cost of fish feeds (Amankwah et al. 2018). Depending on the farming system, feed accounts for at least 40–80% of the total variable cost (TVC) of production (Chia et al. 2020). The availability and accessibility of standardized cost-effective fish feeds is integral to the sustainability of a profitable aquaculture enterprise in Kenya. Because of the high protein requirements of fish, fish meal (FM) and soya bean meal (SBM) have become the primary protein sources (Nogales-Mérida et al. 2018).

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However, due to an increase in global protein demand, the costs of FM and SBM have dramatically grown in the recent decade compared to the other protein sources utilized in feed (Van Huis et al. 2013; Muin et al. 2017; Nogales-Mérida et al. 2018). FM is also utilized in animal feeds, which pushes up demand and market pricing. Significant advancements in feed efficiency have been made in the last two decades as a result of a better understanding of enhanced feed management and the use of a broader choice of alternative components to build balanced digestible diets. Feed management is particularly important in the context of encouraging the utilization of locally sourced non-conventional feed protein ingredients to improve the long-term sustainability of tilapia culture, both with respect to resource utilization and minimization of feeding costs (Mmanda et al. 2020). Arru et al. (2019) suggested that alternative protein sources should be readily available and accessible, have amino acids comparable to or better than fishmeal, and have palatability comparable to fishmeal. In this context, there has been an increase in interest in using insect meals as a potential feed alternative in fish farming (Riddick 2013; Amza and Tamiru 2017; Magalhães et al. 2017; Nyakeri et al. 2017; Ibitoye and Oyetunji 2019; Chia et al. 2020). Due to its high energy conversion efficiency, good nutritional content, and benefits in fish development and health improvement, insect protein continues to gain significant scientific interest (Mousavi et al. 2020).

For the animal feed industry, the Black Soldier Fly (BSF) is the most commonly farmed insect. It's also commonly utilized in organic waste treatment as a bio-convertor. At the same time, it can be used as an alternate protein source in livestock and aquaculture (Lalander et al. 2015; Vogel et al. 2018). In the last ten years, there has been an increase in research and industrial-scale production of Black Soldier Fly Larvae (BSFL) as feed ingredients (FAO 2020; Wang and Shelomi 2017). The BSFL has a high protein content (40% dry weight (DW)) and a well-balanced essential amino acid profile (AA) (Henry et al. 2015; Liland et al. 2017; Wang and Shelomi 2017).

Some fish feeding trials have effectively established that replacing FM with BSFL meal in aquafeeds has no negative effects on growth or performance (Cummins et al. 2017; Renna et al. 2017; Belghit et al. 2018; Dumas et al. 2018; Elia et al. 2018).

The use of BSFL as a novel alternative element in aquaculture feeds is an example of innovation.

While the nutritional qualities of these ingredients are vital for fish growth, their perceived utility and possible acceptability by fish farmers are also important, and must be elicited to ensure that these new aquafeeds are used and adopted long-term as part of improved feeding practices (Brugere et al. 2021). Farmer decision-making research have generally relied on economic models and socioeconomic considerations. As a result, these two approaches have been employed in a variety of research to better understand how farmers make decisions (Yazdanpanah et al. 2022). Previous studies suggest that human decisions do not always seek to maximize profit, with some behaviors based on individual and intrinsic motivation (Zeweld et al. 2017; Despotović et al. 2019). As a result, greater insights into individual decisions can be gained through cognitive and social-psychological factors. Previous research has also used a quantitative socio-psychological model to understand the factors that influence agricultural adoption decisions. Michels et al. (2021), for example, investigated the use of drones in German agriculture. Lalani et al. (2016) investigated smallholder farmers' motivations for using conservation agriculture, Bijttebier et al. (2018) investigated farmer adoption of non-inversion tillage as a soil conservation measure, and Dessart et al. (2019) reviewed behavioral factors influencing the adoption of sustainable farming practices. Sok et al. (2021) went on to conduct a systematic review on the use of socio-psychological models among farmers. However, these cognitive and social-psychological factors, which have a high potential for predicting people's decision making, are typically overlooked and, as a result, are infrequently used in contemporary innovation adoption studies in aquaculture, particularly for BSFL (Zeweld et al. 2018). Furthermore, research on the acceptance of BSFL meal is new in Kenya, and few studies exist that investigate and confirm the determinants of BSFL use among fish farmers from a structured perspective. Additionally, drivers of farmers' intentions to use BSFL meal are not well documented. This study investigates how socio-psychological factors influence fish farmers' decisions to implement BSFL from a micro-level using a novel perspective.

This study seeks to add to the literature by examining factors influencing the adoption of BSFL meal while taking into account socio-psychological issues. Specifically, it aims to establish the intentions of fish farmers towards adopting BSFL and its various determinants using Structural Equation Model (SEM) so as to provide research recommendations for encouraging the adoption and upscaling of BSFL in Kenya and beyond. Thus, the study intends to validate if the TAM framework can also contribute to the understanding fish farmers' decision making with respect to the adoption of BSFL.

Theoretical framework

This study's conceptual model is based on the Technology Acceptance Model (TAM) theory. TAM is a well-known and significant modification to Fishbein and Ajzen's theories of planned behavior and theory of reason action (Ajzen 1991; Fishbein and Ajzen 1977). Davis (1989) developed the TAM, which is based on rational choice theory and provides useful guidelines for identifying the variables influencing users' acceptance of innovations (Castiblanco Jimenez et al. 2021). Because of its high predictive power, the TAM is the most widely used model for the intention to adopt a technology. According to TAM, perceived usefulness (PU) and perceived ease of use (PEOU) determine attitudes toward a novel product or technology and subsequent behavior when using the technology, as shown in Figure 1. Davis (1989) defines perceived ease of use as a person's belief that using a technology requires no effort. On the other hand, perceived usefulness is an individual's belief that a technology improves job performance, as defined by Michels et al. (2021). Both PU and PEOU, according to the TAM framework, influence an individual's intention to use a technology as well as its actual adoption. Furthermore, a person who perceives a technology to be simple also perceives the technology to be more useful (Davis 1989). Ulhaq et al. (2022) also note that PEOU can operate via PU, indicating that a technology's perceived ease of use can make it more useful.

Notably, according to the TAM framework, a fish farmer who perceives using BSFL as simple will be more likely to use it in fish production. Furthermore, if the farmer believes that using BSFL will help increase fish production output, he or she is more likely to adopt it. Furthermore, if a farmer believes that using BSFL is simple, he or she considers this novel feed to be more useful, which is consistent with the previous findings of Michels et al. (2021).

Attitude is defined as an individual's negative or positive feelings toward the behavior in question

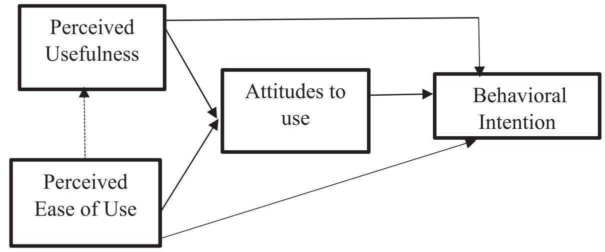

Figure 1. Research model illustrating the hypothetical influence of technology acceptance factors on intentions to use BSFL in fish farming.

(Fishbein and Ajzen 1975). TAM considers attitude as a mediator in the model, according to Kurkinen (2012). On the other hand, perceived ease of use and perceived usefulness are important predictors of attitude (Ducey and Coovert 2016; Verma et al. 2018). Accordingly, in the case of BSFL, if a farmer believes that BSFL are technically easy to use and using BSFL meal as useful, the farmer will form a favorable attitude towards BSFL meal.

In the TAM model, intention indicates how much a person is trying to do a specific behavior. Honkanen & Young (2015) noted that intention captures people's motivation to perform the behavior and their likelihood of following through it. A stronger intention for a behavior, in general, indicates that the behavior is more likely to be practiced (Ajzen 1991). Behavior (actual use) is always after the behavioral intention and is connected to it. Chang et al. (2016) found that farmers' desirable attitudes toward limiting water use could predict the adoption of water-saving policies. Previous research by Aren et al. (2013) found that perceived ease of use could positively affect intentions.

Based on the research model in Figure 1, seven hypotheses were formulated;

H_1: Perceived ease of use has a positive and significant influence on farmer attitude to use BSFL

H_2: Perceived ease of use has a positive and significant influence on farmer intentions to use BSFL

H_3: Perceived usefulness has a positive and significant influence on farmer attitude to use BSFL

H_4: Perceived usefulness has a positive and significant influence on farmer intentions to use BSFL

H_5: Attitude has a positive and significant influence on farmer intentions to use BSFL

H_6: Perceived ease of use has an indirect positive and significant influence on farmer intentions to use BSFL

H$_7$: Perceived usefulness has an indirect positive and significant influence on farmer intentions to use BSFL

The TAM has been used for agricultural research in several research areas including precision agriculture (Michels et al. 2021), acceptance of solar water pump by smallholder farmers (Zhou and Abdullah 2017), farmers adoption of organic rice and integrated production (Silva et al. 2017; Sharfuddin et al. 2018) respectively, consumption of iodine biofortified foods (Mogendi et al. 2016), among others. However, only few studies have used TAM in aquaculture-related studies (Obiero et al. 2019; Ghorbani & Ghorbani, 2020).

Materials and methods

Study area

The study was carried out in three riparian counties of Lake Victoria within the borders of Kenya namely Siaya, Kisumu and Homabay Counties. The lake is the largest tropical and the second largest freshwater lake in the world with a surface area of 68,000 km^2 (Aura et al. 2018). The study sites were selected based on existing geographical zones, high water resource potential, predominance of fish farming activities, adoption of pond and cage culture practices by farmers and presence of large number of active Nile tilapia fish farmers (Opiyo et al. 2018; Orina et al. 2018).

Research design

A cross-sectional survey design was used in this study to collect primary data on fish farmers' intentions to use BSFL. This study's sampling frame was defined as all active fish pond and cage farmers engaged in Nile tilapia culture in the study area. The respondents were chosen using a two-stage sampling technique. The first stage involved the purposive selection of the most tilapia-producing areas in the riparian counties of Lake Victoria Region, Kenya. Siaya, Kisumu, and Homabay counties were purposively selected in this study because they have the highest number of Nile tilapia farmers both in ponds and cage culture farming (Opiyo et al. 2018). The second stage involved selection of pond and cage farmers. In a 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 pond farmers who have spent more than two years in fish pond farming were considered because 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. A total of 211 fish farmers were randomly selected from a list of farmers provided by the Sub-County Fisheries Officers in each of the three selected counties. Using the 2019 Kenya National Bureau of Statistics (KNBS) data on the fish farmer's population of the three counties of interest (clusters) as reported by the Kenya Population and Housing Census, a proportionate to population size (PPS) of respondents for each county was computed to arrive at 211 respondents who were interviewed as in Table 1.

Table 1. Distribution of respondents by farmer category per county.

	County			
Farmer Category	Siaya	Kisumu	Homabay	Total
Fish pond farmer	45	33	35	113
Cage farmer	35	34	29	98
Total	**80**	**67**	**64**	**211**

Note: Survey (2021).

A structured questionnaire was designed based on the TAM and included other socio-demographic variables. The face-to-face survey was conducted by trained enumerators between December 2020 and April 2021. The survey tool comprised of two main sections; the first section containing questions on farm and farmer characteristics. Other information collected were feeding practices, cost of feeds, type, and sources of feeds used on the farm and other issues relating to fish farming. In the second section, participants were asked to evaluate a number of statements (constructs derived from literature review) on a five-point Likert scale which ranged from 1 = strongly disagree to 5 = strongly agree, indicating the degree to which they agreed with the set of statements. The statements were designed to reveal their intentions, attitude, perceived usefulness and perceived ease of use of BSFL (Table A1). The research constructs were developed solely on already validated measures. All scale items were rearticulated to relate exactly to the context of the current study's requirement. A minimum of three items were used per construct so as to guarantee suitable reliability in line with the recommendation by Nunnally (1978). The statements serve as the indicators to estimate the latent variables.

The questionnaire was pre-tested in order to eliminate any potential problems in using it such as time management, complexity, suitability, and appropriateness. Feedback from the pre-test was used to refine the questionnaire. The final questionnaire was loaded into Kobo Collect platform, which was used to collect data using smartphones. Informed consent was sought from the respondents before conducting the face-to-face interviews. All interviews were conducted in line with the World Health Organization (WHO) guidelines on COVID-19 prevention.

Data analysis

Data were received on an aggregate server in real time, where regular quality checks were done to ensure that the data collected met the required standards. On completion of the field survey, the final datasets were downloaded from the server as CSV files and exported to SPSS version 25 software for analysis. Descriptive analysis was done by calculating frequencies, means, and standard errors. Factors listed as weak indicators were excluded from subsequent analyses based on significance of bivariate and multivariate relationships. Statistical significance was considered significant at 5% level.

Analytical framework

The inter-relationship between variables in the conceptual model was assessed using a partial least square structural equation modeling (PLS-SEM) technique. TAM constructs are latent, and thus cannot be observed or measured directly. Hence, a set of measures were derived from a list of questions to act as indicators for the underlying latent variable. As a result, the structural equation model includes an outer sub-model that specifies the relationships between the latent variables and their observed indicators. An inner sub-model is then added, which evaluates the relationship between the dependent and independent latent variables, as well as their respective path coefficients (Mutyasira et al. 2018). Structural equation modeling (SEM) is a method that combines factor analysis and multiple regression analysis (Chin 1998). SEM enables the simultaneous estimation of cause–effect relationships between multiple dependent and independent latent variables, as well as the testing of theoretical relationships. Covariance-based SEM (CB-SEM) and partial least square SEM (PLS-SEM) are the two types of SEM (Haenlein and Kaplan 2004). According to Hair et al. (2017), Partial Least Squares SEM (PLS-SEM) was chosen to test the hypotheses in this study for two reasons: (1) the research objective is exploratory theory based on total variance in the area of agricultural technology adoption, and the goal of this analysis is prediction, and (2) the research objective is to use latent variable scores in subsequent analyses (Ringle et al. 2014). PLS-SEM was a good fit for data analysis in this study because the data was not normally distributed and the sample size was small. Compared to covariance-based SEM, PLS-SEM was more appropriate for non-normal data and small sample sizes (Hair et al. 2014). PLS-SEM is evaluated in two steps, the first step is to assess the relationship between the indicators and the latent variable outer model (measurement model). The causal relationship between the latent variables is estimated in the second step (inner model; structural model). Smart PLS 3.0 was used to examine the structural model and hypothesis. To estimate t-statistics to check for statistical significance of the standardized path coefficients (β), a bootstrapping procedure with 5000 sub-samples was applied.

Results and discussion

Descriptive statistics of fish farmers

Socio-economic characteristics of the respondent's fish farmers showing categorical and continuous variables are presented in Tables 2 and 3 respectively. Pond farmers constituted 53.6% of the farmers while cage farmers constituted 46.4%. Males constituted 73.6% of all fish farmers with 26.1% being females. The possible reason for male dominance in fish farming is attributed to the tedious and energy-sapping nature of activities involved which most women may not be able to cope with. Previous findings have shown that participation by women in fish farming operations varies greatly between African countries (Veliu et al. 2009; FAO 2014; Jahan et al. 2015). About 52.1% of

Table 2. Fish Farmer Socio-economic profile for categorical variables.

Categorical Variables	Frequency (n)	Percent (%)
Category of fish farmer		
Fish pond farmer	113	53.6
Cage farmer	98	46.4
Gender		
Female	55	26.1
Male	156	73.9
Education level		
Primary level	40	19.0
Secondary level	110	52.1
University level	61	28.9
Reasons for fish farming		
Commercial	199	94.3
Subsistence	12	5.7
Occupation		
Farming	114	54.0
Off-farm business	65	30.8
Salaried	32	15.2
Access to credit		
No	129	61.1
Yes	82	38.9
Access to extension services		
Yes	92	43.6
No	119	56.4
Group membership		
No	170	80.6
Yes	41	19.4

the fish farmers had attained secondary level of education. Farmers with a higher level of formal education were more likely to adopt fish farming techniques than those with less formal education since they are likely to attend various fish training seminars, comprehend and apply information packages. Majority of the fish farmers (94.3%) were involved in commercial fish production with only 5.7% involved in subsistence fish production. There is an emerging commercial-scale aquaculture industry in Kenya comprising both large- and small-to medium-scale production.

About 54% of the fish farmers were involved in fish farming as their major occupation, with 30.8% involved in off-farm business and 15.2% in salaried employment. This implies that the majority of the fish farmers have diversified income sources and as such reduces the vulnerability of farmers to risks. Sixty one percent of fish farmers had not accessed credit facilities to boost their fish farming activities while 56.4% had not accessed extension services and 80.6% were not members of fish farming groups. The extension service has a vital role of increasing and improving fish production through their linkage between researchers and end-users. Olaoye et al. (2016) found that adoption of improved technologies could be easily facilitated to group of fish farmers because it is easier to demonstrate the technologies to a group than to an individual.

The findings reveal that the sampled respondents composed of middle-aged fish farmers with an average age of around 43 years which is in line with findings by Muddassir et al. (2019). In relation to years of fish farming experience, the minimum years of experience was found to be 1 year while the maximum was 12 years with a mean of 3.65 years. Regarding the stocking density for ponds and cages, the average stocking density was 3665 fish per pond/cage. Fish farmers had a minimum of 1 pond/cage and a maximum of 195 ponds/cages. The average number of pond/cage ownership was 8 ponds/cages. There was great variation in the size and number of fishponds and cages between fish farming systems within the study sites. This can be explained by existing conditions on each farm including the nature of soils, climatic conditions, availability of labors, building materials, investment capital, and geographical location. This corresponds with previous findings about pond-based fish farming in Kenya, where the majority of smallholder farmers had a minimum of 1 pond to a maximum of 60 fishponds (Obwanga et al. 2017). Fish farmers sourced their fish feeds on an average distance of 52.52 km from the fish farms. The study also found that fish farmers were feeding their fish on average twice a day.

Measurement model analysis

Prior to the measurement model analysis, Harman's single-factor test as suggested by Podsakoff et al. (2003)

Table 3. Fish Farmer Socio-economic profile for continuous variables.

Continuous Variables	Minimum	Maximum	Mean	Std. Deviation
Age in years of respondent	19	82	43.04	11.674
Years of farming experience	1	12	3.65	2.412
Stocking density per pond/cage in m^2	100	25,000	3664.69	5606.955
Number of ponds/cages owned	1	195	7.53	20.378
Distance to feeds source in Km	1	800	52.52	103.042
Number of times of feeding in a day	1	4	1.93	.923

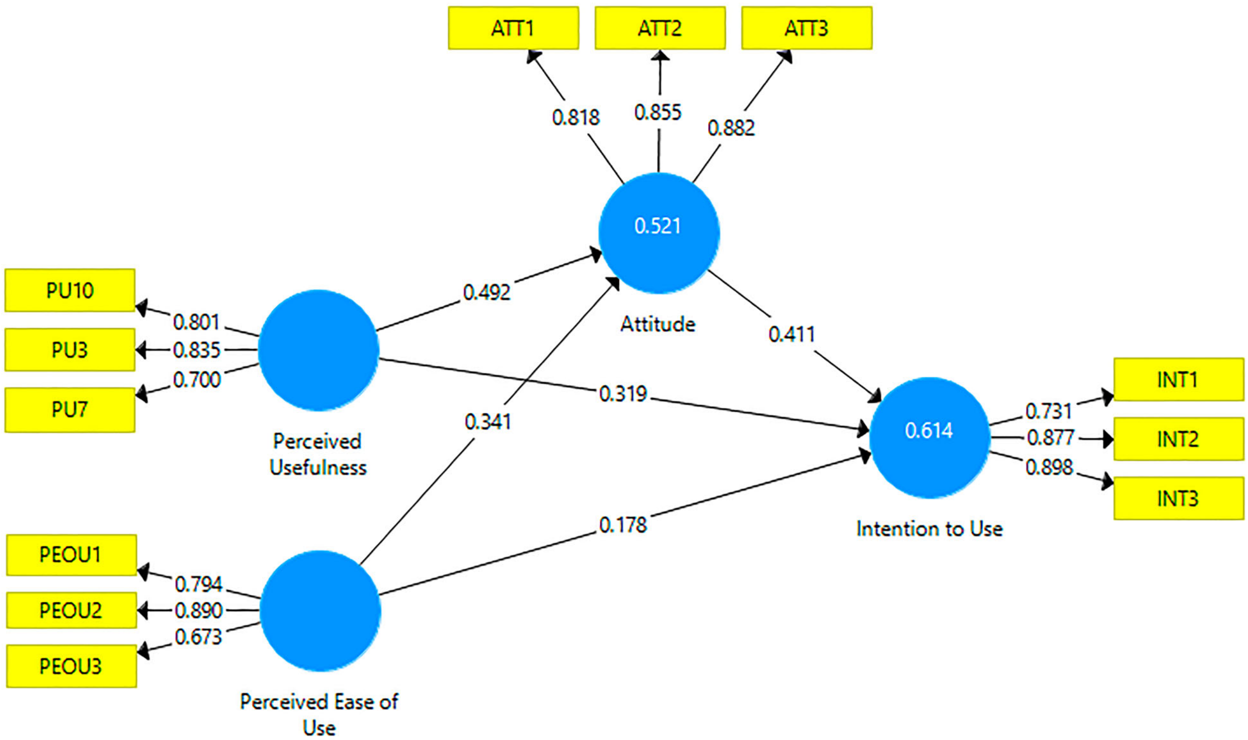

Figure 2. Indicator loadings and path coefficients of key behavioral constructs.

was conducted on the four constructs in our proposed model including PEOU, PU, ATT, and INT to address the issue of common method biases. Results show that there are six factors whose eigenvalues are greater than one, and the variation of the first factor is only 31.15% among the unrotated principal component factors, indicating that the common method bias was unlikely a problem in this study (Table A2).

Convergent and discriminant validity tests were run as part of the measurement model analysis. Convergent validity is concerned with whether the observable variables (items) share sufficient variance in the construct/latent variable. This was evaluated using three indicators: factor loadings, composite reliability, and extracted average variance (AVE). To be retained for the next analysis, an item should have a minimum of 0.707 loading on its theoretical assigned latent construct. Twelve measurement items (PU1, PU2, PU4, PU5, PU6, PU8, PU9, PEOU4, ATT4, ATT5, ATT6, ATT7) had factor loadings below the minimum value, and were exempted from subsequent analysis. The final results of these analyses are presented in Table A3 and Figure 2. The results in Table A3 show that all the constructs, the factor loadings are above 0.6. The scales used in this study were derived from previous research. According to the findings, both Cronbach's alpha and composite reliability, which are alternative measures of internal consistency and reliability, revealed that all constructs had high internal consistency (Hair et al. 2011). The Cronbach alpha values ranged from 0.684 to 0.811, composite reliability ranged from 0.823 to 0.888 while the average variance extracted ranged from 0.610 to 0.726. The composite reliability estimates are above the recommended threshold of 0.7 and the AVEs of the constructs are above 0.5. These results generally confirm the convergent validity of the measurement model (Table 4).

Discriminant validity was assessed by comparing the values of correlates to square root of AVE values. The preconditions are that the correlates must be smaller than the square root of AVE to satisfy the condition of discriminant validity (Fornell and Larcker 1981). The Fornell–Larcker Criterion results (Table 5) show that discriminant validity was well established across all the constructs.

The results show that the discriminant validity of the model has been established, since the HTMT values are significantly lower than 1 (Henseler et al. 2015). The HTMT ratios as in Table 6 were all within the cut off levels of below 0.9 except for the HTMT for intention to use which was exactly 0.9 (Hair et al. 2016).

Table 4. Internal consistency: Cronbach's Alpha, composite reliability, and average variance extracted.

Latent Variable	Cronbach's Alpha	Composite reliability (CR)	Average variance extracted (AVE)
Attitude	0.811	0.888	0.726
Intention to use	0.786	0.876	0.704
Perceived ease of use	0.701	0.831	0.625
Perceived usefulness	0.684	0.823	0.610

Cutoff levels: Cronbach's alpha $>$ 0.7 (0.6); composite reliability (CR) $=$ 0.6–0.9; Average Variance Extracted (AVE) $>$ 0.5; $n = 211$.

Table 5. Fornell-Larcker criterion analysis for checking discriminant validity.

	Attitude	Intention to Use	Perceived Ease of Use	Perceived Usefulness
Attitude	**0.852**			
Intention to Use	0.724	**0.839**		
Perceived Ease of Use	0.579	0.57	**0.79**	
Perceived Usefulness	0.657	0.675	0.482	**0.781**

Note: Values on the diagonal (bolded) are the square root of the average variance extracted (AVE) while the off diagonals are correlations.

Structural model analysis

Prior to the analysis of the structural model, a collinearity test using the variance inflation factor (VIF) was performed to assess the level of collinearity threat among the independent variables. The results of the multi-collinearity analysis showed that there was no multi-collinearity between latent variables in the structural model with a VIF $<$ 5 as shown in Table A4. Ideally, VIF values of 5 or lower are desirable to avoid the collinearity problems (Hair et al. 2011).

Having established the collinearity of the independent variables and validity of the measurement model, the next step was to examine the path coefficients and to test the theoretical relationships (Figure 3). Path analysis was applied to show the direct, indirect, and total impacts of the independent constructs on behavioral intentions, and thereby, fish farmers' application behavior. The determination coefficient (R^2) was applied to show the variances accounted for by each of the constructs and total variance accounted (Table 7).

Since standardized path coefficients were estimated, a comparison of the coefficients' magnitudes indicates the degree each exogenous latent variable influences the endogenous latent variable. The inner model path coefficients suggest that ATT has the strongest effect on farmers' intentions to adopt BSFL (0.411), followed by PU (0.319), and PEOU (0.178). In line with previous studies (McDonald et al. 2016; Obiero et al. 2019), PU had a greater relative influencse on intention to adopt BSFL than PEOU based on the model path coefficients of 0.319 and 0.178, respectively.

The structural model (Figure 2) shows the relationship between one variable and another variable with beta (β) and R-squared (R^2) values. The results showed that the R^2 for attitude was 0.521, and the R^2 for intention to use BSFL was 0.614. The R^2 value of intention to use could be explained or influenced by 61.4% of the independent variables (ATT, PU, and PEOU), and the rest were influenced by other factors outside this model.

Bootstrapping was used to obtain t-statistics to test the statistical significance of both the indicators (outer model) and structural model constructs (inner model). The path significance is used to test the hypotheses formulated in this study. Two-tailed t-tests of significance at 5% level were carried out, with t-statistic values larger than 1.96 indicating significance. Bootstrapping was also used to derive t-statistics in the outer model, and the results showed that all the factor loadings were statistically significant at 5% level. The full results are provided in Figure 3.

Finally, the predictive relevance (Q^2) was determined using the blindfolding procedure in PLS-SEM version 3. According to Hair et al. (2017), the Q^2 should be greater than zero which means that the predictor variable possesses the predictive relevance for the criterion variable. The Q^2 values of attitude was 0.370 and that of intention to use was 0.424 which signifies that the research model had good predictive relevance.

Hypothesis results

The coefficient of PEOU on ATT was positive and significant confirming hypothesis H_1 ($\beta = 0.341$,

Table 6. Heterotrait-Monotrait (HTMT) criterion.

	Attitude	Intention to Use	Perceived Ease of Use	Perceived Usefulness
Attitude				
Intention to Use	0.900			
Perceived Ease of Use	0.745	0.754		
Perceived Usefulness	0.866	0.882	0.651	

Note: Cut-off level: HTMT < 0.9.

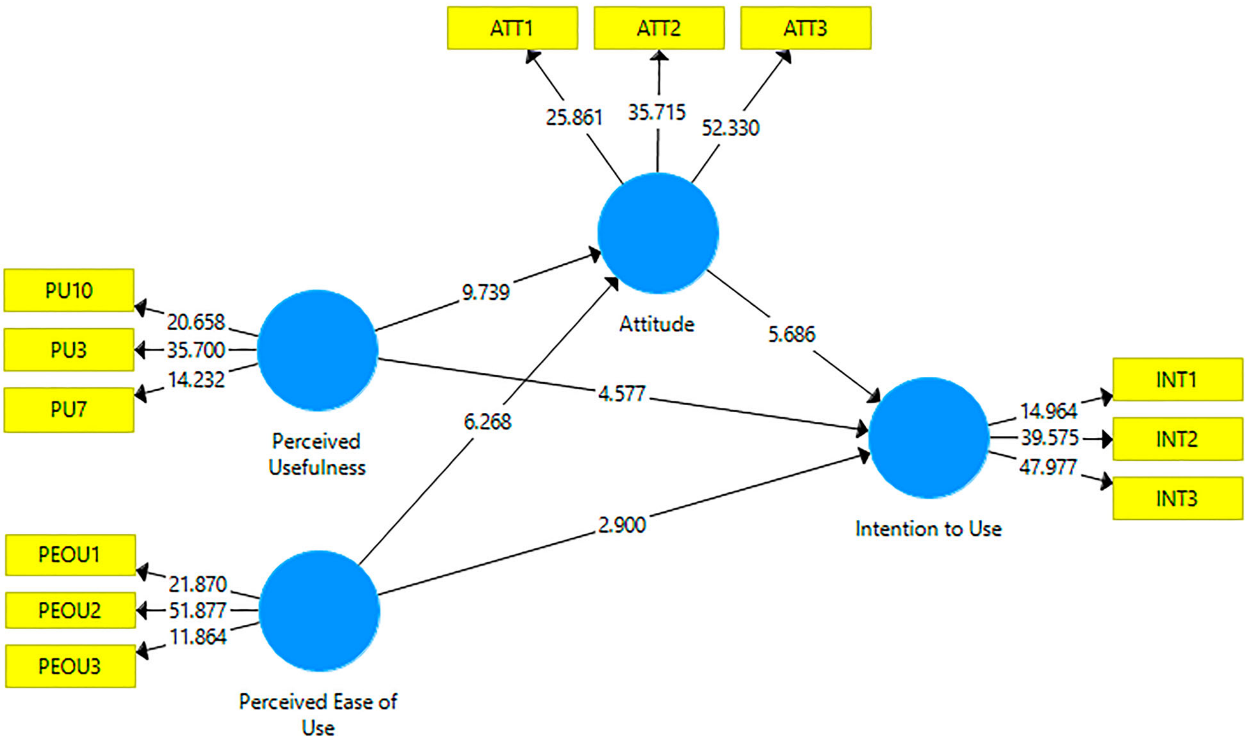

Figure 3. Bootstrapping results showing t-statistics.

Table 7. Results of path coefficients and hypothesis testing, $n = 211$.

Path correlation	Path coefficients	T Statistics[a]	*P* Values	Ho Support
Direct Effects				
Perceived Ease of Use − > Attitude (H_1)	0.341***	6.268	0.000	Supported
Perceived Ease of Use − > Intention to Use (H_2)	0.178**	2.900	0.004	Supported
Perceived Usefulness − > Attitude(H_3)	0.492***	9.739	0.000	Supported
Perceived Usefulness − > Intention to Use (H_4)	0.319***	4.577	0.000	Supported
Attitude − > Intention to Use (H_5)	0.411***	5.686	0.000	Supported
Specific Indirect Effects				
Perceived Ease of Use − > Attitude − > Intention to Use (H_6)	0.140***	4.050	0.000	Supported
Perceived Usefulness − > Attitude − > Intention to Use(H_7)	0.202***	4.493	0.000	Supported

$***p < 0.01$, $**p < 0.05$; [a]calculated by bootstrapping (5000 subsamples); Attitude $R^2 = 0.516$; Intention to use $R^2 = 0.614$; Attitude $Q^2 = 0.370$; Intention to Use $Q^2 = 0.424$.

$p = 0.001$) while the coefficient of PU on ATT was positive and significant confirming hypothesis H_3 ($\beta = 0.492$, $p = 0.000$). Thus, both PU and PEOU had significant impacts on fish farmers' attitudes. Attitude, in turn, had a significant impact on behavioral intention. The coefficient of ATT on INT was positive and significant confirming hypothesis H_5 ($\beta = 0.411$, $p = 0.000$). This finding on influence of attitude on intention to use BSFL is similar to the results of Maleksaeidi and Keshavarz (2019), Meijer et al. (2015) and Yazdanpanah and Forouzani (2015). This result implies that farmers who had positive attitude towards using BSFL were more eager to use it in their fish farms.

The coefficient of PEOU on INT was positive and significant confirming hypothesis H_2 ($\beta = 0.178$, $p = 0.004$). If the BSFL is perceived as easy to use, fish farmers have a higher intention to use it. PEOU reflects fish farmer's confidence in using BSFL. This is in line with the findings of Giampietri and Trestini (2020) and Zhou and Abdullah (2017). The coefficient of PU on

INT was positive and significant confirming hypothesis H_4 ($\beta = 0.319, p = 0.000$). This indicates the more the respondents consider BSFL to be useful in their fish farm's production conditions, the higher is their intention toward adopting BSFL. The findings are consistent with those of Caffaro et al. (2020) who found an association between PU and intention to adopt smart farming technologies. Similarly, Li et al. (2021) found that PU had a positive impact on farmers' participation intention regarding vegetable traceability systems. These results are consistent with TAM that proposes that PU and PEOU are the two major causal variables in determining acceptance and usage behavior of a technology (Obiero et al. 2019). Bagheri et al. (2021) found both positive direct and indirect impacts of PU on INT in the use of biological inputs among cereal farmers. Previous studies have found a direct impact of PU on INT, while PEOU has shown direct impact both on PU and INT (Flett et al. 2004). Perceived usefulness is important to change and reinforcement of behavioral attitude and behavioral intention. It has a significant role in the model so that perceived ease of use and attitude of confidence affect behavioral attitude through perceived usefulness. A study by Adrian et al. (2005) confirmed that perceived usefulness positively has indirect effect on intention to adopt precision agriculture thereby confirming H_7 on the indirect effect of PU on INT through ATT. However, the conflicting results have been reported regarding its impact on intention (Venkatesh and Davis 2000; Venkatesh et al. 2003).

Conclusion and policy implications

The TAM model was used in this study to investigate factors influencing fish farmers' intentions to use BSFL in fish farming. All the seven hypotheses of the TAM could be supported by the model. The results of PLS-SEM therefore confirm the stipulated relationships within the theory and provide further evidence of the profound role of the TAM model used in this study. This implies that the TAM constructs had a direct and indirect effects on intention to BSFL in aquaculture by the fish farmers in Kenya. The study results have revealed that based on the relative sizes of the coefficients, attitude was the main determinant of intention, followed by perceived ease of use and then perceived usefulness. The role of attitude to increase behavioral intention has been emphasized. Since attitude indicated the maximum influence on intention, this means that fish farmers who have positive attitudes toward BSFL are more likely to adopt it in fish production, since they have a higher intention in performing this behavior. As a result, a more positive attitude about the BSFL meal boosts behavioral intent. This study has policy significance for agricultural development policymakers because it can assist extension agents, agricultural educators, and agricultural administrators in providing appropriate training and services to customers in order to improve their attitudes. Setting up nationwide seminars is a good way to boost expert capability and perception.

Perceived usefulness is important to change and reinforcement of behavioral attitude and behavioral intention. It has a significant role in the model so that perceived ease of use and attitude of confidence affect behavioral attitude through usefulness. Thus, trainings should be planned in relation to justifying usefulness of these novel feed technologies by the experts. It is suggested that a practical method instruction should be designed and implemented for raising knowledge and information based on method-demonstration and result-demonstration on use of BSFL in aquaculture.

This study provides strong empirical insights to propose and test a model for assessing technology-acceptance related factors that influence farmers' intentions to use BSFL for improving their fish production. This implies that the results provide a strong foundation for application in different contexts and theoretical assessments in other research fields. The results of this study can be used by actors along fish feed value chain in understanding the process of technology adoption. Previous TAM studies on adoption have typically focused on quantifying adoption predictions, rather than exploring how social factors interact and influence intentions and behaviors. This study demonstrates how the TAM can be qualitatively applied to better understand farmer decision making, in this instance the use of BSLF meal. The study demonstrates how the TAM can provide an evidence-based framework to qualitatively explore fish farmer intentions and behavior. This approach has led to new insights into farmer decision making that will inform improvements in future extension development.

There is a need to raise awareness and promote the use of BSFL in fish production among fish farmers. Strengthening fish farmer groups could also improve fish farmers' attitudes towards BSFL. Relevant government departments can expand the influence and awareness of BSFL feeds through multiple publicity channels and media. For example, public programs such as training for farmers should be put in place to help them understand and realize that using BSFL in fish production can be of great economic benefit.

Limitations and future research scope

There are a variety of potential drawbacks that can be highlighted. First, this study was primarily intended to evaluate farmers' intentions toward BSFL, with little attention devoted to actual measurements of BSFL use (adoption) by fish farmers in the study area. While behavioral intention is a necessary condition for actual adoption, it is not sufficient. Furthermore, socio-demographic factors are not taken into account, despite the fact that these factors are predicted to have direct and indirect effects on intentions, attitudes, and perceived controls. Accordingly, the results may suffer from an omitted variable bias. Nevertheless, the findings of the study are still valuable.

Despite the limitations mentioned above, this research contributes to a better understanding of the essential theoretical and practical implications of fish farmers' intentions to adopt BSFL in their fish production. Future research should look into how socio-demographic factors influence differences in attitudes, perceptions, and intentions about BSFL adoption. For example, it would be interesting to study the effect of scale of production or cultural differences on the actual adoption and decision behavior of farmers in Kenya and elsewhere in the world. Secondly, future studies should also focus on analyzing the factors that influence adoption of BSFL, using a sample of fish farmers that adopt and non-adopt BSFL using regression models and analyze the same sample, to verify the characteristics of farmers who adopted BSFL.

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Data availability

The data that support the findings of this study are openly available in Figshare at https://doi.org/10.6084/m9.figshare.19739023.

Contributions

Conception and design of the research: KOO[1], AWM and KOO[2]; acquisition of data: KOO[1] and KOO[2]; analysis and interpretation of data: KOO[1] and FAO; drafting of manuscript: KOO[1], AWM, KOO[2] and FAO; revision of manuscript for important intellectual content: KOO[1], AWM, KOO[2] and FAO. All authors read and approved the final manuscript.

Ethics approval

Ethical approval was granted by JOOUST Ethics Review Committee [approval number ERC/28/10/20-12] and National Commission for Science, Technology and Innovation (NACOSTI) [research licence number NACOSTI/P/20/8040].

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Appendix

Table A1. Latent variables, indicator ID and the corresponding questionnaire statements used within the survey.

Indicator	Item Measure	References	Scale (1–5)	Mean	SD
PEOU1	Improve the sustainability of fish production	Chia et al. (2019)	Strongly disagree – Strongly agree	3.70	1.000
PEOU2	Improve the societal acceptance in fish farming	Verbeke et al. (2015)	Strongly disagree – Strongly agree	3.05	1.216
PEOU3	Lower the ecological footprint of livestock farming	Chaalala et al. (2018)	Strongly disagree – Strongly agree	1.87	.884
PEOU4	Allow farmers produce high quantities of fish for the world population	Verbeke et al. (2015)	Strongly disagree – Strongly agree	2.21	.893
PEOU5	Lower production cost in fish farming without fish reducing quality	Sinansari and Fahmi (2020)	Strongly disagree – Strongly agree	1.39	.587
PEOU6	Decrease the overexploitation of water bodies	Tiu (2012)	Strongly disagree – Strongly agree	1.87	1.079
PEOU7	Lower our dependence on foreign protein sources	Verbeke et al. (2015)	Strongly disagree – Strongly agree	1.68	.827
PEOU8	Lower the cost of Fish feed	Verbeke et al. (2015)	Strongly disagree – Strongly agree	1.33	.555
PEOU9	Lower our dependence on imported feed	Verbeke et al. (2015)	Strongly disagree – Strongly agree	1.52	.764
PEOU10	Improve organic waste management in the country	Dicke (2018)	Strongly disagree – Strongly agree	1.36	.619
PU1	Use of BSFL feed is a system easy to understand	Oppong (2017)	Strongly disagree – Strongly agree	1.78	1.105
PU2	Use of BSFL is a system that would be easy to implement on my fish farm.	Rana et al. (2015)	Strongly disagree – Strongly agree	2.00	1.229
PU3	Using BSFL meal would enhance my effectiveness on fish production	Mulumpwa (2018)	Strongly disagree – Strongly agree	2.34	1.271
PU4	Using BSF meal will improve my fish production efficiency	Roffeis et al. (2018)	Strongly disagree – Strongly agree	2.19	1.208
ATT1	BSFL provide cheap source of protein in fish farming	Higa et al. (2021)	Strongly disagree – Strongly agree	1.35	.517
ATT2	BSFL Provide nutrients and minerals	Makkar et al. (2014)	Strongly disagree – Strongly agree	1.96	.930
ATT3	Possibility of rearing BSF guarantees availability	Yildirim-Aksoy et al. (2020)	Strongly disagree – Strongly agree	2.21	1.255
ATT4	Rearing BSF requires small space and is cost effective	Van Huis et al. (2013)	Strongly disagree – Strongly agree	1.36	.726
ATT5	BSF has low feeding costs because it feed on wastes thus cleans environment	Dicke (2018)	Strongly disagree – Strongly agree	1.32	.552
ATT6	Hard to create awareness and promote BSFL meal to people based on legislative issues	Belghit et al. (2019)	Strongly disagree – Strongly agree	3.27	1.157
ATT7	Long time required to change attitudes of people to consider BSFL meal as feed.	Kelemu et al. (2015)	Strongly disagree – Strongly agree	2.99	1.123
INT1	I intend to use BSFL in my fish farm	Ssepuuya et al. (2019)	Unlikely-likely	1.83	1.229
INT2	I would recommend the adoption of BSFL meal for other fish farmers in my region	Domingues et al. (2020)	Unlikely-likely	1.68	1.238
INT3	I would also adopt BSFL meal if the neighboring farmers adopt	Joffre et al. (2020)	Unlikely-likely	1.59	1.132

Table A2. Test for common method bias.

Total variance explained						
	Initial eigenvalues			Extraction sums of squared loadings		
Component	Total	% of variance	Cumulative %	Total	% of variance	Cumulative %
1	7.476	31.150	31.150	7.476	31.150	31.150
2	2.262	9.426	40.575			
3	1.885	7.855	48.430			
4	1.373	5.719	54.149			
5	1.293	5.389	59.538			
6	1.150	4.793	64.331			

Extraction Method: Principal Component Analysis.

Table A3. Variance inflation factor (VIF) values.

Variable	VIF
ATT1	1.64
ATT2	1.825
ATT3	1.954
INT1	1.339
INT2	2.166
INT3	2.351
PEOU1	1.397
PEOU2	1.688
PEOU3	1.322
PU10	1.365
PU3	1.364
PU7	1.277
Attitude	2.087
Perceived Usefulness	1.545
Perceived Ease of Use	1.808

Table A4. Outer loadings (factor loadings).

Factor/Indicator	Attitude	Intention to Use	Perceived Ease of Use	Perceived Usefulness
ATT1 BSFL provide cheap source of protein in fish farming	**0.818**			
ATT2 BSFL Provide nutrients and minerals	**0.855**			
ATT3 Possibility of rearing BSF guarantees availability	**0.882**			
INT1, I intend to use BSFL in my fish farm		**0.731**		
INT2 I would recommend the adoption of BSFL meal for other fish farmers in my region		**0.877**		
INT3 I would also adopt BSFL meal if the neighboring farmers adopt		**0.898**		
PEOU1 Use of BSFL feed is a system easy to understand			**0.794**	
PEOU2 Use of BSFL is a system that would be easy to implement on my fish farm			**0.89**	
PEOU3 Using BSFL meal would enhance my effectiveness on fish production			**0.673**	
PU10 Improve organic waste management in the country				**0.801**
PU3 Lower the ecological footprint of livestock farming				**0.835**
PU7 Lower our dependence on foreign protein sources				**0.700**

Source: Field survey (2021).