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Cross-country evidence of consumers' perception of food from animals fed on insects in DR Congo, Mali, and Niger

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ABSTRACT

Insects can represent a valuable and cost effective source of animal feed in Africa. Recently, the interest in incorporating black-soldier fly larvae (BSFL) in animal feed has increased tremendously. However, many factors, including food neophobia and social and cultural context may affect consumers' perception of insect-technologies-derived food products. This study shed light on consumers' perception of the usage of BSFL as animal feed and consumption, buying, and commercialization of food from animals fed on BSFL in DR Congo, Mali, and Niger. We used data from 1560 consumers that were analyzed applying parametric and non-parametric tests and the generalized ordered logit model. Our findings show that about 87 % of respondents consider that consuming food from animals fed on BSFL is acceptable and 34 % accept buying eggs, fish, and meat from animals fed on BSFL. However, about 40 % of consumers recommend the label differentiation of BSF-technologies-derived food products and they also expect a lower price than conventional animal feed products. The analysis of factors driving consumers' readiness to buy BSF-derived food products have revealed that effective market penetration of BSF-technologies-derived food products could be achieved with great awareness creation, targeting farming households, married and literate heads. Furthermore, strategic communication and intensive sensitization through farmers' associations will be crucial. Finally, credit access and income diversification are also necessary to support consumers' choices toward sustainable food habits built on bio-circular economy.

1. Introduction

Consumers' beliefs and perceptions about products are major factors contributing to the acceptance or rejection of products. In many markets, erroneous perceptions and beliefs about a product can lead to its rejection or lower use and vice-versa. For example, cultured meat is considered an alternative protein with many advantages over meat from animals. Yet many consumers are resistant to eating cultured meat. In their article, Rosenfeld and Tomiyama [1] reviewed reasons for consumer resistance and suggested that proper communication about the production and benefits of cultured meat can improve the acceptance of this new product. Udomkun et al. [2] found that nutrition, harmful effects, odor, and availability of meat products in the markets were among the key factors influencing consumers' preference and willingness to pay for meat products in Eastern Democratic Republic of the Congo (DRC). In a recent publication, Hoel et al. [3] demonstrated that misperceptions about the quality of fertilizer in many African countries could prevent learning, and it has contributed to the low use of inorganic fertilizer, contributing to low agricultural productivity in the continent that also includes DRC, Mali, and Niger. Beyond the above examples, the

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literature review focuses on consumer acceptance of products, especially meat products whose demand has recorded an upward trend following the current demographic pressure, making it necessary to provide a comprehensive analysis of consumers' perceptions of new products [4]. Globally, meat supply is expected to reach 374 Mt by 2030 [5], with Africa at the forefront, as continental consumption is predicted to be 30 % higher compared to other world regions [6]. In the Republic of Congo, the fresh meat market is projected to grow by 5.32 % (2024–2028), resulting in a market volume of €380.40 m in 2028 [7]. The meat market in the DRC has also experienced steady growth. The information available shows that the overall growth in the volume of imports (beef, pork, and edible offal) was strong at +128 % and +178 % in value terms between 2010 and 2014 [8]. In Mali and Niger, Desiere et al. [9] found income elasticities estimated based on food expenditure from Living Standards Measurement Study (LSMS) surveys at 0.60 and 1.71 and the expected growth in per capita meat and fish consumption at 32 % and 101 %, respectively, if income (Gross Domestic Product (GDP)) doubles.

Despite the upward trend in meat supply, the meat diet poses several environmental and biodiversity issues [6–10]. Its contribution to agriculture's total greenhouse gas (GHG) emissions is approximately 54 % globally [5], and, as reported by González et al. [11], its contribution to the global GHG emissions ranges between 12 % and 18 %. It is, however, important to note that meat-based diets environmental footprint varies from one type of meat to the other [11–13]. For instance, ruminant production produces more emissions than nonruminant mammals, such as pig, and fish and poultry production [14]. Furthermore, from the economic perspective, the latter categories are cost-efficient. Therefore, the production of nonruminant mammals such as pigs, and poultry and fish is expected to increase in the coming years [5].

Moving forward addressing the environmental challenge of meat supply would require sustainable livestock inputs. Conventional animal feed protein ingredients, such as soybean, fishmeal, and grains, are expensive and unsustainable in reducing the environmental footprint of meat production due to their relatively higher input demand, such as land, water, fertilizer, etc., making them not cost-effective [15,16]. In contrast, interest in insects is growing as a novel, cost-efficient, and eco-friendly alternative protein source in animal feed and, in some contexts, as human food [17–20]. Another good reason why insects become interesting is to reduce the use of agricultural products as feed that should be used as human food products, thus reducing feed-food competition [11,12,15]. However, most consumers have negative attitudes towards eating insects on their own [6]. Therefore, the data suggests that indirect routes of consumption (e.g., consuming animals that have eaten insects) are more acceptable than direct consumption.

Among insects, Black soldier fly (BSF) has been dominant in this course for several reasons. First, BSF production requires less land and water and emits low GHG [20,21]. Second, the BSF larvae (BSFL) are a recycling power tool with high protein and lipid content [20,22]. Last but not least, BSFL reduces the risk of animal-transmitted disease, improving the overall health and growth of livestock and significantly reducing the cost of livestock food production [16,19,23,24].

Furthermore, several products can be derived from the BSF system. First, dried, powdered or pelleted larvae are suitable protein sources for chicken, pig, and fish. Second, soil nutrients are a combination of the excrement of the larvae and died flies, often called BSF frass (BSFF), on the one hand, and the remaining feedstock, which can be used as organic compost, on the other. Finally, insect oil is a product of BSFL lipid extraction. This study focused on the protein meal product essential for livestock farmers. Fig. 1 presents the BSF technology system, including animal food products from animals fed on BSFL. Consumers were asked their opinions regarding eggs, meat, and fish produced from the animals fed on BSFL.

Considering this background, BSFL production holds the potential to become a convenient substitute for conventional protein sources in animal feed in the coming years.

Although the incorporation of BSFL in animal feed does not deteriorate the quality of eggs, meat, or fish, many factors that drive consumers' behavior, such as food neophobia, and social and cultural context, may affect consumers' perception of insect-technologies-derived food products [15,25–33]. BSFL has been thoroughly investigated as a protein source alternative to conventional sources in livestock feeds. Still, evidence on consumers' perception of food from animals fed on BSFL and their driver factors are understudied, especially in sub-Saharan Africa (SSA) (see Pakseresht et al. [15], for a systematic review).

The above overall picture of the relationship between BSFL and consumers' perception of meat products is very relevant to the study countries of DRC, Mali, and Niger, where the incorporation of BSLF in animal feed is still in its infancy. A better understanding of consumers' perception of food from animals fed on BSFL and their driving factors would contribute to the development and scaling of this new technology in the three study countries.

Our work, therefore, contributes to filling the above gap in several directions. First, we investigate consumers' perceptions of using BSFL-based animal feed. Second, this study assesses consumers' perception of food products (meat, fish, and eggs) from animals fed on BSFL. Thirdly, we identify the factors that might explain households' acceptability of buying eggs, fish, and meat from animals fed on BSFL. Finally, we draw recommendations for successful market penetration, consumers' acceptance of BSF-technologies-derived food products, and effective scaling-up of BSF-based technologies in SSA. We hypothesize that consumers' perception of food from animals fed on insects depends on demographic, socioeconomic characteristics, cultural beliefs, and health risks.

The rest of this study is structured as follows: after section 1, which introduces the study, section 2 describes the context, data, and sampling strategy. Section 3 focuses on the methods, presents the empirical model, and describes the data. Section 4 offers and discusses the empirical results, while section 5 concludes and derives policy implications.

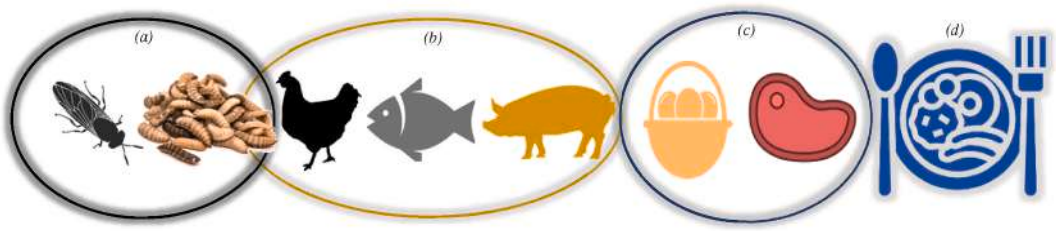

Fig. 1. Black soldier fly technology system and derived animal food-based products
Notes. Panel (a) represents the black soldier fly technology system, panel (b) the animals fed from black soldier fly larvae, panel (c) food products (eggs, meat, or fish) from animals fed on BSFL, and panel (d) represents food consumption. Authors' conception.

2. Context and data description

2.1. Context of the study

This study is part of the baseline studies conducted under the BSF for Bio-circular Economy and Sustainability (BBEST) project with the Norwegian Agency for Development Cooperation (NORAD) fund from March to October 2023. The BBEST project is meant to improve the livelihoods of smallholder chicken, fish, pigs, and vegetable farmers and contribute to improved urban sanitation and climate change mitigation in DRC, Mali, Ghana, and Niger. The 2018 United Nations Environmental Protection [34] Outlook Report on the State of Waste in Africa indicates that Municipal Solid Waste (MSW) generation in Africa is projected to double by 2025, from 125 million tons in 2012. While an estimated 70–80 % of the MSW generated in Africa is recyclable, only 4 % of the MSW enters the recycling process. More than 90 % of the waste generated in Africa is disposed of at uncontrolled dumpsites and landfills, creating unsanitary environmental conditions that pose public health risks and contribute to GHG emissions. With an estimated population of 4.2 million persons, Accra generates nearly 2000 tons of waste daily at a daily per capita rate of 0.47 kg [35]. In Bamako, with an estimated population of 2.71 million, more than 1.9 million tons of solid waste were generated in 2017, amounting to 1470 tons of waste produced per day [36]. With a population of 1.33 million, projected to increase to 6.5 million by 2050 [37], Niamey generates 1000 tons daily [38]. Kinshasa, the third largest city on the African continent after Lagos and Cairo, is home to 15.6 million people. With a waste generation rate of 0.5 kg per capita per day [39], Kinshasa alone generates 7814 tons of waste daily (equivalent to 2.8 million tons of waste annually). On the other hand, food demands in the region are increasing, and consumption patterns are changing, with dietary diversification into vegetables, fruits, and livestock products. The effort to increase the supply of animal products and meet the demand for such products is constrained by the increasing price of animal feeds. And efforts to increase the supply of caloric intake are constrained by farming systems in SSA that remain unsustainable, with most soils in the region being deficient in nitrogen (N), phosphorus (P), and potassium (K) [40].

Therefore, the BBEST project aims to concomitantly address these two challenges (biowaste management and sustainable supply of animal feed and organic fertilizer) by recycling biowastes in the context of circular bio-economy (CBE) using Black Soldier Fly (BSF) (*Hermetia illucens*). Implemented in 2021 in West Africa, it was expanded to DRC in 2022. In total, the project covers five major cities, including Accra in Ghana, Bamako in Mali, Niamey in Niger, Kinshasa, and Bukavu in DRC. However, Accra is not included in this study.

2.2. Sampling and data collection

The BBEST project is targeting urban centers as the main source of urban waste as explained earlier. The project intends to build a BSF facility in the urban city where organic waste collected from the city and its surroundings will be processed using the BSF technology. The proceeds will be used by livestock (fish, poultry and/or pig) and vegetable farmers primarily in peri-urban areas of the urban city.

Therefore a multistage sampling approach was followed for data collection. In the first stage, we purposively selected up to 5 sub-urban districts from the list developed by the officials of agriculture among those that are known to have a strong engagement in the production of fish, poultry, or/and pigs (as criteria) within a radius of 50 km (about 31.07 mi) from the point where the BSF facility of the BBEST project to rear BSF flies and mass production of BSF larvae was planned to be built. The radius of 50 km was decided by the project management in consultation with municipality leaders as cost-effective for the supply and management of biowaste. The pig value chain was considered only in DRC. These suburban districts formed the primary sampling unit from which smallholder farmers were selected.

In the second stage, from the selected suburban districts, we randomly selected the households. The sample size was determined using a probabilistic sampling approach. We determined the sample size in each country using Cochran's formula [41], given as $N = p(1-p)(z|\epsilon)^2$ where N is the total sample size; e is the margin of error; z is the z-score; p is the proportion of agreement of consumers to buy products from animals fed on BSFL. Considering 40 % as the proportion of agreement of consumers to buy products from animals fed on BSFL, z-score at 1.96 (95 % confidence level), a margin of error ϵ at 4.5 %, the sample size for the Kinshasa in DRC is 464 after adjusting for an extra nine households to ensure availability of replacement households in case selected households happen to be not present during the survey period. We came up with a sample of 469 for Bukavu in DRC after adjusting for an extra 14 households to ensure the availability of replacement households. Similarly, considering 45 % as the proportion of agreement of consumers to buy products from animals fed on BSFL in Niger and Mali, z-score at 1.96 (95 % confidence level), a margin of error ϵ at 5.5 %, the sample size for each country is 315 with attrition of three households in Mali. Once we determined the sample size, we randomly selected a minimum of 30 households in each value chainfrom each sub-urban district (or a total of 150 households per city) from the list of pre-identified households.The survey was conducted between March and October 2023. At the end of the survey and upon verification of collected data, the final sample size for data analysis was 1560 households, out of which 933 households in DRC, 315 in Niger, and 312 in Mali (Fig. 2). Respondents were shown videos of living BSFL to stimulate their sensory perception, given the necessary information about the BSF technology system's advantages and the BSFL production process, and explained that incorporating BSFL in livestock feed does not have any known effect on meat or eggs such that their judgment based on their level of food neophobia could guide their responses on perception questions. Our sample subjects are both livestock farmers and consumers. They were producers responding to the perception questions on using BSFL as animal feed. When we asked them about the agreement to buy and consume food products from animals fed on BSFL, these respondents were consumers.

Trained enumerators and supervisors with a minimum BSc. level, some years of experience, and speaking the local language performed the face-to-face interviews. We used computing tablets, and the Ona server enabled data aggregation (www.odk.ona.io). A two-step data review was conducted to ensure data quality. The first step was done by supervisors at the end of each day, and the second step was done remotely by the survey manager. Possible mistakes were brought back to the attention of the field team for correction. Each enumerator received a sample of dried, powdered, and pelleted BSFL in a zipper bag to show the respondents and stimulate their visual perception during the interviews. The survey collected data on the sociodemographic characteristics of farmers, awareness and usage of BSF-based technologies, perception of derived food products of animals fed on BSFL, households' assets, and access to essential services such as finance, credit, extension, and training.

3. Methods

3.1. Description of variables

3.1.1. Explained variable

The term explained variable is used in lieu et place of the term response variable, which is widely known. The explained variable in this study refers to the degree of agreement of consumers to buy eggs, fish, and meat from animals fed on BSFL, regardless of the price. We relied on an ordered variable that takes the value 1 if the consumers disagree, 2 if unsure or neutral, and 3 if they agree. It is worth noting that it is a 3-level Likert scale variable that expresses consumers' degree of agreement due to the treatment of the information received from the enumerators on

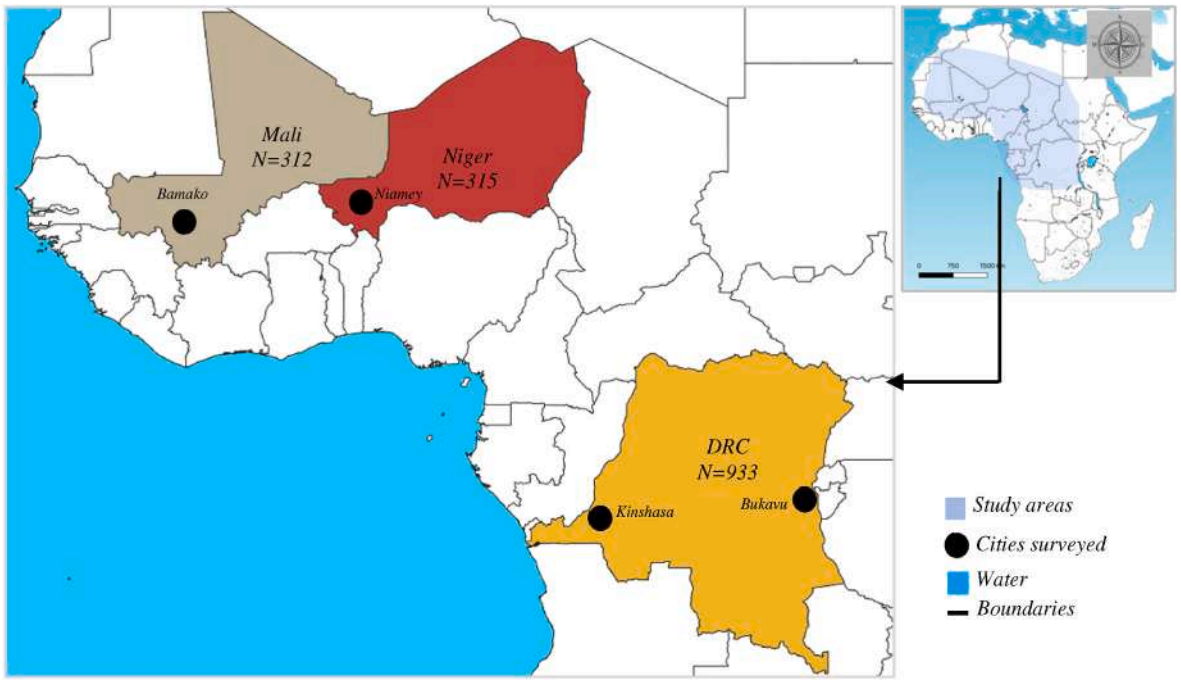

Fig. 2. Map of the study area.
Notes. N denotes the sample size. Author's conception using QGIS 3.10.

multiple advantages of BSF-derived products. Therefore, this variable does not capture consumers' willingness to buy and cannot estimate the BSF-derived food prices and demand in different countries. We used a 3-level Lickert rather than a 5-level scale for two reasons. First, because the limit between strongly disagree, which would have been the first point of the scale, and disagree, our actual first point, or strongly agree and agree, is not easy to establish. Second, having more than 3-scale points would reduce the number of observations within each point scale group and would affect the quality of our estimations.

3.1.2. Variables of interest

The concept variables of interest are used in line with our objectives, while the meaning remains unchanged and refers to the explanatory variable. The consumers' perception is assumed to be an ordered variable built from a 3-level Likert scale (1 = disagree, 2 = neutral, and 3 = agree) to capture the degree of agreement of consumers regarding the statements related to three components of interest, including (1) the usage of BSFL as animal feed, (2) the consumption of food from animals fed on BSFL, and (3) the commercialization of food from animals fed on BSFL. Table 1 presents the sample of survey questions used to assess consumers' perceptions. This approach was used in previous studies by Laureati et al. [31] in Italy and Bazoche and Poret [32] in France. The first component related to the usage of BSF-based animal feed, which includes cultural beliefs and consumers' perceived animal health risks, was included in our econometric model, while other variables of interest were used for descriptive purposes.

Table 1
Sample of survey questions used to assess consumers' perception.

Components	Perception of …	Statements
1	Usage of BSF-based animal feed	Using BSFL as chicken/fish/pig feed goes against the culture
		Using BSFL as animal feed poses animal health risks
2	Consumption of food products from animals fed on BSFL	Consuming eggs, meat, or fish produced from animals fed on BSFL is acceptable
		Eggs, meat, or fish from animals fed on BSFL taste differently compared to conventional ones
3	Commercialization of food products from animals fed on BSFL	Eggs, meat, or fish produced from animals fed on BSFL should be labeled
		The use of insects as chicken, fish, and pig feed will lower the price of eggs, meat, or fish.

3.1.3. Explanatory variables

We selected the explanatory variables following the existent literature on consumers' perception of new food technologies or products (e.g., Pakseresht et al., [15]; Siegrist and Hartmann, [25]; Lippi et al., [30]; Laureati et al., [31]; Bazoche and Poret, [32]; Feldmann and Hamm, [42]; Baldi et al., [43]; Shepherd et al., [44]). They are informational factors (*I*), consumers' main professional activity and income diversity (*A*), access to financial services (*F*), cultural beliefs and perceived animal health risks (*B*), and household and consumer characteristics (*H*). It is worth noting that cultural beliefs in this paper should be perceived in their extensive meaning that also include religious practices by essence. Therefore, we indirectly acknowledge the role of religious aspects in consumer behaviors.

The rationale or the choice of explanatory variables and their measurement are in section 4 concomitantly with the presentation of the results (see Table 2).

3.2. Empirical model

As described in section 3.1.1., we used a 3-level Likert scale to capture the degree of agreement of consumers to buy eggs, fish, and meat from animals fed on BSFL, regardless of the price. Given the ordinal nature of our explained variable, an ordered response model was considered. However, one of the assumptions underlying ordered logistic (and ordered probit) regression is that the relationship between each pair of outcome groups is the same. In other words, ordered logistic regression assumes that the coefficients that describe the relationship between the lowest versus all higher categories of the response variable are the same as those that describe the relationship between the next

Table 2
Descriptive statistics of consumers' characteristics.

Variables labels	Variables description	Country			Pooled Sample (n = 1560)	SD Pooled Sample
		DRC (n = 933)	Mali (n = 312)	Niger (n = 315)		
Household head	1 if yes; 0 if no	0.860	0.827*	0.898**	0.861	0.346
Sex	1 if male; 0 if female	0.854***	0.955***	0.949***	0.894	0.308
Age	Number of years	46.581***	38.577***	43.587	44.376	13.449
Education	1 if literate; 0 if otherwise	0.918***	0.856	0.705***	0.863	0.344
Marital status	1 if married; 0 if otherwise	0.816	0.638***	0.930***	0.803	0.398
Household size	Number of Members	6.759***	9.721	11.861***	8.381	25.667
Group membership	1 if yes; 0 if otherwise	0.191*	0.173*	0.289***	0.207	0.405
Have mobile phone	1 if yes; 0 if otherwise	0.781***	1.000***	0.857	0.840	0.366
Access to credit	1 if access; 0 if otherwise	0.149*	0.073***	0.162	0.137	0.343
Main activity	1 if farming; 0 if otherwise	0.542***	0.327***	0.349***	0.460	0.499
Source of Income	Number of income sources	1.351***	1.474	1.879***	1.483	0.755

Note: SD is the standard deviation. *, **, *** denote significance levels at 10 %, 5 %, and 1 % of the student test used to compare the means of respondent characteristics using the country as a dummy variable under the assumption of unequal variance between the country's respondent and non-country respondent.

lowest category and all higher categories, etc. This is called the proportional odds assumption or the parallel regression assumption. Because the relationship between all pairs of groups is the same, there is only one set of coefficients (only one model). If this was not the case, we would need different models to describe the relationship between each pair of outcome groups. Hence, we performed a test for the proportional odds assumption using the omodel Stata command. The test does a likelihood ratio test where the null hypothesis is that there is no difference in the coefficients between models. Our analysis shows that the proportional odds assumption is violated, with a chi-square of 95.25 significant at a 1 % level (see Wolfe [45] for more details about the *omodel*). Therefore, we used the generalized ordered logit (GOLOGIT) model [46,47], which is an ordered logit model that allows estimates to vary across each pair of outcome groups. Formally, for a dependent variable Y with J categories, the gologit model can be written as in equation (1):

$$P(Y_i > j) = g(X_i\beta_j) = \frac{exp(\alpha_j + X_I\beta_J)}{1 + exp(\alpha_j + X_i\beta_j)}, j = 1, \ldots, J-1, i = 1, \ldots, n \quad (1)$$

with

$$P(Y_i = j) = 1 - g(X_i\beta_j), P(Y_i = j) = g(X_i\beta_{j-1}) - g(X_i\beta_j), (Y_i = j) = g(X_i\beta_{j-1})$$

and where i refers to the household, X_i is the vector of predictors for the i-th respondent and β_j is the vector of parameters to be estimated. Empirically, our estimated model is as follows (equation (2)):

$$Y_{ij} = \zeta + \delta H_i + \vartheta I_i + \rho A_i + \gamma F_i + \partial B_i + \theta C_i + \mu_j \quad (2)$$

Where.

H_i: household and individual characteristics for the i-th respondent
I_i: informational factors
A_i: consumers' main professional activity and income diversity
F_i: access to financial services
B_i: cultural beliefs and perceived animal health risks
C_i: contextual factor.

And.

ζ, δ, ϑ, ρ, γ, ∂ and θ are parameters to be estimated.
μ is the error term

And:
Y_{ij} is the ordered explained variable depicting at what level (disagree, neutral, agree) were consumers' agreement to buy food from animals fed on BSFL, regardless of the price. We reported the marginal effect after the GOLOGIT, which shows the magnitude of the effect of explanatory variables X on the categories of Y_{ij} [48]. We used the gologit2 command of Stata software Williams [46] developed to estimate our models.

4. Empirical results and discussions

4.1. Descriptive data review

The descriptive statistics of the respondents are summarized in Table 2. About 86 % of surveyed households are households head with similar proportions within countries (89 % in Niger, 86 % in DRC, and 83 % in Mali). The average respondent in the sample is about 44 years old, with slight heterogeneity between countries, varying from 47 years old in DRC to 39 years old in Mali. While 86 % of respondents are at least educated overall, this percentage differs from country to country – 92 % in DRC, 86 % in Mali, and 71 % in Niger. About eight out of ten respondents are married, with an average household of about eight members, with significant differences between the Sahelien countries and DRC. Respondents' participation in social groups is relatively low, as about 20 % of respondents are members of groups, associations, or unions. Access to credit is limited in the sample, as only 14 % of respondents have access to credit. However, 84 % of respondents in the sample use mobile phones. Agriculture is the main activity for 46 % of respondents. There are diversified sources of income as, on average, the respondents have 1.5 sources of income.

These results were significantly different from country to country based on the t-test.

The socio-demographic characteristics of the respondents present the potential for adoption of the new BSF-based products. Low participation in social groups and high possession of mobile phones should be considered in developing strategies such as digital tools for the dissemination of technical messages to promote the scaling of new technologies.

4.2. Descriptive statistics of consumers' perception

Fig. 3 summarizes the descriptive statistics of consumers' perception, measured by a 3-level Likert scale. The proportion of consumers who disagree (72 %) about culture being a barrier to using BSFL as animal feed is relatively high across countries (panel (a)). In DRC, about 79 % disagree that culture can be a barrier in using BSFL as animal feed, 74 % in Niger, but a relatively low proportion of respondents disagreed in Mali (50 %).

Panel (b) summarizes consumers' perception of animal health risks posed by BSFL-based animal feed. The results show that about 55 % reject this statement, while 34 % are unsure. Consumers across countries have different perceptions. In Niger, about 64 % of consumers disagree, and 11 % are not sure or neutral, while in DRC, 55 % of consumers reject

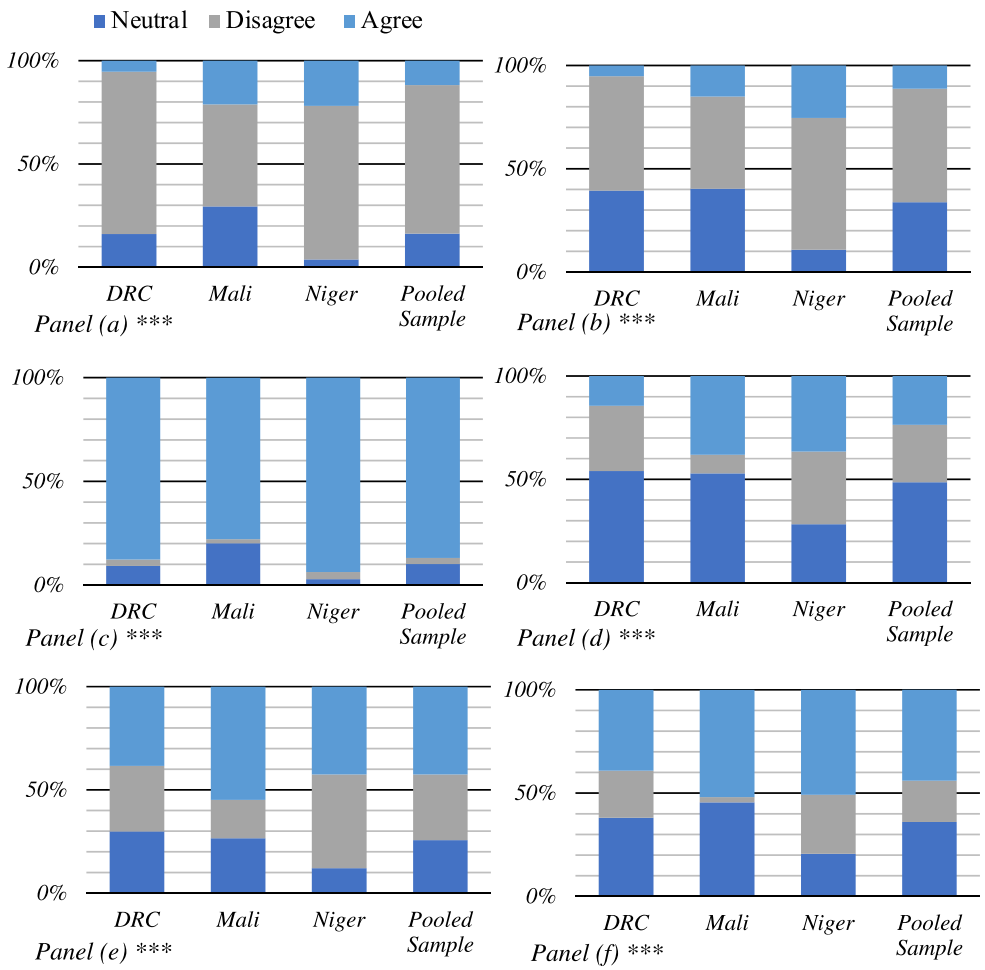

Fig. 3. Descriptive Statistics of Perception Statements

Note: *** denotes the significance level at 1 % of the Pearson chi-square test in all the panels. Panel (a) for consumers who disagree that culture can be a barrier to the consumption of BSFL-derived animal products; Panel (b) for consumers who consider health risks as barriers to the consumption of BSFL-derived animal products; Panel (c) for consumers who consider acceptable consumption of BSFL-derived animal products; Panel (d) for consumers who consider the taste consumption of BSFL-derived animal products; Panel (e) for consumers who consider that BSFL-derived animal products should be labeled for product differentiation in the market; and Panel (f) for consumers who consider that using BSFL-based feed will lower the price of BSFL-derived animal products.

that the usage of BSFL as animal feed poses a health risk, and 39 % are unsure. Mali presents a relatively low rejection rate, as 45 % of consumers disagree, and 40 % are neutral (not sure).

These results on consumers' perception statements toward using BSFL as animal feed found several explanations within the literature. First, as indicated by Pakseresht et al. [15] and Laureati et al. [31], consumers' perceived benefits of insect-based animal feed, such as cost, environmental footprint, and nutrition values, surpass the risks and explain why the usage of insects as animal feed ingredients is acceptable in almost all the countries. Second, cultural, religious, or social norms do not pose barriers to the usage of insects as animal feed, and their effect on consumers' perception is minimal, as shown by Pakseresht et al. [15], Khaemba et al. [49], and Weinrich and Busch [50]. Finally, in SSA, scavenging domestic livestock is dominant, so animals feed from many sources, including insects, and consumers are aware of that [51].

Considering food products produced from animals fed on BSFL, panel (c) shows that about 87 % of consumers accept (agree) that consuming food from animals fed on BSFL is acceptable. This proportion varies from 94 % in Niger, 88 % in DRC, and 78 % in Mali. Panel (d) assesses consumers' perception of the taste of food produced from animals fed on BSFL compared to the conventional ones; the results indicate that about 49 % of consumers are unsure if feeding animals on BSFL could alter meat, fish, or eggs taste. The proportion of consumers who are not sure varies from 54 % in DRC, 53 % in Mali, and 28 % in Niger. These results are similar to those of Lippi et al. [30] and Baldi et al. [43], who have demonstrated that consumers are more open to buying and consuming food from animals fed on insects and perceive no taste difference compared to conventional food products. The reason is that consumers perceived that foods derived from animals fed on insects were of high quality and rich in nutrients [15,44].

Consumers were asked to give their opinion on two aspects regarding the commercialization of food from animals fed on BSFL. First, as presented in panel (e), the sample is significantly balanced between consumers who accept (agree) or reject (disagree) that food products from animals fed on BSFL should be labeled for product differentiation on the market. About 32 % disagree, and 42 % agree. In DRC, 32 % of consumers reject, and 38 % reject. In Niger, about 45 % reject and 43 % accept. In Mali, 55 % accept, and only 19 % reject. Considering the price implication of using BSFL as animal feed on animal food products, panel (f) shows that the majority (44 %) of consumers agree that the usage of BSFL as animal feed will lower the price of eggs, meat, or fish compared to the conventional ones. This proportion is slightly homogenous across countries. In Niger, 51 % of consumers agree, 52 % in Mali, and 39 % in DRC.

Some previous studies have investigated the traceability and labeling of food products from animals fed on insects and demonstrated that

labeling and certification of quality play an essential role in the acceptability of food derived from animals fed insects [30,43]. Although our results are mixed, they demonstrate the role of well-established standards and the necessity to ensure symmetric information through appropriate communication strategies aimed at reassuring about the wholesomeness of the final product and the sustainability of farms in SSA [25].

Regarding the price, consumers expect low prices for food derived from animals fed on insects. In fact, since BSFL products use low-cost flies and biowaste, consumers can think food from animals fed on insects should be cheap [52,53]. Animal feed represents the highest proportion of production costs in poultry, fish and pig production for small-scale producers in particular. Therefore, their expectation is to get access to alternative and low cost animal feed such as BSFL. It is important to note that information plays a significant role in this process, and comparing insect-based and conventional protein sources can be misleading or biased against consumers ' expectations without accounting for the resources (knowledge, time, livestock investment, etc.). Notably, Giotis and Drichoutis [55] demonstrated that some categories of consumers, such as "ecology consumers," were willing to pay a premium price for such products. Similarly, Khaemba et al. [49] found that most consumers were willing to purchase eggs produced from hens fed on BSFL regardless of the price.

4.3. Factors explaining the probability of buying eggs, fish, and meat from animals fed on BSFL

Our findings demonstrated that about 34 % of consumers in the three countries agreed on buying food from animals fed on BSFL, 37 % were neutral, and 29 % disagreed. Considering the heterogeneity across countries, with about 26 % of agreement in DRC, 30 % in Mali, and 62 % in Niger, it is essential to analyze the factors explaining consumers' opinion of "disagree" with buying eggs, fish, and meat from animals fed on BSFL, regardless of the price.

Table 3 presents the econometric results of equation (2). The results disaggregated per country are in Table A1. We interpret column (1) of Table 3, which sheds light on consumers' opinions of "disagree" with buying food from animals fed on BSFL. Overall, six variables significantly explain the consumers' opinion within the sample, while three additional variables were found significant after disaggregation by country, forming a total of ten significant determinants. The latter include education, group membership, access to finance, professional activity, cultural beliefs, and the perceived animal health risks to which we add age, marital status, and income diversity significant for some countries.

Specifically, educated respondents who had farming as their main professional activity were less likely to disagree with buying food from animals fed on BSFL. The likelihood to disagree was high and above 5 % and varied from 12 % for educated consumers to 18 % for respondents whose farming is the main professional activity. Moreover, respondents who are members of groups, associations, cooperatives, or unions were less likely by a likelihood of 7 % to disagree with buying food from animals fed on BSFL, regardless of the price. Consumers who agreed that using BSFL as animal feed does not pose a cultural problem or does not pose animal health risks were also less likely to disagree with buying food from animals fed on BSFL by a likelihood of 13 % and 10 %, respectively. Finally, consumers who have access to credit were less likely by a likelihood of 7 % to disagree.

Considering country-specific results (Table A1), we found that consumers' age was positively associated with the likelihood of disagreeing by a likelihood of 0.4 %. In comparison, those having mobile phones were more likely to have a livelihood of 9 % in Kinshasa (column (1) of Table A1). In addition, an additional source of income increased the likelihood of disagreeing by 7 % in Bukavu (column (4) of Table A1). Finally, married consumers were less likely by a likelihood of 10 % to disagree in Niger (column (10) of Table A1).

Table 3
Factors explaining the probability of buying food from animals fed on BSFL.

VARIABLES	Pooled sample		
	(1)	(2)	(3)
	Disagree	Neutral	Agree
	Marginal Effects	Marginal Effects	Marginal Effects
Household and individual characteristics			
Respondent household head (1 = Yes; 0 = No)	0.035	−0.079**	0.044
	(0.030)	(0.040)	(0.039)
Sex of the respondent (1 = Male; 0 = Female)	−0.051	0.061	−0.010
	(0.039)	(0.040)	(0.042)
Age of household head (number of years)	0.001	−0.001	0.001
	(0.001)	(0.001)	(0.001)
Education (1 = Literate; 0 = Illiterate)	−0.124***	0.019	0.106***
	(0.040)	(0.040)	(0.033)
Marital status (1 = Married; 0 = Not married)	0.042	−0.063*	0.021
	(0.029)	(0.037)	(0.035)
Household size (Number of members)	−0.003	−0.000	0.003
	(0.003)	(0.003)	(0.002)
Informational factors			
Group membership (1 = Yes, 0 if otherwise)	−0.069***	−0.023	0.092***
	(0.025)	(0.032)	(0.033)
Have mobile phone (1 = Yes, 0 if otherwise)	−0.008	0.034	−0.026
	(0.032)	(0.038)	(0.038)
Access to financial services			
Access to credit (1 = Access, 0 if otherwise)	−0.073***	−0.090***	0.163***
	(0.027)	(0.034)	(0.041)
Professional activity and income diversity			
Main activity (1 = farming, 0 if otherwise)	−0.184***	0.051*	0.133***
	(0.023)	(0.028)	(0.028)
Number of sources of income	−0.015	−0.047***	0.062***
	(0.015)	(0.016)	(0.017)
Cultural beliefs and perceived animal health risks			
Cultural beliefs	−0.130***	−0.004	0.134***
	(0.024)	(0.027)	(0.024)
Animal health risk	−0.102***	0.077***	0.025
	(0.022)	(0.026)	(0.024)
Contextual factors			
City	Yes	Yes	Yes
Country	Yes	Yes	Yes
Observations	1560	1560	1560

Note: Values in parenthesis are standard errors. *, **, *** denote significance level at 10 %, 5 %, and 1 %. Approximated likelihood ratio test of proportionality of odds across response categories after ordered logit, Chi2 = 95.25***. Disaggregated data pre-country are in Appendix Table A2.

4.4. Discussion

The positive relationship between marital status and consumer's opinion to disagree in Niger might be explained by the underlying context. In Niger, polygamy is among the dominant form of marriage; married consumers have, on average large families, as we find in Table 3, and therefore more open to affordable food products, regardless of whether they are from animals fed on BSFL. Moreover, the empirical literature sustains that married consumers are open to buying new food, but dominantly when formed by larger families, who generally face more food budget constraints than smaller families. This result is similar to De Groote et al. [56] and Zhou and Hu [57], who demonstrated that married consumers were more open and willing to pay for fortification cereals in Kenya and nano foods in the United States.

The findings patterns were similar across the cities in all three countries, as in Table A1, columns 1–12. Therefore, the following discussion is general rather than country-specific.

As part of consumers' human capital, education is essential in treating information about new food technologies and their acceptance. The readiness of consumers to accept eggs, fish, and meat from animals fed on BSFL is mainly associated with their prior tacit knowledge of insect-based feed, as evidenced by Khaemba et al. [49], Sogari et al. [58], Baldi et al. [48], Spartano and Grasso [54], and Feldmann and

Hamm, [42]. Although communities' awareness about the advantages of BSF technologies is limited, literate consumers were likelier to perceive the benefits of BSF technologies and, therefore, less likely to disagree with buying food from animals fed on BSFL, regardless of the price, compared to illiterate consumers. This result demonstrates the need for intensive sensitization that brings forward the nutritional, environmental, and economic advantages of sustainable animal feed with diverse consumer benefits.

Like Bazoche and Poret [32] and Feldmann and Hamm [42], we found that group membership is significantly associated with consumers' acceptance of buying food from animals fed on BSFL. BSF innovations can be subject to misinformation that might affect the image of food from animals fed on BSFL and, therefore, consumers' attitudes. This might explain the positive relationship between having a mobile phone and the likelihood of disagreeing in Kinshasa. Empirically, Hwang and Choe [59] and Siegrist and Hartmann [25] found that a negative image of food products reduces consumers' intention to use and willingness to pay, implying that strategic communication through local groups or associations will be a centerpiece for effective market penetration of BSF-system-derived food products [30–32,43,57].

Our findings show that households with better incomes through diversified sources of income or access to credit are ready to accept foods from animals fed on insects. One explanation, but not the least, is that acquiring foods from animals fed on BSFL might not always be low-cost products despite the low cost of protein ingredients. BSFL production requires resources that may be incurred in capacity building, collecting feedstock, production of BSFL, processing of larvae, and investment in livestock farming [16]; therefore, ensuring the cost-effectiveness of BSF innovations and sustainable livestock models will translate into accessible food products for the poor, and more efficient agribusinesses [60]. These findings are similar to those of Fleischhacker et al. [61] and French et al. [62], who found that high-income households eat healthier and specialized food.

Moreover, dependence on agriculture motivates consumers to be likely to accept BSF-system-derived technologies and, therefore, food products. Furthermore, domestic livestock farming within our study area is dominantly nomadic, meaning most farmers rely on natural resources, and know that insects are part of animal feed and, therefore, do not pose any cultural or religious problems [15,49–51]. This implies that farmer households are ready consumers.

The relationship between cultural beliefs and perceived animal health risks is not uncommon. The existent literature provides several explanations on consumers' perception statements toward using BSFL as animal feed, which would explain why consumers with positive beliefs, as defined above, are less likely to disagree with buying BSF-derived food products. First, as indicated by Pakseresht et al. [15] and Laureati et al. [31], consumers' perceived benefits of insect-based animal feed, such as cost, environmental footprint, and nutrition values, surpass the risks and explain why the usage of insects as animal feed ingredients is acceptable in almost all the countries. Second, the usage of insects does not pose cultural, religious, or social norms barriers as animal feed because of the dominance of nomadic livestock farming, as shown by Khaemba et al. [49] and Weinrich and Busch [50]. The perceived benefits and the local context justify the association between cultural beliefs and the consumers' perception statements toward buying food from animals fed on BSFL. However, as mentioned above, the image of BSF-derived products is crucial for their market penetration and acceptability in different countries.

5. Conclusions and implications for future studies

This study has analyzed consumers' perceptions and determinant factors of the usage of BSFL as animal feed, consumption, and commercialization of food (fish, meat, and eggs) from animals fed on BSFL in DRC, Mali, and Niger. We found that consumers in all countries agree on using BSFL as animal feed and consuming eggs, fish, and meat from animals fed on BSFL. However, the promotion of BSFL-technology-derived food products has practical market implications. In the sample, a significant proportion of respondents, up to four consumers to ten, support the label differentiation of BSF-technologies-derived food products. Moreover, once consumers understand the production process of BSFL, they tend to expect low prices of meat, eggs, and fish from the BSF technology system. Most respondents shared the latter consumers' perceptions, with slight heterogeneity across countries.

Analyzing factors that drive consumers' perception demonstrated that the scaling-up of the BSF-technology system and effective market penetration of BSF-technologies-derived food products could be achieved with successful awareness creation via groups, associations, or cooperatives and intensive sensitization. Furthermore, market segmentation will be needed to target farming households primarily, as well as married and literate heads. Finally, access to credit and income diversification are also necessary to support consumers' food choices toward sustainable food habits. However, to effectively unlock the potential of the bio-circular economy in SSA, particularly in the study area, comprehensive and coherent policies that protect consumers' rights and needs must be formulated and vulgarized for a reasonable and sustainable crowd-in effect within the system.

This study's findings contribute to the development of the BSF technologies in SSA. However, the limitation of this study is on its methodology. The fact that the BSF products are still in the development phase in the study countries the consumers' overall perception was based on videos of living BSFL and explanations about the BSF technology provided by the enumerators to the respondents and not on the physical products. Future studies are needed to validate our results once meat, fish, and eggs from animals fed on BSFL reach a reasonable market share, which is still in its infancy at the time we write this manuscript.

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CRediT authorship contribution statement

Paul-Martin Dontsop Nguezet: Writing – review & editing, Supervision, Conceptualization. **Dieu-Merci Akonkwa Nyamuhirwa:** Writing – review & editing, Writing – original draft, Methodology, Investigation, Data curation, Conceptualization. **Feleke Shiferaw:** Writing – review & editing, Supervision, Conceptualization. **Victor Manyong:** Writing – review & editing, Writing – original draft, Supervision, Funding acquisition, Conceptualization. **Dioukou Sissoko:** Writing – review & editing, Investigation. **Bokar Moussa:** Writing – review & editing, Investigation. **Abel-Gautier Kouakou:** Writing – review & editing, Conceptualization. **Seydou Zakari:** Writing – review & editing, Investigation. **Tahirou Abdoulaye:** Writing – review & editing, Funding acquisition, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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Appendix

Table A1
Factors explaining the probability of buying food from animals fed on BSFL

VARIABLES	DRC					
	Kinshasa			Bukavu		
	(1)	(2)	(3)	(4)	(5)	(6)
	Disagree	Neutral	Agree	Disagree	Neutral	Agree
	Marginal Effects	Marginal Effects	Marginal Effects	Marginal Effects	Marginal Effects	Marginal Effects
Household and individual characteristics						
Respondent household head (1 = Yes; 0 = No)	0.100	−0.139	0.039	0.016	−0.069	0.052
	(0.062)	(0.109)	(0.103)	(0.060)	(0.057)	(0.036)
Sex of the respondent (1 = Male; 0 = Female)	−0.037	0.011	0.026	−0.096	0.131*	−0.035
	(0.072)	(0.074)	(0.062)	(0.074)	(0.070)	(0.052)
Age of household head (number of years)	−0.004**	0.004**	−0.001	0.001	0.000	−0.002
	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.001)
Education (1 = Literate; 0 = Illiterate)	−0.162*	−0.094	0.256***	−0.296***	0.254***	0.042
	(0.097)	(0.096)	(0.039)	(0.098)	(0.084)	(0.061)
Marital status (1 = Married; 0 = Not married)	0.040	0.009	−0.048	0.091	−0.049	−0.042
	(0.057)	(0.070)	(0.064)	(0.062)	(0.061)	(0.048)
Household size (Number of members)	0.010	−0.025***	0.015**	−0.009	0.015**	−0.006
	(0.006)	(0.007)	(0.007)	(0.008)	(0.007)	(0.005)
Informational factors						
Group membership (1 = Yes, 0 if otherwise)	0.002	−0.112*	0.110*	−0.004	0.072	−0.068**
	(0.050)	(0.060)	(0.060)	(0.069)	(0.064)	(0.033)
Have mobile phone (1 = Yes, 0 if otherwise)	0.089*	0.001	−0.090	−0.056	0.078	−0.022
	(0.047)	(0.061)	(0.059)	(0.066)	(0.065)	(0.046)
Access to financial services						
Access to credit (1 = Access, 0 if otherwise)	0.098	−0.080	−0.018	−0.071	−0.239***	0.310***
	(0.120)	(0.123)	(0.100)	(0.054)	(0.053)	(0.054)
Professional activity and income diversity						
Main activity (1 = farming, 0 if otherwise)	−0.342***	−0.053	0.395***	−0.104**	0.081	0.023
	(0.052)	(0.056)	(0.044)	(0.050)	(0.049)	(0.035)
Number of sources of income	0.026	−0.046	0.020	−0.072**	0.010	0.062***
	(0.040)	(0.054)	(0.054)	(0.033)	(0.029)	(0.018)
Cultural beliefs and perceived animal health risks						
Cultural beliefs	−0.069*	−0.099**	0.168***	−0.313***	0.140*	0.173***
	(0.036)	(0.042)	(0.043)	(0.082)	(0.082)	(0.046)
Animal health risk	−0.033	0.027	0.005	−0.048	0.076	−0.028
	(0.035)	(0.041)	(0.038)	(0.049)	(0.049)	(0.035)
Contextual factors						
City	No	No	No	No	No	No
Country	No	No	No	No	No	No
Observations	464	464	464	469	469	469
VARIABLES	Mali			Niger		
	(7)	(8)	(9)	(10)	(11)	(12)
	Disagree	Neutral	Agree	Disagree	Neutral	Agree
	Marginal Effects	Marginal Effects	Marginal Effects	Marginal Effects	Marginal Effects	Marginal Effects
Household and individual characteristics						
Respondent household head (1 = Yes; 0 = No)	0.009	0.082	−0.091	−0.056	−0.056	0.140
	(0.028)	(0.104)	(0.108)	(4.009)	(4.009)	(10.776)
Sex of the respondent (1 = Male; 0 = Female)	0.034	−0.110	0.077	0.030	0.030	−0.109
	(0.037)	(0.118)	(0.116)	(2.348)	(2.348)	(8.283)
Age of household head (number of years)	0.002	0.002	−0.003	0.001	0.001	−0.001
	(0.001)	(0.003)	(0.003)	(0.046)	(0.046)	(0.046)
Education (1 = Literate; 0 = Illiterate)	−0.091	−0.092	0.183***	0.008	0.008	0.037
	(0.058)	(0.077)	(0.060)	(0.639)	(0.639)	(5.136)
Marital status (1 = Married; 0 = Not married)	0.014	−0.094	0.080	−0.992***	−0.992***	1.253***
	(0.034)	(0.074)	(0.070)	(0.007)	(0.007)	(0.035)
Household size (Number of members)	−0.001	−0.005	0.006*	−0.009	−0.009	0.002
	(0.002)	(0.004)	(0.004)	(0.651)	(0.651)	(0.950)

(*continued on next page*)

Table A1 (*continued*)

VARIABLES	Mali			Niger		
	(7)	(8)	(9)	(10)	(11)	(12)
	Disagree	Neutral	Agree	Disagree	Neutral	Agree
	Marginal Effects	Marginal Effects	Marginal Effects	Marginal Effects	Marginal Effects	Marginal Effects
Informational factors						
Group membership (1 = Yes, 0 if otherwise)	−0.061**	0.030	0.031	−0.032	−0.032	−0.040
	(0.025)	(0.079)	(0.079)	(2.419)	(2.419)	(8.428)
Have mobile phone (1 = Yes, 0 if otherwise)				−0.087	−0.087	0.059
				(6.070)	(6.070)	(6.763)
Access to financial services						
Access to credit (1 = Access, 0 if otherwise)	0.001	−0.003	0.001	−0.048	−0.048	0.002
	(0.044)	(0.108)	(0.113)	(3.649)	(3.649)	(6.342)
Professional activity and income diversity						
Main activity (1 = farming, 0 if otherwise)	0.007	0.077	−0.084	−0.026	−0.026	0.070
	(0.030)	(0.062)	(0.059)	(1.972)	(1.972)	(5.189)
Number of sources of income	−0.005	−0.030	0.034	−0.002	−0.002	−0.021
	(0.015)	(0.033)	(0.034)	(0.173)	(0.173)	(2.532)
Cultural beliefs and perceived animal health risks						
Cultural beliefs	−0.153***	−0.111*	0.264***	0.031	0.031	−0.131
	(0.034)	(0.057)	(0.047)	(2.343)	(2.343)	(11.318)
Animal health risk	−0.078**	0.026	0.052			
	(0.035)	(0.059)	(0.051)			
Contextual factors						
City	Yes	Yes	Yes	Yes	Yes	Yes
Country	No	No	No	No	No	No
Observations	312	312	312	315	315	315

Note: Values in parenthesis are standard errors. *, **, *** denote significance level at 10 %, 5 %, and 1 %. Approximated likelihood ratio test of proportionality of odds across response categories after ordered logit, DRC (Chi2 = 30.87*** for Kinshasa and Chi2 = 46.93***), Mali (29.03***), and Niger (98.79***).

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