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Smallholder farmers' willingness to pay for commercial insect-based chicken feed in Kenya

RESEARCH ARTICLE

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Abstract

The cost of chicken production in developing countries is 300% higher than in developed nations. Overreliance on the key protein feed ingredients especially soybean and fishmeal (SFM) that are characterized by rising food-feed competition and supply chain impediments exacerbate the situation. The use of insect protein as a sustainable alternative protein source has attracted global attention recently. However, there is a dearth of empirical insights on farmers' preferences for commercial insect-based feed for chicken production in Sub-Saharan Africa. This study evaluated farmers' willingness to pay for attributes of insect-based commercial chicken feed in Kenya using a choice experiment based on a survey of 314 predominantly chicken farmers. Results show that the farmers are willing to pay premium prices ranging between US$ 0.35 and US$ 3.45 for insect-based feed in the form of either pellets or mash, feed explicitly labelled as containing insects, insect protein feed mixed with SFM and dark-colored feed. These findings provide evidence for multi-stakeholder collaborations to facilitate the creation of an inclusive insect-based feed regulatory framework for sustainable feed and chicken production.

Keywords: chicken, insect-based feed, choice experiment, Kenya
JEL code: Q12, Q18

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1. Introduction

Feed forms the most critical component in the nutritional development of livestock. However, human population pressure and competing land uses only leave one-third of global arable land for production of crops such as soybean that provide proteins, which are the key feed ingredients. The main protein ingredients, that is, soybean and fishmeal (SFM) constitute the most expensive component of the inputs used in feed production. This is due to competition in their use in food and feed production chains. The food-feed competition for SFM has led to high prices of these feed inputs. Rampant food insecurity challenges in developing countries lead to scarcity of protein-based ingredients for the feed industry, further increasing their prices (Fraval *et al.*, 2019). Consequently, there is a dilemma on how to create a sustainable balance between sourcing for raw materials for food and meeting feed requirements for livestock production.

In Kenya, the shift to commercial intensive chicken production system implies a growing demand for commercial feed (Carron *et al.*, 2017). Chicken enterprises contribute to food and nutrition security, as well as income to households, and about one-third of agricultural gross domestic product (GDP) in the country (Acosta *et al.*, 2021; Carron *et al.*, 2017). Further opportunities are expected within the chicken industry, which is projected to record the highest growth of 121% within the livestock sub-sector by the year 2050 (Mottet and Tempio, 2017). Developing countries like Kenya will play a key role in spurring this growth at the rate of 2.4% compared to 1.8% at the global level for chicken production (Mottet and Tempio, 2017). Therefore, continuous feed production is crucial for the sustainability of commercial chicken enterprises, which use up to 71% of industrialized feed (Makkar, 2018).

Chicken production costs in developing countries are about 300% higher than in the developed countries (Etuah *et al.*, 2019). Kenya is a net importer of protein ingredients for feed from neighboring countries like Tanzania, Uganda and Zambia (Republic of Kenya, 2020). Disruptions from international trade disputes and the recent Covid-19 pandemic affect local and regional supply chains (Nordhagen *et al.*, 2021) and the final pricing of the feed inputs for local formulation of feed. Further increases in these costs and influx of cheap imports of processed chicken products threaten the margins of small-scale farmers who dominate chicken production in the region (Brauw and Bulte, 2021).

Evidence suggests that the use of locally available feed ingredients, like insect protein, will not only mitigate the chicken production challenges but also address the developmental setbacks of low and middle-income nations (Abro *et al.*, 2020; Nyakeri *et al.*, 2017; Onsongo *et al.*, 2018; Republic of Kenya, 2019a; Sogari *et al.*, 2019). Within the Sub-Saharan Africa (SSA) region, the insect-based feed sub-sector can reduce chicken production costs by 17%, contribute to youth employment, food security and poverty alleviation depending on timely dissemination of context-specific information (Onsongo *et al.*, 2018). In Kenya, the sub-sector has potential of increasing the annual total income by at least US$ 69 million, which represents a rise of not less than 7% of chicken's contribution to GDP; create a minimum of 3,300 additional jobs; and increase food security by availing approximately 35,000 tons of available cereals for human consumption (Abro *et al.*, 2020).

There is overwhelming research on the nutritional and environmental benefits of insect protein particularly the black soldier fly (BSF) larvae, which is the insect of interest in this study. De Marco *et al.* (2015) found that the amount of crude protein and other essential nutrients in BSF larvae meal is higher than those of the other ingredients used in chicken feed formulation; making the insect meal attractive for chicken feed formulation. Insect farming has a low environmental impact owing to the limited requirement for land and water resources, low greenhouse gas and carbon dioxide emissions (Madau *et al.*, 2020). Processing of insects for feed promotes the circular economy model, a pertinent approach in a society that is characterized with high food loss and waste in food supply chains (Shumo *et al.*, 2019; Spranghers *et al.*, 2017). Discarded organic waste accounts for about one third of all food produced for human consumption (Madau *et al.*, 2020; Skrivervik, 2020; Spranghers *et al.*, 2017; World Bank, 2021), and has negative economic and environmental impact particularly in developing countries, which have inefficient waste disposal and processing strategies.

Currently, there is a lag in the adoption of insect-based feed because it is an emerging enterprise in Africa with limited volume available (Tanga *et al.*, 2021).

Commercially viable protein alternatives like BSF larvae that reduce environmental footprint of food systems do not only align with global policies on climate action (World Bank, 2021) but also with national efforts to transform the livelihoods of smallholder farmers in developing countries. For instance, livestock policies in Kenya emphasize the need to transform the sub-sector from a subsistence level to a commercial (market-oriented) undertaking by employing various modern technologies and innovative practices (Republic of Kenya, 2019a). The premise of the policy focus is that commercialization acts as a pathway out of poverty (Cazzuffi *et al.*, 2020). Market-driven advancements that aim at expanding the livestock sub-sector have strong associations with welfare and efficient use of resources (Enahoro *et al.*, 2019). However, both animal welfare and environmental management concerns remain elusive within livestock production in SSA as majority of the policies lack an appropriate framework that integrate these crucial components into a sustainable sector-enhancing strategy (Marescotti *et al.*, 2020; Selaledi *et al.*, 2021a). In this study, we evaluate the interactions presented by different insect-based feed attributes to bring out the preferred scenarios to accommodate the aforementioned policy concerns of commercialization, livestock welfare and environmental issues for a sustainable livestock sub-sector and emerging insect industry (FAO, 2017).

Overcoming social barriers associated with some insect-based products is pertinent in ensuring successful adoption and sustainability of the sector. Within SSA, farmers have traditionally harvested insects to supplement livestock diet particularly for the growth of chicken (Dao *et al.*, 2019; Pomalégni *et al.*, 2018; Sebatta *et al.*, 2018). In Kenya, farmers have demonstrated increased willingness to incorporate insects into their livestock production systems (Chia *et al.*, 2020; Waithanji *et al.*, 2019). This is probably attributed to indigenous knowledge of the various communities that have observed chicken picking up insects at all life stages and eating them voluntarily, which indicates that they are evolutionarily adapted to insects as a natural part of their diet (Bovera *et al.*, 2015; Lin *et al.*, 2014). Furthermore, the traditional practice of consuming edible insects like termites and crickets in different regions in Kenya has favored farmers' readiness to also use them for feed (Ayieko *et al.*, 2010; Kinyuru *et al.*, 2018; Kusia *et al.*, 2021). Therefore, it seems reasonable to consider the inclusion of insect proteins as raw material to be used in commercial feed manufacturing and to develop intensive farming systems for these insects. Insects are a rich source of protein (40-60%): essential amino acids and fat (De Marco *et al.*, 2015; Makkar *et al.*, 2014; Van Broekhoven *et al.*, 2015) and several experimental trials published to date have expressed both nutritional and health benefits of feeding insect-based feed to broiler and layer chickens (Makkar *et al.*, 2014). These studies revealed high total tract amino acids digestibility (over 90%) and lower feed intake as compared to control diet with soybean meal indicating an improved feed conversion (FCR) (Makkar *et al.*, 2014). Cognizant of this and the need to conserve biodiversity (Selaledi *et al.*, 2021b), this study highlighted the understanding of farmers' creativity and potential to innovate using indigenous knowledge to overcome the protein gap experienced as hindrance to poultry production but also consider their purchase behavior that drives their preferences for commercial insect-based feed. Specifically, using the choice experiment (CE) method, this study analyzed farmers' preferences for the inclusion of the BSF larvae protein in commercial chicken feed in Kenya. Okello *et al.* (2021) points that in addition to majority of the farmers willing to use insect-based feed, they also demand the products based on specific features of the feed. This means that farmers purchase goods by considering various components and not the entire good as a whole, hence it would be paramount to identify and quantify these features. Therefore, this study quantified farmers' willingness to pay (WTP) for specific insect-based feed attributes, identified in a consultative process with various stakeholders in the chicken value-chain.

Understanding farmers' preferences is critical to forestall product failure for insect-based feed and the sustainability challenges that often characterize top-down non-consultative development processes (Gasco *et al.*, 2019). Although there are some recent studies on farmers' acceptance and WTP for insect-based feed in Benin and Kenya (Chia *et al.*, 2020; Pomalegni *et al.*, 2018) as well as consumers' acceptance of insect-based feed chicken meat in Germany (Altmann *et al.*, 2019), studies on the WTP for insect-based commercial chicken feed attributes are scarce. This analysis sought to fill this gap.

Considering that the insect-based feed value chain is an emerging sector in SSA, this study aims to make three contributions to the sustainability of insect-based products. First, the findings contribute to the national discourse on effective and appropriate legislation necessary to facilitate insect farming for protein and commercialization of insect-based products, which depend on availability and generation of evidence-based data to inform policy (Kenya Bureau of Standards (KEBS), 2017). Second, the study accounts for preference heterogeneity by applying the random parameter logit to also control for unobserved correlation presented by repeated choice tasks by individual farmers. This allows for efficient estimation of the value (premium or discount) placed by the farmers on the identified attributes to inform the design of insect-based feed market. Lastly, the study further generates welfare estimates for different chicken production systems based on selected market-driven attributes. Through the estimates, we identify the most preferred policy scenarios to guide the implementation procedure for insect-based feed.

The remainder of the paper is organized as follows: Section two provides the methods applied in the study, while results are presented and discussed in Section three. The paper concludes with a discussion of possible policy interventions.

2. Methods

2.1 Theoretical framework

Given that use of insect protein to make commercial feed is still in pilot stage, the study used the CE approach; a stated preference non-market valuation technique to elicit farmer preferences. The CE method allows decomposition of a good or service into its characteristics or attributes. The CE method is based on the random utility theory, which posits that given a choice task involving alternative combinations of attributes of a product, a rational individual would choose the option that yields the highest level of utility (McFadden, 1974). Since utility is unobservable, the satisfaction derived by the individual can be inferred from the value represented by the choice made (Hall *et al.*, 2004).

Empirical applications of the CE approach are vast in the extant literature. Most recently, the CE approach has been used to value preferences for: environmental attributes for leguminous fertilizer (Xin *et al.*, 2022); consumer WTP for certified pork labels (Wang *et al.*, 2018); and preferences for eco-labelling and extension (Bronnmann and Hoffmann, 2018; Oyinbo *et al.*, 2019). In Kenya, the CE approach has recently been applied in the analysis of various policy issues for both consumer and producer product development (Maina *et al.*, 2019; Otieno and Ogutu, 2020; Zhu *et al.*, 2018). The only empirical valuation of preferences for insect-based livestock feed is that of Altmann *et al.* (2019) that applied CE approach to understand WTP for insect meal or micro-algae chicken products in Germany. This study makes a novel application of the CE method to evaluate farmers' preferences for use of insect protein in the preparation of commercial chicken feed in a developing country context.

2.2 Choice experiment design

The CE process involved three key steps: review of literature to identify potential attributes of BSF-based chicken feed; validation of the attributes and their levels through expert consultations and focus group discussions (FGDs) with farmers and; use of statistical procedures to combine various attributes to generate feed bundles/packages. The experts consulted included a local feed miller, a representative from the Association of Kenya Feed Manufacturers and livestock extension officer.

With the list of attributes developed from in-depth literature review, the stakeholders were involved through face-to-face interviews to verify the validity of each attribute. In line with the suggestion by Greiner *et al.* (2014), three FGDs were conducted with ten chicken farmers who were representative of different age groups, gender and income categories in each session, to understand the contextual relevance of the attributes and their levels. The aim of the rigorous consultative procedure was to identify compulsory and optional attributes. The compulsory features are mandatory and must be included in the policy design to ensure a feasible insect-based feed regulatory framework. Four compulsory and five optional attributes were identified. First, it was envisaged that decentralization of quality regulatory institutions to local administrative levels (county and sub-county levels in this case) would ease access to the feed and ensure regular inspection of quality and safety aspects in different market outlets. Second, in line with the Animal Foodstuffs Act (Cap 345), enforcement of strict penalties on individuals who default on quality and other standards through monetary fines, prosecution and confiscation of business licenses was deemed necessary to prevent adulteration of feed and thus, protect the safety of chicken as well as consumers from hazardous substances (Republic of Kenya, 2012).

Farmers are keen on the introduction of hefty fines on defaulters instead of prosecution due to the lengthy nature of court proceedings, which might have adverse economic effect on the feed millers/sellers and by extension impede farmers' business progress. Use of technology-based standards and quality verification mechanisms that are accessible to all farmers was identified as another mandatory feature. Considering that counterfeit insect-based feed may penetrate the market, it was suggested that verification codes that are compatible with mobile phones would ensure instant traceability in the supply chain and the purchase of authentic insect-based feed. Finally, partnership among the farmers, public and private sector contributes significantly to the implementation of policy interventions based on the ingredients and formulation process of insect-based feed. This would reduce overlapping roles and minimize delays that come with standards specification of novel ingredients among the stakeholders.

The optional attributes are those that typically go into the CE design and they allow farmers' flexibility on what levels they desire to be incorporated in the feed design and distribution. Badar *et al.* (2015) noted that the optional attributes allow consumers to identify and examine the product prior to initiating a purchase. The authors classify these attributes as search and marketing features. In this study, the search attributes included the final form of the feed, protein source and color of the feed, while the marketing features considered were labelling and price (Table 1).

The inclusion of the feed form as an attribute in this study was meant to provide insights on farmers' preferences based on their experience in feeding diverse breeds of chicken. According to the KEBS (2020), milled insect products can be presented in three main forms including mash, pellets or crumbs. Pelleting of feed reduces wastage and increases feed intake by birds (Abdollahi *et al.*, 2013). Processing of the crumble diet involves pelleting the ingredients before crushing them to a consistency coarser than the mash (Jafarnejad *et al.*, 2010) whereas the mash is the finely ground form so that the birds cannot easily separate out the ingredients. However, Sena *et al.* (2013) noted faster growth among birds reared on pellets.

Appropriate labelling is an important marketing aspect that positively drives consumers' purchasing behavior for the products' existing and new attributes (Wang *et al.*, 2021). While Popoff *et al.* (2017) noted that retailers are reluctant to disclose the type of insects used in livestock feed due to potential negative attitudes by some consumers, Van Huis (2020) and KEBS (2020) argue that clear labelling of the insect-type on chicken feed is crucial in reducing uncertainties and informing farmers' purchasing decisions. Specifically, KEBS (2020)

Table 1. Attributes included in the choice experiment design.[1,2]

BSF-based feed attributes	Description of attributes	Levels of attributes
Feed form	the physical structure of the feed	pellets; crumble; mash
Labelling	labelling of the feeds to indicate that it contains BSF	yes; no
Protein source	indication of the protein type included in the feed	BSF only; BSF mixed with SFM
Color	the color of the feed	dark; light
Price	the price of one kg of the feed (Kshs)	24; 44; 64

[1] 100 Kenyan shillings (Kshs) were equivalent to 1 US$ at the time of the survey.

[2] BSF = black soldier fly; SFM = soybean and fishmeal.

stipulates that the insect-based feed packaging label should include the name and class of the insect product, insect species, form of processing, and type of substrate used. This study sought to understand whether chicken farmers would prefer disclosure or non-disclosure of insect type on the feed labels.

The protein source determines nutritional value of feeds. Moreover, the choice of a particular source of protein to include in the feed depends on individual farmers' attitudes. Even though most farmers in Kenya are aware of the high nutritional value of chicken naturally fed on insects (Chia *et al.*, 2020; Waithanji *et al.*, 2019), other factors such as cases of allergic reactions, disgust and phobia affect farmers' preference for insects as feed (Kornher *et al.*, 2019; Lombardi *et al.*, 2019; Onwezen *et al.*, 2019). This may prohibit wide adoption of commercial BSF based feed. The KEBS (2020) recommends several sources of insect proteins among them the BSF larvae, adult crickets, housefly larvae, mealworm larvae and pupae, adult termites and adult or nymph cockroach. This study included two levels of the protein source: exclusive use of insect in feed, or insect mixed with SFM.

The color of feed depends on the ingredients used and due consideration must be given to whether the resultant color will be appealing to chicken as well as farmers. While the use of synthetic dyes to enhance color is recommended, a deviation from the typical appearance should be critically evaluated as this could have an implication on the quality (BioVision, 2018). Given farmers' experience in chicken-feeding practices, the inclusion of two levels of color (dark and light) was appropriate in this study.

Considering that production or improvement of any feed requires resources, end users rationally pay a price premium to compensate for the production costs and some mark-up as business incentive. Therefore, the price attribute provides a basis for estimating trade-offs for the insect-based feed attributes. Further, El Benni *et al.* (2019) observed that price is directly proportional to food quality and safety. Following Bronnmann and Hoffmann (2018), the average market price per kilogram of chicken feed was computed as the average from local retail shops in Kiambu Township. This price, which was Kshs 44 at the time of the survey, was used as the base price level. Following the standard practice in CE studies (for instance, Bronnmann and Hoffmann, 2018; Otieno and Ogutu, 2020; Pascucci and de-Magistris, 2013), two other price levels set at 45% above and below the base level to account for differentials in farmers' income and price premiums.

Following Scarpa *et al.* (2013), the CE design was done using a two-stage process in Ngene statistical software (Ngene, ChoiceMetrics). First, a fractional orthogonal design was generated and used to collect preliminary data from a pilot survey of 42 farmers. The data from the preliminary survey was analyzed to obtain prior coefficients that were subsequently used to generate a D-efficient design: a design that allows estimation of parameters with low standard errors on a minimum sample size necessary to achieve a certain degree of estimation accuracy (Bliemer and Rose, 2010; Scarpa and Rose, 2008). The efficient design resulted in 24 paired choice sets that were systematically blocked into six profiles. Through blocking, the detrimental effect on data quality that comes with task complexity is reduced (Hensher, 2006). The CE design obtained had a high D-efficiency measure of 83% and utility balance, B-estimate, of 81%: confirming D-optimality and absence of dominance by any alternative in the choice sets (Kessels *et al.*, 2011).

Each choice situation contained two alternative types of feed (BSF-based feed type A or type B). In line with the completeness axiom of choice, an opt-out option (neither BSF-based feed type A nor B) was included as the third alternative to accommodate farmers who would not wish to choose between the feed types offered, or those whose preferred combinations may not have been fully captured by the design (Greiner *et al.*, 2014). Inclusion of the opt-out option is known to reduce the over-estimation of the WTP values that is sometimes reported in comparative studies between CE and contingent valuation method (Danyliv *et al.*, 2012; Ryan and Watson, 2009; Van der Pol *et al.*, 2008). Overall, our CE design alternatives conform to the optimal dimensions suggested by Hensher (2006) and Caussade *et al.* (2005), four to six attributes with two or three levels and providing a maximum of four alternatives in each choice task. A pretest of the CE choice cards and survey questionnaire on a sample of 15 farmers proved that the exercise was not complex to the respondents. An example of a choice set presented to the farmers is illustrated in Table 2.

Table 2. Example of insect-based feed choice set.[1]

BSF-based feed attributes	BSF-based feed type A	BSF-based feed type B	Neither A nor B
Feed form	pellets	mash	none
Labelling for BSF-based feed	not labelled	labelled	none
Protein source	BSF mixed with SFM	BSF only	none
Color	dark	light	none
Feed price per kg (Kshs)	24	64	none
Which ONE would you choose? (*tick where appropriate*)			

[1] BSF = black soldier fly; SFM = soybean and fishmeal.

2.3 Sampling and data collection

The study was conducted in Kiambu County (Figure 1) which was purposively selected because of its dominance in commercial small-scale chicken production in terms of the total number of chicken reared in the country, which is approximately 3.7 million birds (KNBS, 2019). Further, 68% of the chicken producers are commercially-oriented, an indication that they purchase commercial feed (Carron *et al.*, 2017; KNBS, 2019). Therefore, farmers in the area were considered as the right target for the valuation of commercial insect-based feed. The county is adjacent to Nairobi city, an urban market that has high demand for chicken products where more than 50% consume commercial chicken (McCarron *et al.*, 2015; Otieno and Kerubo, 2016). Affordable and quality feed like the insect-based feed has the potential of attracting poor households

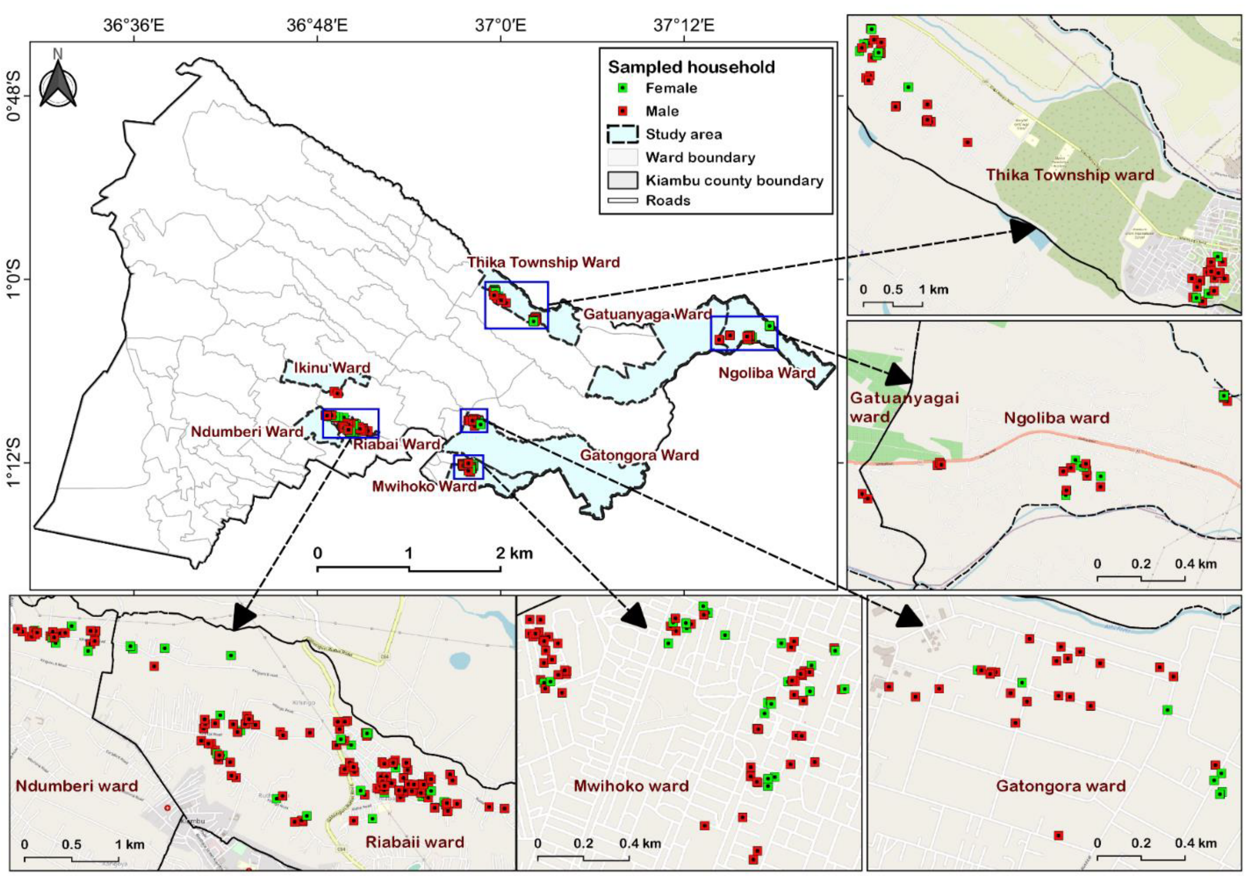

Figure 1. Map illustrating the study sites in Kiambu County, Kenya.

into commercial chicken production and boost their livelihoods, thus contributing to reduction of the poverty level that currently stands at 23% in Kiambu (KNBS, 2018).

A multi-stage sampling technique was employed to identify the respondents. In the first stage, three sub-counties namely: Kiambu Township, Ruiru and Thika were purposively selected from a total of 12 sub-counties in the county due to their high intensity of chicken production and relative proximity to shopping centers around Nairobi City. Since the simple random sampling gives all the individuals an equal chance of being selected to participate in the study, the procedure was employed in identifying the wards and individual farmers to be interviewed (Acharya *et al.*, 2013; Onwuegbuzie and Collins 2007). Furthermore, the simple random sampling allows us to make reliable generalizations to the smallholder farmers in the region based on the findings of the study (Acharya *et al.*, 2013). Two wards in each of the three selected sub-counties were selected by also using the lottery method of the simple random sampling procedure. The selected wards were Ndumberi and Riabai in Kiambu Township, Gatong'ora and Mwihoko in Ruiru, and Gatuanyaga and Thika Township in Thika. Following the recommendations of Orme (2010) on sample size determination for choice-based research, a minimum sample of 300 farmers was required. Therefore, in the final sampling stage, 50 farmers were selected in each ward from a sampling frame of smallholder chicken farmers that was provided by the sub-county government extension agents through the lottery method of simple random sampling. The sampling frame comprised of 150 to 200 smallholder farmers in each sampled ward. Fifteen extra respondents from Kiambu Township were included in the sample to account for potential non-response.

Data was collected through face-to-face interviews using a semi-structured questionnaire in the household survey. The face-to-face interview method maximizes rapport with the farmers and ensures mutual benefit in outcomes for both the researcher and the respondents. The semi-structured questionnaire contained a list of mixed questions that limited the respondents to pre-determined responses to choose from and questions that allowed open responses from the farmers. The latter allows open lines of communication to be established between the researcher and the respondent and gives opportunity for further elaboration on the objectives of the study (Brown and Danaher, 2019). The CE section of the questionnaire was implemented in two steps. First, owing to the hypothetical nature of the study, an introductory session was conducted where farmers were provided with information about the novel feed and were reminded to mimic their buying behavior in a real market situation, when choosing their most preferred alternative. The information provided covered aspects pertaining to the present status of the development of the insect-based feed, the need for farmer-involvement in specifying their preferred combinations of the feed based on the choice cards and the process used to come up with the feed attributes among other issues like the current challenges facing the chicken feed industry, the economic and environmental opportunities presented by insect-based feed for the farmer. The importance of making truthful choices to limit non-attendance to certain attributes was emphasized. Subsequently, each farmer was presented with four hypothetical choice scenarios and after careful evaluation of the options, they were asked to choose their most preferred feed type in each choice set. Based on Greiner *et al.* (2014), each farmer responded to a one profile out of the six with each profile containing four choice tasks. Each task contained three alternatives with the first two containing insect-based feed package with differing attribute combinations while the third alternative being the opt out option as earlier described (Table 2). The profiles were randomly assigned to the farmers and the study ensured that each farmer responded to only one to reduce task complexity while also ensuring that all profiles had an equal number of responses by the end of the survey exercise. The survey questionnaire also contained sections on the household socio-demographics, chicken resource endowments and institutional support services. The survey was implemented using both hard copy questionnaires which captured the CE data and computer-assisted personal interviewing open data kit (ODK) software and uploaded on tablets for the rest of the household demographic features. The CE data was analyzed using the NLOGIT software version 4 (Econometric Software, Inc., Plainview, NY, USA). The eventual sample size dropped to 314 after one questionnaire was removed from analysis due to incomplete information on the choice sets.

2.4 Data analysis

Following Hensher and Greene (2003) and McFadden and Train (2000), the study applied random parameter logit (RPL) model in the analysis of CE data since it accounts for preference heterogeneity. The utility function (U) is made up of observed/systematic and unobserved components. The systematic component (V) is the portion of the product that relates to the attributes of interest to the analyst while the variations in the choices made by the farmers combined with other measurement errors are captured in the unobserved (random) component (ε) of the utility function. Following Revelt and Train (1998) and Train (2002), the RPL formulation of the utility function of the n^{th} farmer for a particular alternative j in choice situation t is expressed as follows:

$$U_{nj} = \beta'_n X_{nj} + \varepsilon_{nj} \tag{1}$$

where X_{nj} is the attribute vector of alternative j and β_n is the unobserved vector of the corresponding coefficient assigned by individual n and varies among farmers with a density function $f(\beta_n|\theta)$, whereby θ is the parameter vector of the distribution. The random component is independent and identically distributed over alternatives and thus permits estimation of the probability that farmer n chooses alternative j in a given choice set. The choice probability of the random parameter logit is as follows:

$$P_n(\theta) = \int S_n(\beta_n)\, f(\beta_n|\theta)\, \mathrm{d}\beta_n \tag{2}$$

where $f(\beta|\theta)$ is the density function of β which is described by parameters θ. The objective of the RPL is to estimate the θ using the log-likelihood function because the choice probability from Equation 2 does not have a closed mathematical form. The log-likelihood function is given as follows:

$$LL(\theta) = \sum_n \ln P_n(\theta) \tag{3}$$

Following the standard RPL practice, simulation method was used to approximate the probability. A total of 200 Halton simulation draws were used over randomly selected values of β_n. The simulated probability of n's sequence of choices is:

$$SP_n(\theta) = \left(\frac{1}{R}\right)\sum_{r=1}^{R} S_n(\beta_n^{r|\theta}) \tag{4}$$

where R represents the 200 Halton draws, $\beta_n^{r|\theta}$ is the r^{th} draw from $f(\beta_n|\theta)$.

The estimated parameters are those that maximize the simulated log-likelihood (SLL) function which is estimated as:

$$SLL(\theta) = \sum_n \ln\left(SP_n(\theta)\right) \tag{5}$$

Following Hanemann (1984), the WTP for BSF attributes (k) were computed as ratios of the estimated coefficient of each attribute k (β_k) and the price attribute (β_p) as shown in Equation 6:

$$WTP_k = -\left(\frac{\beta_k}{\beta_p}\right) \tag{6}$$

where the negative sign ensures compliance with the rationally expected inverse relation between price and quantity in the conventional law of demand. The results of the CE were further used to measure the compensating surplus (CS) to generate BSF-based feed policy scenarios for targeted policy intervention. The CS measures the change in income that would make the farmer indifferent between the initial and subsequent situations based on the assumption that the farmer has the right to initial utility level (Hanemann, 1984; Othman *et al.*, 2004). The income change is an indication of the farmers' WTP for an improved feed that is expected in the BSF-based feed. Following Morrison *et al.* (1999), the CS was estimated using Equation 7:

$$CS = -\frac{1}{\beta_p}(V_0 - V_1) \tag{7}$$

where β_p is the coefficient of the marginal utility of income while $V0$ and $V1$ represent the indirect unobservable utility before and after the introduction of the BSF-based feed.

3. Results and discussion

3.1 Socio-economic characteristics of chicken producers

A summary of some socio-demographic features of the chicken-producing households interviewed is presented in Table 3. More than three-quarters of the households (77%) were male-headed with an average age of 50 years, an indication that middle-aged farmers dominate chicken production. Based on the findings of Chia *et al.* (2020), older farmers are willing to pay for insect-based feed owing to their experience, which informs their understanding of the challenges presented by high cost of feed. On average, farmers had 12 years of formal education implying that most of them had attained a secondary school level of education. Therefore, they could comprehend the attributes and evaluate the different choice sets presented to them regarding commercial insect-based feed.

The average monthly household income was slightly more than Kshs 57,000, which is almost ten times the national minimum wage (Kshs 6,736.30) (Republic of Kenya, 2019b). Additionally, majority of the farmers (81%) reported engaging in off-farm activities, which complemented their household income. The availability of additional income can positively influence farmers' likelihood and willingness to pay for the innovative feed. This is in line with the findings of Okello *et al.* (2021) and Toma *et al.* (2018) who reported that higher incomes among farmers increased the probability of their uptake of innovative technologies and insect-based products. Three-quarters of the farmers (75%) confirmed that they sold chicken and related

Table 3. Characteristics of chicken-producing households in Kiambu County, Kenya.[1]

Variables	Statistic (n=314)
Average age of household head (years)	50 (12.05)
Average years of schooling	12 (3.01)
Average household income per month (Kshs)	57,750 (24,296)
Gender of household head (% male)	77.39
Off-farm income source (% yes)	80.89
Commercial chicken production (% yes)	75.48
Share of chicken income in total income (%)	8.95
Membership to poultry group (% yes)	13.38
Awareness of chicken feeding on insects (% yes)	61.78
Willing to use insect-based feed (% yes)	93.32
Sources of information on use of insect as chicken feed	
Fellow farmers	34.52
Own experience/culture	30.58
Extension officers	14.48
Icipe	17.11
University exhibitions	1.32
Agricultural trade fairs	1.32
Other sources	0.68

[1] 100 Kenyan shillings (Kshs) were equivalent to 1 US$ at the time of the survey. Standard deviations for continuous variables are presented in parentheses.

products in various markets. On average, chicken production contributes about 10% to the farmers' total household income, which is 7% less than that of Okeno *et al.* (2012). As mentioned earlier, our finding could be because of farmers diversifying into other income-generating activities to reduce economic risks associated with high feed costs.

Membership to poultry groups was low at 13%. Similarly, Kiprop *et al.* (2020) observed that only 27% of chicken farmers belonged to groups in Kenya. In this study, farmers reported that the main role of the groups was feed production while other value chain activities like marketing were solely managed by the farmer. Whereas groups provide a platform for advocating for efficient production (Abdul-Rahaman and Abdulai, 2018; Ingutia and Sumelius, 2022): their redundancy and collapse in developing countries in recent years has been due to reduced farmer participation in chicken production in light of rising feed costs (Ssepuuya *et al.*, 2017).

Nearly a quarter of the farmers cited having received agricultural training pertaining to livestock production. Therefore, in line with the views of Argent *et al.* (2014), they could be expected to better manage different aspects of their livestock. Based on local knowledge and individual observations, almost two-thirds of the farmers (62%) were aware of chicken feeding on various types of insects as an essential source of nutrients. Insects form part of the natural diet for chicken, which scavenge outdoors for insects, among other diets like vegetables. Almost all farmers (94%) were willing to use insect-based feed in their chicken production, an indication that farmers are receptive to interventions aimed at improving their livelihoods.

Peer learning among farmers was the main source of information (35%) on the use of insect in chicken feed, followed by individual experience (31%). These findings are consistent with those of Ipara *et al.* (2021) and Shams and Fard (2017) who reported that farmers with experience on innovations share similar information with each other. The popularity of farmer-to-farmer method of information transfer is attributed to inadequate supply of and costly nature of public extension services (Waithanji *et al.*, 2019). Furthermore, Sebatta *et al.* (2018) observed that farmers' awareness and knowledge of the nutritional role of insects in chicken diet is based on own observations in free-range extensive production systems. Research institutions such as the International Centre of Insect Physiology and Ecology (*icipe*) and private extension agents also played a role in the dissemination of information regarding the use of insect in chicken feed. The use of insects in commercial feeds is an emerging concept, which still requires more information dissemination programs by relevant stakeholders including agricultural extension and university exhibitions (Chia *et al.*, 2020).

3.2 Farmers' willingness to pay estimates for insect-based feed attributes

Results of the random parameter logit (RPL) and WTP estimates for commercial insect-based chicken feed attributes are presented in Table 4. All attributes were statistically significant at the 1% level ($P<0.0001$). The RPL model was highly significant ($P<0.0001$) and exhibited a good explanatory power with pseudo-R^2 of 0.37, which fits within the recommended range for discrete choice models (Louviere *et al.*, 2000; Scarpa *et al.*, 2003). Further, the RPL model shows an improvement from the starting log-likelihood value of -956.51 in the multinomial logit (MNL) model to -869.76. The use of the RPL framework is further justified with statistically significant standard deviations on three out of the five attributes, indicating the presence of substantial heterogeneity of preferences for the attributes across the farmers (Table 4).

All the attributes considered in this study were significant and with the expected signs, an indication of their importance in influencing farmers' decisions regarding insect-based feed for chicken production. Moreover, the statistically significant and negative sign of the price coefficient indicates that a lower price level is preferred and further permits the computation of monetary trade-offs of the insect-based feed attributes.

Farmers had a higher preference for the form of the feed as indicated by the relatively large coefficient associated with pelleted feed. Farmers gave twice more weight to the feed form than they did to labelled feed and about four times more than they did to the protein source and color attributes. Farmers preferred either

Table 4. Random parameter logit (RPL) and farmers' willingness to pay (WTP) estimates for insect-based feed attributes.[1,2]

Variable	RPL coefficient (std. err.)	*P*-value	WTP estimates (at 95% CI) in Kshs[3]	*P*-value
Pellets	4.300 (0.550)	0.000***	341.78 (188.6-494.5)	0.000***
Mash	3.687 (0.550)	0.000***	293.13 (151.2-435.1)	0.000***
Label	1.978 (0.188)	0.000***	157.94 (99-217)	0.000***
Mixed	0.739 (0.183)	0.001***	58.69 (24.7-92.7)	0.001***
Dark	0.435 (0.103)	0.000***	34.53 (16.4-52.7)	0.000***
Price	-0.013 (0.003)	0.000***		
Standard deviation of parameter distributions				
sdPellets	1.316 (0.410)	0.001***		
sdMash	0.600 (0.944)	0.532		
sdLabel	0.746 (0.258)	0.004**		
sdMixed	2.189 (0.231)	0.000***		
sdDark	0.327 (0.349)	0.357		
Log-likelihood		-869.79		
Adjusted pseudo-R^2		0.3669		
Chi-square (ρ-value)		1,020.13 (0.000)		
n (respondents)		314		
n (choices)		1,256		

[1] ** and *** denote statistical significance at 5 and 1% levels, respectively.

[2] CI = confidence interval at 95% derived from the Delta method; log-likelihood = -956.51; starting MNL pseudo-R^2 = 0.0145; std. err. = standard error.

[3] 100 Kenyan shillings (Kshs) were equivalent to 1 US$ at the time of the survey.

pelleted or mashed feed than that crumbled feed. However, pelleted feed is valued one and half times more than the mashed one. Even though pellets are expensive, they reduce wastage because they can be easily collected when scattered in the chicken coops as opposed to mashed feed, which is usually swept off when cleaning the coops. This finding corroborates those of other studies that have recommended the use of pellets in feed processing because chicken spend less time and energy yet obtain more nutrients when fed on pellets (Abdollahi *et al.*, 2019). Despite farmers' willingness to pay for mashed feed possibly due to its widespread familiarity and its ease of digestion for chicks, the study reveals that moving forward farmers would highly appreciate technological advancements like pelleted feed that minimize costs associated with feed wastage.

Farmers are interested in labels explicitly showing the presence of insect to build their trust in insect-based products. The preference for clearly labelled feed could be informed by rising cases of feed adulteration with non-nutritious substances, which pose a health risk to the chicken and an economic burden to the smallholder farmers. Farmers consider labels as informative during the transaction process as they are able to understand and track any changes in the feed components, which eventually informs their purchasing decisions. This finding aligns with those of Pascucci and de-Magistris (2013) and Van Huis (2020), who noted the importance of labels in communicating nutritional contents and in enabling traceability of safety and quality aspects in the insect-based feed industry.

The need for a combination of conventional proteins like fishmeal together with insect protein is an indication of the risk averse nature of farmers regarding novel technologies. Factors such as food novelty and affective drivers like the fear of new foods (neophobia) and disgust play an important role in farmers' decision to use insect-based products (Onwezen *et al.*, 2019; Verbeke *et al.*, 2015). Studies like that of Sebatta *et al.* (2018) in Uganda found that farmers combine commercial feed with supplements like fishmeal and leafy vegetables to boost the growth of chicken. In Kenya, Mutisya *et al.* (2020) revealed that partial replacement of commercial insect-based feed with fishmeal protein and plant proteins results into faster growth and the chicken attract higher profit compared to the exclusive use of insect protein in commercial feed.

Farmers preferred feed that is dark in color compared to the light-colored feed. Farmers perceive dark-colored feed as containing more protein, particularly fishmeal owing to the dark brown pigment of the protein source when dried. Few studies have looked into the relevance of feed color in chicken production. Khosravinia (2007) found that chicken farmers preferred rich-colored feed compared to plain-colored in Iran. This study offers novel insights into the selective nature of chicken farmers in a developing country context pertaining to feed color in relation to purchased feed. Interestingly, the exoskeleton of insects is usually visible in insect-based feed and this combined with fishmeal particles guarantees the farmer of a dark feed with both insect and conventional proteins.

Farmers are willing to pay premiums for all the attributes. Specifically, they are willing to pay between Kshs 189 and Kshs 495 for feed in pelleted form; Kshs 151 and Kshs 435 for feed in mashed form; Kshs 99 and Kshs 217 for insect-based explicitly labelled as containing insects; Kshs 25 and Kshs 93 for feed mixed with SFM as the sources of protein and; Kshs 16 and Kshs 53 for feed that is dark in color.

Relative to the current market price of conventional chicken feed, the WTP estimates reflect a desire by farmers to pay premiums of 87% for pellets, 85% for mashed feed, 72% for explicit labelling to indicate presence of insect and, 25% for insect-based feed mixed with SFM. However, the WTP for insect-based feed in dark color is 26% lower than the current market price of conventional feed. Overall, these results are consistent with recent studies such as Chia *et al.* (2020) who found that chicken producers were willing to pay a premium range of 12% to 57% for insect-based feed in chicken production. In terms of internal consistency, the sum of average WTP values for all attributes is lower than the market price of a mature indigenous live chicken (about Kshs 886 compared to Kshs 1000) in the city of Nairobi where most farmers from Kiambu sell their chicken. This demonstrates that farmers who opt to use the improved insect would be able to make profits in their chicken businesses without requiring resources from other enterprises to offset any potential loss.

3.3 Estimation of compensating surplus for insect-based feed scenarios

In order to understand how insect-based feeds can be positioned in various segments of chicken producers, we derive CS estimates for three policy scenarios representing various combinations of different insect-based feed-attributes: profit-focused farmers (Scenario 1); environmental sustainability-conscious farmers (Scenario 2) and; chicken safety and welfare-sensitive farmers (Scenario 3). The results presented in Table 5 show that Scenario 3, which includes feed that is pelleted, explicitly labelled as containing insects, mixed

Table 5. Compensating surplus estimates for insect-based feed policy scenarios.[1]

Scenario	Attributes								Compensating surplus (in Kshs[2])
	Pellets	Mash	Labelled	Not labelled	Insects and SFM	Insects only	Dark	Light	
1		✓	✓		✓		✓		544.30Ψ (110.07)
2	✓		✓			✓		✓	499.73 (102.47)
3	✓		✓		✓		✓		592.95 (117.46)

[1] ✓ indicates presence of an attribute at the non-zero level; Ψ all the CS estimates are statistically significant at 1% level; corresponding standard errors are shown in parentheses.

[2] 100 Kenyan shillings (Kshs) were equivalent to 1 US$ at the time of the survey.

with conventional protein and is dark in color has the highest CS estimate (Kshs 592). This can be explained by the findings of Nakimbugwe *et al.* (2020) that innovative food products will be accompanied by increased consumer demand for safe insect-based products and associated regulations to ensure compliance. In this case, the safety aspect is ensured through the ability to prevent pellets from contamination as opposed to other feed forms such as mash. Scenario 1, in which all attributes are similar to those of Scenario 3 except that it includes mashed feed form rather than pellets, has the second highest CS of Kshs 544, confirming the desire of profit-focused farmers to spend less on the production costs but still reap more returns. Scenario 2 with mashed feed, labelled as containing insects, exclusive use of insect protein and light-colored feed had the lowest CS of Kshs 499. This scenario targets farmers who are conscious of the harsh environmental impact of conventional protein sources on natural resources. A closer inspection reveals that the exclusive use of insect protein and light color pull the CS downwards in Scenario 2.

Evidently, the CS estimates are higher than the actual market price of feed per kilogram. However, it is important to note that these values are not indicative of the need to increase the prices of already problematic feed prices. On the contrary, the CS estimates aim to bring to the attention of policy makers and other authorities in the chicken value chain the strategies that are more implementable and acceptable by all stakeholders, by considering the feed production costs which ultimately have a considerable effect on chicken production costs and farmers' profitability.

4. Conclusions and policy implications

We analyzed chicken farmers' WTP for commercial insect-based chicken feed attributes using the CE approach. Our results show that farmers are willing to pay premiums for the five insect-based feed attributes, that is, feed form (pelleted or mashed feed), explicit labelling to show presence of insects in the feed, insect feed mixed with soybean and fishmeal proteins, and dark-colored feed.

Based on these findings, various policy implications are suggested. First, there is need to encourage the production and use of locally fabricated pelleting machines to ease the cost of pelleting. This could be achieved through establishing communication platforms between local artisans and feed millers, through their respective associations, to relay information on recommended pellet sizes, and further assist in developing insect defatting equipment to ensure efficient grinding and mixing of mashed feed. Second, the importance of labelling as a means of identification and creating trust in quality calls for consultations between quality regulators and insect producers on the appropriate and standard logos to use for insect-based feed, that will differentiate certified insect-based products from other livestock-related inputs. This could be complemented with capacity building for farmers to enhance their technical knowledge on identifying quality insect products in the market.

Third, research institutions could liaise with farmers to identify the optimal proportions of insect meal combined with soybean and fishmeal proteins for competitive chicken growth and performance. Through this approach, farmers would also participate in instant assessment of the benefits of the feed and provide valuable feedback to improve the policy framework. Fourth, our data revealed that there are differences in the importance of attributes of insect-based feed, which can be associated with differences in individual and behavioral preferences. This implies that a 'one-size fits all' approach to designing feed formulation strategies ought to be discouraged. Therefore, policy interventions that are targeted at ensuring acceptability of the feed should be participatory and adjusted to the contextual preferences of the relevant community. Considering the multi-stakeholder environment in which feed formulation takes place, we recommend further studies to understand the risk factors and preferences within a wider geographical coverage to generate more insights on behavioral preferences of different actors besides farmers; this would ensure wider acceptability and sustainability of insect-based feeds in the chicken value chain.

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Conflict of interest

The authors declare no conflict of interest.

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