



Food Science and Applied Biotechnology

e-ISSN: 2603-3380

Journal home page: www.ijfsab.com
<https://doi.org/10.30721/fsab2026.v9.i2>



Research Article

Economic feasibility and consumer acceptance of *Tenebrio molitor* larvae as an alternative protein source in poultry production: A circular economy perspective

Georgi Krumov Toskov^{1,2}, Desislava Vlahova-Vangelova^{1,2}, Desislav Balev^{1,2}, Nikolay Kolev^{1,2}, Ana Yaneva¹, Angelina Topalova¹

¹ University of Food Technologies, 26 Maritsa Blvd, 4002 Plovdiv, Bulgaria

² Center of Competence AgriFoodSystems and Bioeconomy, 4000 Plovdiv, Bulgaria

Abstract

This research investigates the integration of *Tenebrio molitor* larvae (yellow mealworm) as an alternative protein source in poultry feed, framed within circular economy principles. As global demand for sustainable animal protein rises, insect-based feed offers a strategic solution for waste valorization and resource efficiency in the 2025-2030 period. The study analyzes consumer target groups and factors influencing their willingness to consume insect-fed poultry, utilizing a direct survey of 100 respondents conducted at a food technology exhibition. Furthermore, a comparative economic analysis of five experimental groups reveals that while electricity and fixed costs remain stable, the inclusion of *T. molitor* increases production costs per kilogram meat by 8.30% to 25.75% compared to conventional feed. Results suggest that while the sensory qualities of the meat are well received - with 2.5 % and 5.0 % inclusion groups outperforming the control in taste tests - achieving market success depends on transparent communication to overcome food neophobia. Addressing cost-competitiveness is paramount for realizing the potential of insect-based circular food systems.

Keywords

Tenebrio molitor larvae; Insect-based feed; circular economy; consumer acceptance; alternative proteins; poultry production

Abbreviations

CE – circular economy; COGS – cost of goods sold; TM – *Tenebrio molitor*. WTP – willingness-to-pay;

✉Corresponding author: Georgi Krumov Toskov, Department of Tourism and Culinary Management, Faculty of Economics, University of Food Technologies, 26 Maritsa Blvd., 4002 Plovdiv, Bulgaria, tel.: +359 884807316; e-mail: g_toskov@uft-plovdiv.bg

Article history:

Received 16 March 2026

Reviewed 7 July 2026

Accepted 21 September 2026

Available on-line 12 October 2026

<https://doi.org/10.30721/fsab2026.v9.i2.699>
2026, UFT Academic publishing house, Plovdiv

Introduction

Over the past decade, a significant shift in consumer attitudes and behavior towards food has been observed. The attention of the modern consumer is directed to taste characteristics and price and also to the origin of products, production methods, environmental impact, and the degree of sustainability (Hartmann and Siegrist 2017; Quintieri et al. 2023). These new criteria outline the emergence of a contemporary consumer culture characterized by a demand for healthy, ethical, and environmentally responsible nutrition.

In this context, interest in so-called alternative proteins is intensifying - innovative food solutions with the potential to transform how animal products are produced and perceived. One of the promising aspects of this transformation is the application of alternative protein sources in animal husbandry, including broiler feeding (Parisi et al. 2020). Given the challenges associated with climate change, demographic growth, and limited natural resources, such practices are viewed as sustainable and economically justified in the long term. Alongside traditional soy and corn-based feeds, new feeding models involving insects, larvae, microalgae, and other protein-rich alternatives are currently being tested in experimental farms.

However, the consumer plays a central role in this process, as their beliefs and emotions directly influence the acceptance of innovative products. This is particularly true when insects are utilized in the food chain—even if they are absent from the final product. For many, an instinctive aversion and doubt regarding the "naturalness" and "purity" of the meat arise, often leading to a refusal to consume despite the rational benefits (Nirmal et al. 2025). Thus, psychological barriers frequently prevail over the objective assessment of quality.

This situation poses significant challenges for producers and retailers, who must develop effective strategies for presenting such products. It requires not only the application of appropriate marketing tools but also a deep understanding of the socio-psychological mechanisms shaping consumer attitudes. Identifying barriers to acceptance and selecting appropriate communication approaches to build trust is particularly crucial. In this context, insects—specifically *Tenebrio molitor* larvae (yellow mealworm)—have emerged as a high-

potential solution for the "protein transition". As bioconverters, insects can valorize organic side-streams and agricultural by-products, transforming them into high-quality biomass rich in protein and fat. This capability allows for the creation of closed-loop agricultural systems where waste is minimized and resources are kept in use for as long as possible.

Despite the clear environmental justifications, the widespread adoption of insect meal in poultry feed faces two substantial hurdles: economic viability and consumer acceptance (Subedi et al. 2025). While the European Union has established a permissive regulatory framework—classifying *T. molitor* as a "Novel Food" and authorizing its use in poultry feed—the production costs of insect protein remain high relative to conventional commodities (Belhadj Slimen et al. 2023). Furthermore, the introduction of insects into the food chain, even indirectly, triggers complex psychological responses in Western consumers, ranging from curiosity to deep-seated disgust.

This article addresses these challenges by integrating a detailed economic analysis of production costs with an empirical investigation of consumer attitudes. Unlike previous studies that often focus on one aspect in isolation, this research correlates the specific economic premiums required for insect-fed poultry with the actual willingness-to-pay of consumers in a controlled market environment.

Theoretical Framework

The Role of *Tenebrio molitor* larvae in the Circular Bioeconomy. The circular economy model in agriculture aims to decouple growth from resource consumption. *Tenebrio molitor* larvae fits squarely into this paradigm due to its efficiency in converting feed to mass. Literature suggests that insect production emits significantly fewer greenhouse gases and requires a fraction of the land and water needed for traditional livestock (van Huis 2013). Moreover, the larvae act as "mini-livestock," producing frass (solid excreta of insects) that serves as a potent organic fertilizer, thus closing the nutrient cycle.

Taxonomically belonging to the order Coleoptera (family Tenebrionidae), *T. molitor* larvae are nutrient-dense, containing a high percentage of crude protein (44–69%) and fat (23–47%) on a dry

matter basis. Biologically, *T. molitor* larvae are nutrient-dense, rich of protein and fat, the amino acid profile comparable to soybean meal and fishmeal. Beyond basic nutrition, recent studies have highlighted their "nutraceutical" properties. The larvae contain antimicrobial peptides (AMPs) such as tenecin 1, 2, 3, and 4, which demonstrate activity against Gram-positive and Gram-negative bacteria. Furthermore, components like chitin and chitosan can interact with Toll-like receptors (e.g., TLR-2), potentially activating the innate immune response. Research by Bovera et al. (2016) and others indicates that low to moderate inclusion levels (0.2–0.3%) can improve growth performance and resistance to pathogens like *E. coli* without compromising intestinal morphology.

Nutritional and Functional Properties of *Tenebrio molitor* larvae. The yellow mealworm (*Tenebrio molitor* larvae) is increasingly recognized as a strategic protein source in animal husbandry, particularly within the paradigm of sustainable food systems. Empirical research indicates that the incorporation of insect meal into broiler diets correlates with improved growth performance and general health status. Notably, studies utilizing full-fat meal from *Tenebrio molitor* larvae and *Zophobas morio* have demonstrated enhanced productivity and a stimulated immune response in poultry. While the interest in insects as a feed ingredient for human-grade poultry has surged, further research is required to optimize inclusion rates and clarify their functional potential beyond basic nutrition. In this context, insects are increasingly evaluated as "nutraceuticals"—sources of biologically active compounds that contribute to health beyond their caloric and protein value (Biasato et al. 2016).

While traditional studies focus on the macronutrient value of insect meal, attention is shifting toward its potential as a functional feed additive at low inclusion levels. Previous research indicates that diets supplemented with *T. molitor* meal (0.2–0.3%) enhance growth and activate the immune response, evidenced by decreased serum IgM levels and increased concentrations of IL-2 and TNF- α . These effects suggest that the benefits are derived not solely from nutritional value but from the nutraceutical properties of the meal. It is hypothesized that low inclusion levels (0.5–2.0%) can significantly improve innate immunity in

broilers, specifically under conditions of inflammation induced by lipopolysaccharides (LPS) from *Escherichia coli* (Bovera et al. 2016).

The Biological and Cognitive Basis of Neophobia. The acceptance of novel protein sources, such as insects, is fundamentally constrained by "neophobia"—the fear of the new. While younger and sustainability-oriented producers often show openness to innovation, traditionalists frequently exhibit skepticism, awaiting further evidence of benefits (Subedi et al. 2025). To understand these reactions, it is necessary to examine the underlying behavioral mechanisms.

Psychologists and behavioral ecologists utilize neophobia tests to measure behaviors ranging from anxiety to predator avoidance. While psychologists focus on the cognitive mechanisms underpinning these behaviors, behavioral ecologists emphasize their adaptive function. Neophobia is an ecologically relevant fear arising from the cognitive assessment of novel stimuli. In nature, the avoidance of unknown foods or objects shapes survival strategies; however, in the context of modern food systems, this same mechanism can hinder the adoption of sustainable solutions.

Historically, neophobia was first studied by comparative psychologists in the 1950s to measure fear and curiosity in non-humans. Today, with growing evidence that animals—and humans—exhibit stable individual differences in temperament (personality), neophobia levels are found to be negatively correlated with innovative behavior (Dall et al. 2012). However, methodological inconsistencies persist. The so-called "jingle-jangle fallacy"—grouping different behaviors under one name or naming one behavior with different terms—complicates the interpretation of results. For instance, reacting to a stimulus simply because it is new involves classifying it as such, a cognitive process distinct from other fear reactions (Greggor et al. 2015).

This theoretical distinction is critical for consumer studies. The "disgust factor" associated with insect consumption may not be a simple rejection but a cognitive misclassification of the product as a "risk" rather than "food." Subjective fear cannot be directly observed, but it manifests in measurable avoidance behaviors. Novelty is not an inherent characteristic of the stimulus but arises from the

interaction between perception and memory. Therefore, when consumers reject insect-fed poultry, they may be reacting to evolutionary biases that categorize insects as "danger" or "waste," regardless of the rational safety assurances provided (Ventricelli et al. 2022).

Understanding that neophobia is a deeply rooted biological adaptation, rather than a mere preference, highlights the necessity for specific communication strategies. Effective interventions must bypass the immediate "fear response" by framing the novel food within familiar categories, thereby reducing the perception of risk.

Regulatory and Macro-Economic Context in the European Union. The publication of the FAO report "Edible Insects: Future Prospects for Food and Feed Security" (van Huis et al. 2013) marked a paradigm shift in the global discourse on entomophagy. Since then, the sector has attracted significant attention from policymakers, industry, and the scientific community. In the European Union, this evolution is characterized by a transition from niche interest to a structured industry driven by startups and significant financial investment in closed-cycle farming systems.

The Legislative Framework: The dynamics of the insect sector in Europe are governed by two primary legislative pillars: the "Novel Food" Regulation (EU) 2015/2283 and the progressive relaxation of the "Feed Ban".

- **Novel Foods:** Insects for human consumption are categorized as "Novel Foods," requiring rigorous scientific safety assessment by EFSA before market authorization. The first authorization for *Tenebrio molitor* larvae in 2021 was a watershed moment, providing legal certainty for producers (EFSA NDA Panel 2021).
- **Feed Regulations:** Regarding animal feed, the strict rules originally imposed following the BSE crisis have been amended. In 2017, insect proteins were permitted for aquaculture, and in 2021, this permission was extended to poultry and porcine feed, acknowledging insects as a sustainable protein source capable of valorizing organic waste (European Commission 2017; European Commission 2021).

Drivers of Adoption: Sustainability vs. Security: A critical distinction in the European context is the motivation for adoption. Unlike in developing regions where entomophagy addresses basic food insecurity, the European driver is predicated on health, sustainability, and the Circular Bioeconomy (CE). The sector's growth aligns directly with the UN Sustainable Development Goals (SDGs), aiming to reduce the environmental footprint of livestock production rather than merely increasing caloric supply.

Stakeholder and Farmer Readiness: Despite the favorable regulatory shifts, the integration of insects into the supply chain faces practical hurdles at the farm level. Farmers play a pivotal role, yet their acceptance is contingent upon economic feasibility and logistical practicality. While younger, sustainability-oriented farmers are often open to innovation, traditionalists remain skeptical, awaiting clearer evidence of cost-effectiveness (Subedi et al. 2025). Currently, the high market price of insect meal compared to soy remains a significant barrier, requiring streamlined regulatory frameworks to facilitate mainstream adoption (Kumar and Ogwu 2025), alongside strict adherence to the applicable safety standards.

Materials and Methods

Economic Experimental Design. The experiment involved a total of 250 broiler chickens, with 50 birds randomly assigned to each of the five dietary groups. To ensure a fair economic comparison, all diets were formulated to be isocaloric and isonitrogenous, maintaining a consistent nutrient density and protein level across all inclusion rates.

- Group 1 (Control): 0% *T. molitor*.
- Group 2: 2.5% *T. molitor*.
- Group 3: 5.0% *T. molitor*.
- Group 4: 7.5% *T. molitor*.
- Group 5: 10.0% *T. molitor*.

The economic analysis calculated the Total Cost per Bird and the Cost per Kilogram of Meat. The cost structure included:

- **Variable Feed Costs:** Calculated based on daily consumption and the specific price of

the feed mix, which increased with insect meal inclusion.

- **Fixed and Operational Costs:** These included the cost of one-day chicks (1.28 EUR), slaughter (0.41 EUR), packaging (0.20 EUR), transport (0.48 EUR), electricity (0.06 EUR), and depreciation.
- **Production Metrics:** Cold carcass weight was recorded for each group to determine the final yield efficiency.

Consumer Survey Design and Data Collection Strategy. To gather primary empirical data regarding consumer perceptions, attitudes, and behavioral models, a structured survey was conducted. The sampling strategy and data collection methods were rigorously planned to ensure the practical relevance and reliability of the findings.

The survey was executed within the framework of the specialized FOOD TECH exhibition, held in February, 2025. While the event spanned several days, data collection was strategically concentrated into a single full day. This methodological decision was imposed to ensure homogeneity in the survey conditions and to mitigate the influence of external temporal variables that could skew respondent answers if data were collected across different days or times.

A total of 100 respondents participated in the study, completing structured questionnaires utilizing a 5-point Likert scale for key measures. An example question assessed willingness to consume insect-fed poultry on a scale from 1 representing Definitely no to 5 representing Definitely yes. Participants were asked a screening question to identify their primary role as either end-consumers or industry professionals. For the purpose of establishing a general market baseline, the data from both groups were analyzed together as a single aggregate cohort representing the interested public. The sample spanned a wide age range, with the predominant group in active working age. The majority held a university degree. Geographically, the sample included residents from major urban centers like Plovdiv as well as smaller towns. The selection of this specific respondent group was purposive; targeting individuals already sensitized to food

technology topics enriches the data quality compared to a random population sample.

The direct survey method was employed, with participants completing questionnaires on-site immediately after being briefed on the study's objectives. Participation was voluntary, with an explicit option to withdraw at any time, fostering a relaxed and non-formal atmosphere conducive to honest responses. Collecting data in a naturalistic setting—such as a trade exhibition—provides high ecological validity. It allows for capturing authentic opinions from individuals exposed to real commercial stimuli and industry trends, offering a distinct advantage over laboratory or online surveys, which often suffer from isolation from the real consumer context.

The accumulated data was subjected to quantitative analysis to determine frequency distributions and identify potential dependencies between demographic variables and acceptance levels.

Results and Discussion

Results

Respondent Profile and Consumption Habits.

The study engaged respondents with a diverse demographic profile, allowing for an objective assessment of societal attitudes toward insect-based poultry production.

Dietary Habits: Understanding current meat consumption patterns is crucial for evaluating the potential for substitution. The study sample (n=100) consisted predominantly of active working-age individuals with higher education, residing mainly in urban centers.

Over 95% of respondents consume meat at least twice a week (Fig. 1), confirming its central role in the diet, with daily consumption being the most common frequency (38%).

Poultry is the preferred meat source (46%), closely followed by pork (42%), validating the market relevance of innovations specifically within the poultry sector (Fig. 2).

CONSUMPTION FREQUENCY

■ Every Day ■ 4-5 Times a Week
 ■ 2-3 Times a Week ■ Once a Week or Less

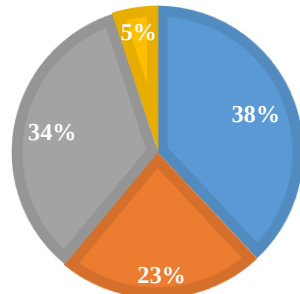


Figure 1. Frequency of Meat Consumption among Respondents

CONSUMPTION PREFERENCES

■ Poultry ■ Pork ■ Beef ■ Lamb ■ Other

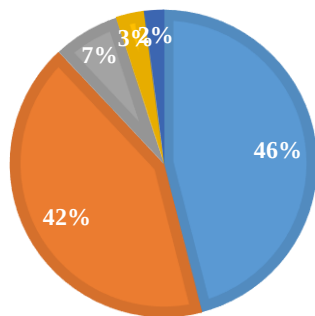


Figure 2. Consumer Preference by Meat Type

Sensory Evaluation. Contrary to potential expectations of negative palatability, the blind sensory tests yielded positive results for the insect-fed groups. These results suggest that moderate inclusion of *T. molitor* (2.5% to 7.5%) enhances the organoleptic profile of the meat.

Experimental groups with 2.5% and 5.0% (Fig 3) *T. molitor* inclusion consistently outperformed the control group in taste, smell, and consistency, indicating that moderate insect inclusion enhances product appeal.

SENSORY EVALUATION

■ Color Votes ■ Smell Votes
 ■ Taste Votes ■ Consistency Votes

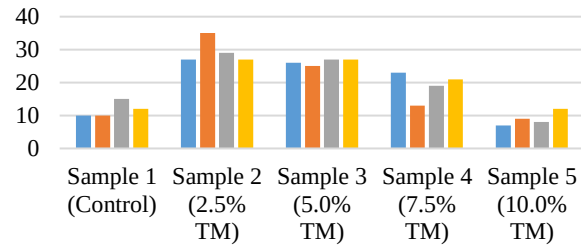


Figure 3. Comparative Sensory Evaluation (Color, Smell, Taste, Consistency)

Attitudes toward Entomophagy and Insect-Fed Poultry. The survey investigated the gradation of consumer acceptance, distinguishing between direct entomophagy and indirect consumption via the feed chain.

Direct vs. Invisible Consumption: Responses regarding the consumption of whole insects were mixed. While some respondents expressed curiosity ("Yes, out of curiosity"), a significant portion indicated barriers related to culture, emotion, or hygiene ("No" or "I don't know"). However, attitudes shifted positively when presented with processed insect protein (e.g., flour or concentrate) incorporated invisibly into familiar food matrices. This confirms that the visual aspect and aesthetic perception significantly influence the decision-making process.

Acceptance of Insect-Fed Poultry (Indirect Entomophagy): When asked, "Would you try chicken meat from birds fed with diet enriched with insects?", the results indicated a predominantly positive attitude (mean score > 3.5 on a 5-point Likert scale):

ACCEPTANCE OF INSECT-FED POULTRY (INDIRECT ENTOMOPHAGY)

- Strong Acceptance (Definitely yes)
- Moderate Acceptance (Probably yes)
- Uncertainty (I cannot judge)
- Rejection (Negative attitudes)

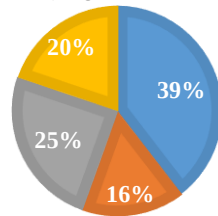


Figure 4. Willingness to Consume Insect-Fed Poultry

A majority of respondents (56%) expressed a positive willingness to consume insect-fed poultry, although 25% remain uncertain, highlighting the need for transparent communication regarding safety (Fig. 4).

These findings suggest that while psychological barriers persist, the majority of consumers are ready to accept insect-based innovations if they occur upstream in the supply chain (i.e., as feed) rather than on the plate.

Economic Feasibility Analysis. The economic data reveals a clear trade-off between the inclusion of alternative protein and production efficiency. Table 1 summarizes the cost structure per bird.

Table 1. Production Costs per Bird

Cost Component, EUR	Control	2.5% TM	5.0% TM	7.5% TM	10.0% TM
Feed Cost	0.53	0.54	0.63	0.70	0.79
Electricity	0.06	0.06	0.06	0.06	0.06
Other Fixed Costs*	2.83	2.83	2.83	2.83	2.83
Total Cost/Bird	3.42	3.43	3.52	3.59	3.68

Source: Authors' calculations based on experimental cost and production data.

*Includes chick cost (1.28), slaughter (0.41), packaging (0.20), transport (0.48), and depreciation (0.46).

While the total cost per bird increases moderately with inclusion, the economic impact is magnified when converting to Cost per Kilogram of Meat, as shown in Table 2. This is driven by an observed decrease in the cold carcass weight in the experimental groups.

The inclusion of *T. molitor* increases the production cost per kilogram of meat by 8.30% to 25.75% due to lower carcass yields; the 2.5% inclusion rate offers the most economically viable entry point with a cost of €2.18/kg.

Table 2. Cost Effectiveness and Meat Price per Kilogram

Group	Total cost, EUR	Cold carcass weight, g	Cost per kg, EUR	Increase vs Control
Control	3.42	1702.5	2.01	-
2.5% TM	3.43	1576.6	2.18	+8.30%
5.0% TM	3.52	1526.9	2.31	+14.76%
7.5% TM	3.59	1428.6	2.51	+25.10%
10.0% TM	3.68	1456.8	2.53	+25.75%

Discussion

Synthesizing Economic Reality and Consumer Willingness-to-Pay (WTP). The integration of production cost data with consumer attitudinal metrics reveals a critical structural challenge for market entry. Survey results regarding price sensitivity indicate that over **70%** of respondents consider price a decisive determinant in their choice of poultry meat. While **57%** expressed willingness to purchase insect-fed poultry at price parity with conventional products, only **28%** are willing to pay a premium.

Juxtaposing the calculated production costs against this willingness-to-pay (WTP) highlights a significant "market gap":

- **Control Group:** Production cost of **2.01 EUR/kg** (Baseline).
- **2.5% *T. molitor*:** Production cost of **2.18 EUR/kg** (+8.30% vs. Control).
- **5.0% *T. molitor*:** Production cost of **2.31 EUR/kg** (+14.76% vs. Control).
- **7.5% *T. molitor*:** Production cost of **2.51 EUR/kg** (+25.10% vs. Control).
- **10.0% *T. molitor*:** Production cost of **2.53 EUR/kg** (+25.75% vs. Control).

Implications for Market Strategy: The analysis demonstrates that even the lowest inclusion rate

(2.5%) results in a cost increase **(+8.30%)** that likely exceeds the price tolerance of the majority (72%) of consumers who are not willing to pay extra. The higher inclusion levels (7.5% and 10%), despite their potential nutritional benefits, result in a cost premium (>22%) that renders them economically unviable for the mass market under current conditions.

Therefore, market realization faces a clear bottleneck. Bridging this gap requires a dual strategy:

1. **Supply-Side:** Achieving economies of scale in insect rearing to lower the input cost of *T. molitor* meal.
2. **Demand-Side:** Implementing aggressive marketing campaigns that emphasize specific functional benefits (e.g., "immune-boosting" or "superior taste") to justify the higher price point to the niche segment of 28% who are open to premiums. Without these measures, the product risks being positioned outside the acceptable price range for the average consumer.

SWOT Analysis: Synthesis of Economic Data and Consumer Attitudes. To evaluate the strategic viability of the proposed "Green Line" product, a SWOT analysis was conducted, synthesizing the quantitative results from the economic experiment with the qualitative data from the consumer survey

Table 3. SWOT Analysis of Insect-Fed Poultry Product

Strengths	Enhanced Organoleptic Properties with specific inclusion levels receiving higher approval ratings. Sustainability and Brand Equity contributing to a lower carbon footprint. Consumer Openness with foundational acceptance of insects as feed.
Weaknesses	Production Cost Disadvantage leading to increased cost of goods sold. Reduced Yield Efficiency showing lower average cold carcass weight. Lack of Awareness maintaining a cognitive barrier to adoption.
Opportunities	Strategic Segmentation targeting the market willing to pay a premium. Functional Marketing leveraging the nutraceutical and immunity boosting angle. Global Trends supporting ethical and sustainable nutrition.
Threats	Price Sensitivity in a highly price-elastic mass market. Consumer Neophobia where skepticism may override curiosity. Communication Failure risking focus solely on the higher price rather than value.

PESTE Analysis: Evaluation of the Macro-Environmental Context. To contextualize the market potential of insect-fed poultry within the broader European landscape, a PESTE analysis was conducted, evaluating the external factors influencing adoption.

- **Political Factors:** The regulatory climate in the European Union is increasingly favorable. The EU's "Farm to Fork" strategy explicitly encourages the use of sustainable resources, including insects, to reduce the dependency on imported feed proteins. Political will to address climate change is translating into funding programs for innovative agrarian projects, creating a supportive ecosystem for producers transitioning to circular models.
- **Economic Factors:** The economic landscape presents a dichotomy. On one hand, the expanding market for "eco-friendly" and "functional" foods offers significant opportunities for niche realization. On the other hand, the mass market remains highly price-elastic. As indicated by the survey results, consumer willingness to pay is limited; the majority of buyers require price parity with conventional meat. While initial production costs are higher (+8.30–25.75%), long-term economies of scale in insect rearing are expected to drive costs down.
- **Social Factors:** Social acceptance is the most volatile variable. While deep-seated cultural barriers regarding entomophagy persist, systematic reviews indicate that familiarity and visibility of the ingredient significantly influence consumer evaluation (Pakseresht et al. 2023). The survey reveals a shifting paradigm among younger and educated demographics, who demonstrate higher acceptability.
- **Technological Factors:** Technological readiness is high. Technologies for mass-rearing insects are maturing rapidly, ensuring consistent supply chains. Furthermore, the integration of digital tools for traceability (e.g., Blockchain, QR codes) offers a mechanism to bridge the trust gap. By providing transparency regarding the feed source and production method, technology can directly mitigate consumer neophobia.

- **Environmental Factors:** This is the strongest driver for adoption. Insect-based feed production is measurably more sustainable than traditional sources like soy and fishmeal, requiring less land and water. Since the survey confirmed that environmental protection is a key decision factor for 61% of participants, this "ecological value" constitutes the primary unique selling proposition (USP) of the product.

Generational Segmentation and Target Audiences. Demographic analysis reveals distinct behavioral patterns across generational cohorts, which is critical for defining the market entry strategy.

- **Millennials (1981–1996):** This cohort acts as the primary driver for the "clean label" trend in Europe. Data indicate that 66% of Millennials are willing to pay more for organically sourced groceries, while 54% report willingness to pay more for groceries in sustainable packaging (Capgemini Research Institute 2022). Their consumption is driven by ethical engagement and health functionality, making them the ideal early adopters for insect-fed poultry if the health benefits are scientifically validated.
- **Generation Z (Born after 1997):** This group is the most receptive to "future foods." Research suggests that younger consumers are 2–3 times more likely to try insect-based products due to their fluid dietary habits (flexitarianism) and strong ethical orientation toward global climate goals (Fischer and Reinders 2016). For Gen Z, marketing must be digital-first, authentic, and visually creative.
- **Older Generations (Gen X and Boomers):** These cohorts exhibit more conservative behavior, prioritizing traditional taste, price, and brand trust. For this segment, the "insect" component should not be the primary marketing hook; instead, communication should focus on safety, certification, and regional origin.

Conclusion and Policy Recommendations

The integration of *Tenebrio molitor* larvae into poultry production offers a viable pathway toward a circular bioeconomy, reducing reliance on unsustainable protein sources. This study confirms

that biologically and regarding sensory quality, insect-fed poultry is a superior product. However, economic viability is currently constrained by higher feed costs and reduced carcass yields at higher inclusion rates.

To bridge the gap between production costs and consumer willingness to pay, the following strategies are recommended for the 2025–2030 period:

1. Optimize Inclusion Rates: Focus on the 2.5% to 5% inclusion range, where cost increases are moderate (+8.30 – 14.76 %) and sensory benefits are maximized.
2. Industrial Scaling: Reduce the cost of insect meal by scaling up production using low-value agricultural side-streams as substrate.
3. Targeted Communication: Shift the narrative from "eating insects" to "upcycled protein," emphasizing the improved taste and natural diet of the birds to justify the price premium.

A primary limitation of this study is the relatively small sample size of 100 respondents within a specific event context, which may not fully represent the broader market. Future research should expand the consumer survey across multiple demographics to validate these initial findings. Additionally, longitudinal economic studies scaling the 2.5 percent inclusion rate to commercial farm levels are necessary to confirm practical viability.

Author Contributions

Conceptualization, G.K.T. and D.V.-V.; methodology, G.K.T. and D.B.; formal analysis, N.K. and A.Y.; investigation, G.K.T., A.Y. and A.T.; resources, D.B.; writing – original draft preparation, G.K.T.; writing – review and editing, D.V.-V. and D.B.; visualization, N.K.; funding acquisition, G.K.T. All authors have read and agreed to the published version of the manuscript.

Funding

This research was funded by both the Bulgarian National Science Fund, Ministry of Education and Science in Bulgaria (Grant number KP-06-N76/7, 5 December 2023) and by project BG16RFPR002-1.014-0012-C01 „Establishment and sustainable development of a Center of Competence „Agrifood Systems and Bioeconomy”, financed by the

European Regional Development Fund through the „Program for Research, Innovation and Digitalisation for Smart Transformation“ (PRIDST).

Institutional Review Board Statement

The experimental protocol used in this study was designed in compliance with the guidelines of the European and Bulgarian legislation regarding the protection of animals used for experimental and other scientific purposes

Informed Consent Statement

Informed consent was obtained from all subjects involved in the consumer survey study.

Data Availability Statement

The original contributions presented in this study are included in the article. Further inquiries can be directed to the corresponding authors.

Conflicts of Interest

The authors declare no conflicts of interest.

References

- Belhadj Slimen I., Yerou H., Ben Larbi M., M'Hamdi N., Najar T. Insects as an alternative protein source for poultry nutrition: a review. *Frontiers in Veterinary Science*, 2023, 10(8): 1200031. <https://doi.org/10.3389/fvets.2023.1200031>
- Biasato I., De Marco M., Rotolo L., Renna M., Lussiana C., Dabbou S., Capucchio M.T., Biasibetti E., Costa P., Gai F., Pozzo L., Dezzutto D., Bergagna S., Martínez S., Tarantola M., Gasco L., Schiavone A. Effects of dietary *Tenebrio molitor* meal inclusion in free-range chickens. *Journal of Animal Physiology and Animal Nutrition*, 2016, 100(6): 1104-1112. <https://doi.org/10.1111/jpn.12487>
- Bovera F., Loponte R., Marono S., Piccolo G., Parisi G., Iaconisi V., Gasco L., Nizza A. Use of *Tenebrio molitor* larvae meal as protein source in broiler diet: effect on growth performance, nutrient digestibility, and carcass and meat traits. *Journal of Animal Science*, 2016, 94(2): 639-647. <https://doi.org/10.2527/jas.2015-9201>
- Capgemini Research Institute. Consumer trends in sustainability. 2022. Available at: <https://www.capgemini.com/insights/research-library/consumer-trends-2022/>

- Dall S.R.X., Bell A.M., Bolnick D.I., Ratnieks F.L.W. An evolutionary ecology of individual differences. *Ecology Letters*, 2012, 15(10): 1189-1198. <https://doi.org/10.1111/j.1461-0248.2012.01846.x>
- EFSA Panel on Nutrition, Novel Foods and Food Allergens (NDA). Safety of dried yellow mealworm (*Tenebrio molitor* larva) as a novel food pursuant to Regulation (EU) 2015/2283. *EFSA Journal*, 2021, 19(1): e6343. <https://doi.org/10.2903/j.efsa.2021.6343>
- European Commission. Commission Regulation (EU) 2017/893 of 24 May 2017 amending Annexes I and IV to Regulation (EC) No 999/2001 and Annexes X, XIV and XV to Commission Regulation (EU) No 142/2011 as regards the provisions on processed animal protein. *Official Journal of the European Union*, 2017. Available at: <https://eur-lex.europa.eu/eli/reg/2017/893/oj>
- European Commission. Commission Regulation (EU) 2021/1372 of 17 August 2021 amending Annex IV to Regulation (EC) No 999/2001 as regards the prohibition to feed non-ruminant farmed animals, other than fur animals, with protein derived from animals. *Official Journal of the European Union*, 2021. Available at: <https://eur-lex.europa.eu/eli/reg/2021/1372/oj>
- Fischer A.R.H., Reinders M.J. Consumer acceptance of novel foods. In: *Innovation Strategies in the Food Industry: Tools for Implementation* (C.M. Galanakis Ed.). Academic Press, London, 2016, pp. 271-292. Print ISBN: 978-0-12-803751-5. <https://doi.org/10.1016/B978-0-12-803751-5.00014-3>
- Greggor A.L., Thornton A., Clayton N.S. Neophobia is not only avoidance: improving neophobia tests by combining cognition and ecology. *Current Opinion in Behavioral Sciences*, 2015, 6(12): 82-89. <https://doi.org/10.1016/j.cobeha.2015.10.007>
- Hartmann C., Siegrist M. Consumer perception and behaviour regarding sustainable protein consumption: a systematic review. *Trends in Food Science and Technology*, 2017, 61(3): 11-25. <https://doi.org/10.1016/j.tifs.2016.12.006>
- Kumar P., Ogwu M.C. Regulatory frameworks and challenges for edible insects: pathways to mainstream adoption. In: *Edible Insects: Nutritional Benefits, Culinary Innovations and Sustainability*. Springer, 2025, pp. 165-188. https://doi.org/10.1007/978-3-031-90087-7_8
- Nirmal N., Anyimadu C.F., Khanashyam A.C., Bekhit A.E.D.A., Dhar B.K. Alternative protein sources: addressing global food security and environmental sustainability. *Sustainable Development*, 2025, 33(3): 3958-3969. <https://doi.org/10.1002/sd.3338>
- Pakseresht A., Vidakovic A., Frewer L.J. Factors affecting consumers' evaluation of food derived from animals fed insect meal: a systematic review. *Trends in Food Science and Technology*, 2023, 138(8): 310-322. <https://doi.org/10.1016/j.tifs.2023.05.018>
- Parisi G., Tulli F., Fortina R., Marino R., Bani P., Dalle Zotte A., De Angeli A., Piccolo G., Pinotti L., Schiavone A., Terova G., Prandini A., Gasco L., Roncarati A., Danieli P.P. Protein hunger of the feed sector: the alternatives offered by the plant world. *Italian Journal of Animal Science*, 2020, 19(1): 1204-1225. <https://doi.org/10.1080/1828051X.2020.1827993>
- Quintieri L., Nitride C., De Angelis E., Lamonaca A., Pilolli R., Russo F., Monaci L. Alternative protein sources and novel foods: benefits, food applications and safety issues. *Nutrients*, 2023, 15(6): 1509. <https://doi.org/10.3390/nu15061509>
- Subedi K., Tiwari U., Bhatta S., Luitel H., Grande J., Molden L.H., Khanal P. Exploring stakeholder willingness to adopt alternative poultry feeds: insights from Nepal. *Cleaner and Responsible Consumption*, 2025, 19(12): 100338. <https://doi.org/10.1016/j.clrc.2025.100338>
- van Huis A. Potential of insects as food and feed in assuring food security. *Annual Review of Entomology*, 2013, 58(1): 563-583. <https://doi.org/10.1146/annurev-ento-120811-153704>
- van Huis A., Van Itterbeeck J., Klunder H., Mertens E., Halloran A., Muir G., Vantomme P. *Edible insects: future prospects for food and feed security*. FAO Forestry Paper No. 171. Food and Agriculture Organization of the United Nations, 2013. Available at: <https://www.fao.org/4/i3253e/i3253e.pdf>
- Ventricelli M., Gratton P., Sabbatini G., Addressi E., Sgaraglia G., Rufo F., Sirianni G. Individual variation in response to novel food in captive capuchin monkeys (*Sapajus* spp.). *Frontiers in Ecology and Evolution*, 2022, 10(4): 820323. <https://doi.org/10.3389/fevo.2022.820323>