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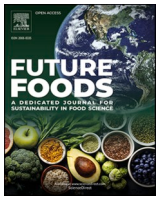

# Exploring consumers' attitude and sensory perception of *circular eggs* from hens fed with black soldier fly larvae (*Hermetia illucens*) reared on agroindustrial by-products

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ABSTRACT

Insects as a protein source in animal feed represent a sustainable alternative to conventional feeding practices. This study explored consumers' attitudes and sensory perception of *circular eggs*, defined as eggs from hens partially fed with black soldier fly larvae (*H. illucens*) reared on agroindustrial by-products. A questionnaire was administered ($n = 456$; mean age: 40; $F = 62$ %) to investigate the impact of sociodemographic characteristics, Food Neophobia (FN), Disgust Sensitivity (DS) and sustainability awareness on attitude towards *circular eggs*. Results showed that men, highly educated and environmentally-engaged consumers, and subjects with low FN and DS were more prone towards *circular eggs*. Sensory evaluation was performed ($n = 143$, mean age: 30; $F = 60$ %) to compare circular and conventional eggs, prepared as hard-cooked and poached, through liking and Check-All-That-Apply tests. Consumers preferred *circular eggs* for overall appearance, yolk and albumen colour, yolk and overall flavour and yolk texture. Sensory attribute differences between circular and conventional eggs were more pronounced in hard-cooked samples, while poached samples showed fewer distinctions. These findings highlighted the potential of insect-based poultry feed to support food systems sustainability while maintaining consumers' acceptance. However, targeted communication strategies addressing food neophobia, disgust sensitivity and economic incentives might be necessary for broader market adoption of *circular eggs*.

## 1. Introduction

Animal nutrition significantly contributes to the environmental footprint of livestock production (Elferink et al., 2008). Thus, there is an urgent need to identify sustainable and alternative feed sources to mitigate this impact (Elferink et al., 2008; Tabassum-Abbasi et al., 2016). One emerging solution is the use of insects as a sustainable alternative protein source in animal feed (Makkar et al., 2014). Among all the various species of insect, the black soldier fly (*Hermetia illucens*) larvae (BSFL) have garnered particular attention due to their high protein content, rapid growth rate and ability to be reared on food waste side-streams, aligning with SDG Goal 12 (United Nations, 2015) aimed at minimizing waste along the food supply chain (Singh and Kumari, 2019; Wang and Shelomi, 2017). This dual benefit of waste reduction and sustainable feed production highlights the potential of BSFL to address critical environmental and economic challenges. The use of BSFL-based feeds has been evaluated in aquaculture (Tran et al., 2015), swine (Chia et al., 2021) and poultry production systems (de Souza Vilela et al., 2021; Dorper et al., 2021; Roccatello et al., 2024), with promising performance in terms of animal growth and feed efficiency.

In the poultry sector, BSFL has been used as a feed ingredient for both broilers and laying hens. Bejaei and Cheng (2024) suggested that the inclusion of BSFL in poultry diets improves animal welfare and simulates a natural omnivorous diet. Moreover, previous studies have shown that adding BSFL in poultry diets can influence the nutritional profile of the final products, such as meat and eggs. For example, Cattaneo et al. (2025) highlighted an impact of the BSFL supplementation on the fatty acids profile of egg yolk, showing higher levels of saturated and poly-unsaturated fatty acids, thus suggesting a potential benefit in egg quality when hens were fed with 30 % BSFL-enriched diets. Despite this,

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research is still limited in assessing the combined effects of BSFL-based animal diet on both product characteristics and consumers' preferences.

Consumers' acceptance of insect-based feed products is influenced by sociodemographic, psychological and sustainability-awareness factors or sensory expectations (Baldi et al., 2022; Khaemba et al., 2022; Lippi et al., 2021; Pakseresht et al., 2023; Sogari et al., 2023; Verbeke et al., 2015). As summarized by Pakseresht et al. (2023), young males with higher education were generally more favourable towards insects as part of animal feed, even though demographic effects were sometimes contradictory across studies. Furthermore, in a previous study focused on eggs from hens fed with BSFL, Khaemba et al. (2022) observed that consumers with lower income or who bought eggs from open-air markets or kiosks were more likely to accept the final product, particularly when they were aware of the use of insects in feed. In addition to demographic variables, psychological traits, particularly food neophobia, resulted important factors influencing consumers' attitude towards insect-based feed products. Lippi et al. (2021) specifically investigated consumers' readiness to adopt eggs from insect-fed hens and found that acceptance decreased as food neophobia increased, suggesting that personality-related variables are critical in predicting acceptability of innovative and more sustainable food products and should be always considered alongside sociodemographic characteristics, as also evidenced by Naranjo-Guevara et al. (2021). However, these studies have not considered the added complexity of consumer perceptions related to the use of agroindustrial by-products as a substrate for rearing BSFL. These substrates, while eco-friendly, may evoke negative associations among certain consumers' groups, further complicating their acceptance (Aschemann-Witzel et al., 2023; Cela et al., 2024).

To the best of our knowledge, no studies have investigated the combined impact of using BSFL reared on agroindustrial by-products as feed for laying hens on the sensory characteristics of the resulting eggs and on their consumers' acceptability. Therefore, the objective of this study was to evaluate: (a) the sociodemographic factors and psychological predictors influencing consumers' attitude towards *circular eggs* - defined as eggs from hens partially fed with BSFL reared on agroindustrial by-products; (b) the effects of feeding laying hens with BSFL reared on agroindustrial by-products on the sensory characteristics of eggs. Therefore, this study combined a consumer study with sensory analysis to provide practical insights for the development and promotion of circular and sustainable egg production system.

## 2. Materials and methods

The study was conducted in accordance with the ethical guidelines of the Declaration of Helsinki and received approval from the Ethics Committee of the University of Gastronomic Sciences in Pollenzo (Ethics Committee Proceedings n. 5/2024). All participants voluntarily took part in the study and provided their informed consent before joining it.

### 2.1. Questionnaire

#### 2.1.1. Questionnaire structure

An online questionnaire, designed in Italian language, was developed and distributed using the Qualtrics® platform (Provo, UT) in order to assess consumers' attitude towards *circular eggs* (Supplementary material). Participants were recruited via a shared link disseminated through social media platforms (LinkedIn, Facebook, Instagram, WhatsApp), the official website of the NODES project (https://ecs-nodes.eu/en/7-secondary-agroindustry), emails and flyers containing a QR code distributed during public events. The link to the survey was left active for three months (from 21st August to 22nd November 2024) and targeted adult consumers ($\geq$ 18 years) across Italy.

The survey consisted of seven sections, each focusing on specific variables: (1) sociodemographic characteristics; (2) egg consumption behaviour; (3) knowledge of hens' typical diet; (4) consumer sustainability consciousness; (5) personality traits; (6) attitude towards eggs from hens fed a) insect larvae and b) insect larvae reared on agroindustrial by-products; (7) willingness to try (WTT), buy (WTB), consume regularly (WTC) and pay a premium (WTP) for eggs from hens fed a) insect larvae and b) insect larvae reared on agroindustrial by-products.

In the first section, participants provided sociodemographic information, including gender, age, educational level (Palmieri et al., 2022) and context of living (Piochi et al., 2022).

The second section assessed egg consumption behaviour in terms of consumption frequency and importance of attributes influencing egg purchasing. Consumption frequency was investigated through the question: "*How often do you consume eggs*?", as described by Piochi et al. (2022). Attribute importance was evaluated using a five-point scale (1= not important; 2= less important; 3= neutral; 4= important; 5= very important) for 13 attributes, including egg weight, shell colour, yolk colour, rearing type, feed given to hens, brand, price, animal welfare information, nutritional claims, supply chain sustainability, ethical production, local provenience of eggs, national provenience of eggs, by answering the following question: "*How important are the following attributes to you when choosing eggs*?" (Lippi et al., 2021; Palmieri et al., 2022).

The third section evaluated participants' knowledge of hens' typical diet by asking: "*What do you think constitutes the usual diet of hens?*". Participants were asked to select one of the three options: omnivorous diet, vegetal diet, I don't know.

In the fourth section, the consumer sustainability consciousness (CSC) was measured using a validated questionnaire developed by De Carvalho et al. (2015) and integrated by Jaca et al. (2018). For this study, three domains of the CSC questionnaire were selected, as also reported by Cela et al. (2024): Labelling and Peer Pressure (LPP, 4 items), Sense of Retribution (SR, 6 items), and Circular Economy (CE, 4 items). Participants rated their agreement with each item on a seven-point scale (1= never take it into account; 7= I always take into account).

The fifth section included personality traits, such as Food Neophobia (FN) and food Disgust Sensitivity (DS). The level of FN, defined as the reluctance towards unfamiliar food products (Pliner and Hobden, 1992), was measured using the Italian version of the 10-item FN scale (Laureati et al., 2018). DS, intended as a food-rejection emotion to stop people from eating potentially harmful and/or pathogen-containing foods (Chapman and Anderson, 2012; Haidt et al., 1994), was evaluated with the short eight-item Food Disgust Scale, as developed and validated by Hartmann and Siegrist (2018), and back-translated into Italian language.

Attitudes towards eggs from hens fed (a) insect larvae (ATT_L) and (b) insect larvae reared on agroindustrial by-products (ATT_LAB) were assessed using a seven-point scale (1= extremely negative; 7= extremely positive). Participants were first presented with a statement outlining the environmental benefits of using insects as animal feed, adapted from Laureati et al. (2016): "*The global increase in population resulting in a higher demand for food has led to the need to find new and more sustainable sources of proteins. The consumption of insects, already practiced in some Eastern cultures, could spread to our culture. Insects are increasingly recognized as an excellent alternative protein source for use in animal feed and human diets. Many species are highly nutritious, and the production of insects has less environmental impact compared to that of traditional sources of protein. Insects can also be raised inexpensively and rapidly on a wide range of organic materials, such as the vegetable waste of households and industries, reducing the overall quantity of waste by up to 60 %*".

The final section assessed WTT, WTB and WTC (Tuccillo et al., 2020) eggs from hens fed (a) insect larvae (WTT_L, WTB_L and WTC_L) and (b) insect larvae reared on agroindustrial by-products (WTT_LAB, WTB_LAB and WTC_LAB) using a seven-point Likert scale (1= definitely no; 7= definitely yes). WTP was evaluated by asking the question: "*How much more would you pay for a pack of four eggs from hens fed insect larvae compared to a pack of four conventional eggs priced at €1.85?*". Participants

selected from three options: nothing extra, up to 50 % more, more than 50 % more. The baseline price of €1.85 was based on the current market price of a pack of four cage-free eggs of the supplier who provided eggs for the sensory analysis (Fantolino, Fiano, TO, Italy).

#### 2.1.2. Questionnaire data quality check

A total of 663 participants initially engaged with the survey. Of these, 139 did not provide informed consent or failed to complete the questionnaire and were excluded from the statistical analysis. From the remaining 524 valid responses, an additional 68 participants were excluded for completing the questionnaire outside the acceptable time range (5-25 minutes). Overall, after excluding "careless respondents" (Jaeger and Cardello, 2022), the final dataset comprised 456 participants. Thus, the questionnaire completion rate (calculated as the percentage of respondents who fully completed the questionnaire in the acceptable time range out of those who started it) was 68.8 %. The average completion time was 11.8 minutes, consistent with the estimated 12 minutes communicated to participants at the beginning of the survey.

### 2.2. Sensory analysis

#### 2.2.1. Participants

A total of 143 subjects (females: 60 %; age range: 18-63 years; mean age: 27.0 ± 9.5), predominantly students and staff from University of Gastronomic Sciences (UNISG, Pollenzo, Italy), were recruited via email and word of mouth. Most participants reported consuming eggs at least once a week (75 %), followed by those consuming eggs at least once a month (12 %), daily (10 %) and less than once a month (3 %). Eighty percent of the participants were Italian.

#### 2.2.2. Products

Two different egg samples from two types of hens feeding systems were analyzed: Control and Circular. The Control sample consisted of eggs from hens fed with a conventional diet (cereals calcium carbonate, soy, vitamins and minerals), whereas the Circular sample consisted of eggs from hens fed for one month with a diet including 4 % (dry matter) BSFL reared on agroindustrial by-products. Hens were fed daily with 120 ± 19.66 g of feed (control or treatment) per hen. In order to identify whether different cooking conditions could modulate sensory attributes influenced by the hens' diet, each type of egg was prepared using two cooking methods (hard-boiled and poached), resulting in four total samples for evaluation. Fresh egg samples were stored at room temperature (20 ± 2°C) in the Sensory, Behavior and Cognition Lab at UNISG until preparation. One day prior to testing, hard-boiled eggs were cooked by immersing them in boiling water for 9 minutes, while poached eggs were oven-cooked on racks at 64 ± 1°C for one hour in a static oven at the Pollenzo Food Lab at UNISG. On the day of the sensory evaluation, samples were reheated in a water bath at 55 ± 1°C for one hour. Just before the sensory session, samples were shelled, divided into 90 mL disposable containers coded with random three-digit numbers, covered with PLA lids, and immediately served to the participants. Participants were served one half of each hard-boiled egg, whereas poached eggs were served whole. To ensure proper tasting balance, half of the participants first tasted the hard-boiled egg samples followed by the poached egg samples, while the other half tasted the poached eggs first. For each cooking method, samples were presented in a randomized and balanced order among participants.

#### 2.2.3. Evaluation procedure

The sensory evaluation was conducted at the UNISG Sensory, Behavior and Cognition Lab, in individual computerized booths under controlled temperature (22 ± 2°C) and white light. Sensory analysis was conducted as a blind test: participants were not provided with any information about the nature or origin of the eggs. Firstly, consumers were asked to observe, smell and taste each sample and rate their liking for the following attributes: overall appearance, yolk colour, albumen colour, overall odour, yolk flavour, albumen flavour, overall flavour, yolk texture, albumen texture, overall texture and overall liking, on a nine-point hedonic scale (1 = extremely dislike, 9 = extremely like) (Peryam and Pilgrim, 1957). Then, consumers were asked to select, from a list of 20 attributes (salty, sweet, umami, bitter, sour, astringent, hard, soft, spongy, firm, watery, smooth, gritty, dry, pale yellow egg yolk, intense yellow egg yolk, white albumen, off-white albumen, sulphur, buttery) all those perceived and considered useful to describe the sensory characteristics of the evaluated sample, according to the check-all-that-apply (CATA) method (Adams et al., 2007; Ares et al., 2010). The CATA attributes list was developed based on benchtop tastings and literature input (Baxter et al., 2024). The presentation order of CATA terms was randomized across subjects, but fixed within each individual, as recommended by Ares et al. (2013). Subsequently, participants rated their willingness to eat again (WTE), WTB and WTC each sample using a seven-point Likert scale (1= definitely no; 7= definitely yes).

Between samples, participants had a 45-second break and were instructed to eat a little piece of unsalted cracker and rinse their mouth with water to restore the neutrality of the mouth. Sociodemographic information (gender, age, nationality) and egg consumption frequency were collected after the evaluation of the first two samples. The sensory test lasted approximately 25 minutes. Data were collected using Fizz Biosystèmes software, version 3.8.0.9.

### 2.3. Statistical analysis

Questionnaire data were analysed using descriptive statistics and reliability analyses to assess internal consistency, with Cronbach's α coefficients calculated to ensure acceptable reliability (Cronbach's $\alpha > 0.6$, as per Gravesande et al. (2019) and Mohajan (2017)). One-way analysis of variance (ANOVA) with Tukey's post-hoc test was employed to compare mean values for egg choice attributes and the domains of CSC questionnaire. Two different Hierarchical Multiple Linear Regression (HMLR) models were conducted to predict consumers' attitude towards *circular eggs* (ATT_L and ATT_LAB were used as independent variables, respectively) including sociodemographic information, CSC domains, FN and DS as dependent variables. The model was built in different step: Model 1 included sociodemographic characteristics, Model 2 added CSC domains, and Model 3 incorporated personality traits. For all tests, statistical significance was set at $p < 0.05$. Moreover, the impact of all variables (sociodemographic characteristics, CSC domains, FN and DS levels, consumers' knowledge of hens' typical diet) on ATT, WTT, WTB and WTC was also evaluated by performing one-way ANOVA. To examine the effect of gender, only data from male and female participants were considered, as the other two gender categories were represented by only two and one individual, respectively. Participants were divided into three groups (low, medium and high level) based on FN score, according to Laureati et al. (2018). The same procedure was applied for DS and CSC domains. This grouping was performed separately for FN, DS, LPP, SR and CE scores, resulting in distinct divisions for each independent variable. Sensory data, including liking scores, were analyzed using two-way ANOVA (fixed factors: feeding/cooking method; random factor: subject), followed by Tukey's post-hoc test for pairwise comparisons. CATA data were examined via Cochran's Q test in order to identify significant differences between samples based on sensory attributes selection, followed by multiple pairwise comparisons using Sheskin's Critical Difference test. Correspondence Analysis (CA) was performed on CATA sensory attributes that determined statistical differences among samples according to Cochran's Q test results, in order to visualize the relationship between samples and sensory attributes. Then, Penalty-Lift Analysis was conducted to determine sensory attributes influencing overall liking. All statistical analyses were performed using XLSTAT Premium software (Version 2020.3.1, Addinsoft, Paris, France), except for HMLR analysis

which was performed by using the software IBM SPSS Statistics (Version 29.0.1.0).

## 3. Results and discussion

### 3.1. Questionnaire

#### 3.1.1. Characteristics of participants

As reported in Table 1, the questionnaire sample of respondents was moderately balanced in terms of gender, with a slightly higher percentage of females (62.1 %) compared to males (37.3 %), while the categories "Other" and "I prefer not to declare it" accounted in total for less than 1 % of the respondents. The age distribution indicated a predominance of young adults, with 34.0 % aged 18-30 years, followed by 31.8 % in the age group of 31-45 years. Participants aged 46-60 years represented 20.0 % of the sample, while older individuals ($\geq$ 61 years) accounted for 14.2 %. In terms of educational level, 78.7 % of respondents reported that they had at least a bachelor degree, while the remaining 21.3 % had a lower level of education. Moreover, participants were distributed relatively evenly across different contexts of living. Egg consumption frequency data revealed that most participants (78.7 %) consumed eggs at least once per week. Participants were asked to describe what they believed constituted the typical diet of hens. The results showed that 73.7 % of respondents correctly identified hens as omnivorous animals, whose natural diet includes not only plant-based foods such as grains and cereals but also insects, worms and other small animals.

Consumers' awareness regarding sustainability was investigated using the CSC questionnaire, which assesses the factors driving conscious consumption of sustainable products from a social, environmental and economic perspective (Jaca et al., 2018). The CSC questionnaire was organized into three main domains, all of them showing a reliable internal consistency (Cronbach's $\alpha > 0.6$). The descriptive statistics of the CSC questionnaire are reported in the Supplementary Materials (Table S1). The LPP domain – which refers to environmental labels and additional sources of information that can facilitate consumers' decision-making processes – achieved an average score of 4.8 on a seven-point Likert scale. The SR domain - which represents the sense of responsibility and awareness of the social and environmental impact of the individual's food choices – also obtained an average score of 4.8, which did not significantly differ from the mean value obtained for the LPP domain ($p > 0.05$). The CE domain - which reflects consumer behaviours with a positive attitude toward sustainable environmental practices, resource reuse and resource savings – obtained an average score (5.5) statistically higher than the others two domains ($p < 0.05$). The higher mean score of CE domain compared to the LPP and SR domains suggested a more comprehensive understanding of systemic environmental impacts than economic and social aspects of sustainability, most probably because it is easier to comprehend environmental issues rather than abstract social and economic concepts (Hanss and Böhm, 2012). Overall, the three domains LPP, SR and CE received a mean score above the mid-point of the scale, indicating a moderate to high awareness of sustainability concepts.

Previous studies showed that the acceptability of sustainable products is often influenced by psychological barriers (Faria and Kang, 2022). Both FN and DS scales showed acceptable internal consistency (Cronbach's α: 0.899 and 0.744, respectively). The descriptive statistics of the FN and DS questionnaires results are reported in the Supplementary Materials (Table S2). The maximum possible value for FN scale was 70, whereas for DS scale was 48. In this study, FN scores ranged from 10 to 66, with a medium value of 26.1 ± 11.4, whereas DS scores ranged from 9 to 48, with a medium value of 25.4 ± 7.3.

**Table 1**
Characteristics of the questionnaire respondents.

| Variables | N = 456 | % |
|---|---|---|
| *Gender* | | |
| Male | 170 | 37.28 |
| Female | 283 | 62.06 |
| I prefer not to declare it | 2 | 0.44 |
| Other | 1 | 0.22 |
| *Age* | | |
| 18-30 years | 155 | 33.99 |
| 31-45 years | 145 | 31.80 |
| 46-60 years | 91 | 19.96 |
| $\geq$ 61 years | 65 | 14.25 |
| *Educational level* | | |
| Primary or secondary (low education) | 97 | 21.27 |
| Degree, master and/or PhD (high education) | 359 | 78.73 |
| *Context of living* | | |
| City (>70.000 inhabitants) | 132 | 28.95 |
| Town (10.000-70.000 inhabitants) | 169 | 37.06 |
| Village/rural context (<10.000 inhabitants) | 155 | 33.99 |
| *Egg frequency consumption* | | |
| Daily | 19 | 4.17 |
| At least once per week | 359 | 78.73 |
| At least once per month | 63 | 13.82 |
| Less than once per month | 15 | 3.29 |
| *Knowledge about hens' typical diet* | | |
| Omnivorous diet | 336 | 73.68 |
| Exclusively vegetal diet | 89 | 19.52 |
| Unsure | 31 | 6.80 |
| | Mean | Dev Std |
| *Consumer Sustainability Consciousness* | | |
| Labelling Peer Pressure | 4.8 | 1.1 |
| Sense of Retribution | 4.8 | 1.2 |
| Circular Economy | 5.5 | 1.2 |
| *Personality traits* | | |
| Food Neophobia | 26.1 | 11.4 |
| Disgust Sensitivity | 25.4 | 7.3 |

#### 3.1.2. Importance of attributes in egg purchasing decision

Results from ANOVA test (Fig. 1), evaluating the degree of importance of attributes in egg purchasing decisions, indicated that the type of rearing system (free-range, organic, cage-free, caged) significantly ($p < 0.05$) emerged as the most critical factor with a mean importance score of 4.5 ± 0.8 (on a five-point scale). Animal welfare ranked as the second most important attribute (4.3 ± 0.8), demonstrating that consumers prioritized practices that guarantee animals live in respectful environments. These findings aligned with prior research highlighting the contribution of rearing conditions in shaping consumer preferences for egg (Palmieri et al., 2022; Rahmani et al., 2019) and the increasing social concern on ethical farming practices and on animal welfare (Bozzo et al., 2019; Napolitano et al., 2010; Verbeke, 2009).

Ethical production ranked third (4.2 ± 0.8), closely followed by the national provenience of eggs (4.1 ± 1.0). The hens' diet attribute ranked fifth (4.1 ± 0.9) and its importance was significantly ($p < 0.05$) lower compared to rearing system and animal welfare attributes but higher than that of intrinsic attributes such as yolk colour (3.2 ± 1.1), shell colour (2.6 ± 1.1) and egg weight (2.6 ± 1.0) or extrinsic attributes, including price (3.3 ± 1.0), nutritional claims (2.9 ± 1.1) and brand (2.9 ± 1.2). Therefore, it was interesting to note that intrinsic and extrinsic attributes traditionally considered pivotal in egg purchasing decisions, such as yolk colour and price, appeared to have diminished in importance compared to sustainability and ethical aspects within the production chain. The relatively high position of the hens' diet attribute suggested that consumers may be interested in alternative protein sources as animal feed, such as insect larvae, if these are in line with ethical production standards and ensure animal welfare. These findings suggested that producers aiming to meet consumers' expectations should give priority to communication strategies highlighting sustainable practices and animal welfare-based rearing methods. By doing so, they can improve marketability by matching product attributes with emerging consumers' values.

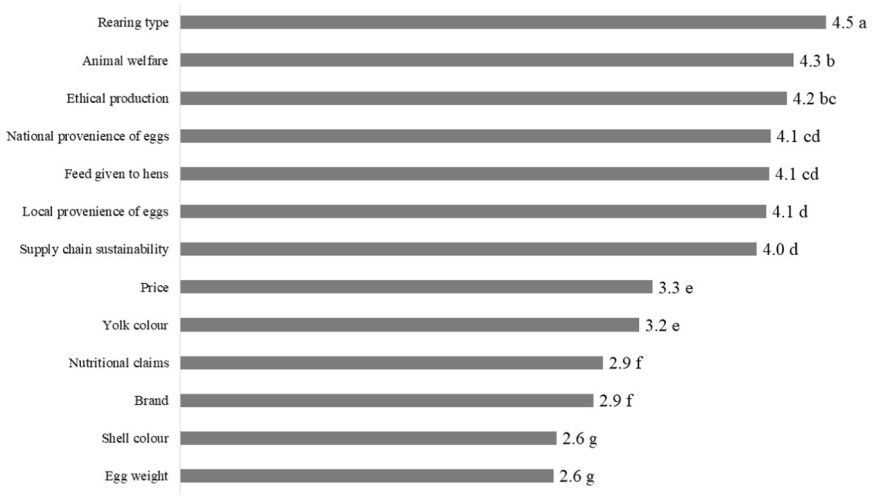


**Fig. 1.** Importance of attributes influencing egg purchasing (How important are the following attributes to you when choosing eggs? 1= not important; 5= very important). Different letters indicate significant difference, according to Tukey's post-hoc test ($p < 0.05$).

*3.1.3. Predictors of consumers' attitudes*

The study aimed to identify the predictors of consumers' attitudes towards *circular eggs*. HMLR results showed some differences and similarities in the predictors of attitudes towards eggs from hens fed insect larvae and from hens fed insect larvae reared on agroindustrial by-products. As reported in Table 2, the HMLR analysis for ATT_L highlighted the significant influence of sociodemographic characteristics, consumer sustainability awareness and personality traits on consumers' attitude. Indeed, in the first step, sociodemographic characteristics accounted for a minor but statistically significant portion of the variance in ATT_L ($R^2$=0.03, $F = 3.468$, $p = 0.008$). Among these variables, gender ($B = 0.282$, $p = 0.042$) and age ($B$ = -0.149, $p = 0.030$) emerged as significant predictors. Specifically, males demonstrated a slightly higher positive attitude than females, whereas younger participants expressed higher positive attitude compared to older ones. Education and context of living were not statistically significant in this step. In the Model 2, the CSC questionnaire domains were added. The inclusion of the CSC questionnaire domains in the second step increased the model's explanatory power ($R^2$=0.073, $F = 5.019$, $p < 0.001$). Gender ($B$ = 0.384, $p = 0.005$) and age ($B$ = -0.192, $p = 0.005$) remained significant predictors. Among the CSC domains, the CE domain ($B = 0.151$, $p = 0.057$) showed a positive and quite significant contribution, highlighting its potential impact on consumers' attitude toward eggs from insect-fed hens. However, LPP and SR did not significantly predict ATT_L. In the final step, adding personality traits further enhanced the model's predictive capacity ($R^2$=0.168, $F = 9.979$, $p < 0.001$). Gender ($B = 0.296$, $p = 0.025$) and age ($B = -0.142$, $p = 0.030$) remained significant, while the CE domain ($B = 0.153$, $p = 0.043$) was significant in this model, confirming its role in influencing attitude. Food Neophobia ($B$ = -0.467, $p < 0.001$) was a strong negative predictor, indicating that individuals with higher levels of food neophobia were less likely to have a positive attitude toward insect-fed hens' products. Disgust sensitivity also had a negative contribution ($B$ = -0.277, $p = 0.006$), further supporting that personality traits are critical barriers to acceptance.

In the first step of the second HMLR analysis performed considering ATT_LAB as dependent variable (Tab. 3), sociodemographic characteristics explained a small but statistically significant variance in ATT_LAB

**Table 2**
Hierarchical Multiple Linear Regression models explaining attitude towards eggs from hens fed insect larvae (ATT_L).

| ATT_L | Variables | Unstandardized coefficients (B) | Std.Error B | β | Sign. | $R^2$ | F | Sign. Model |
|---|---|---|---|---|---|---|---|---|
| Step 1 | (Constant) | 5.044 | 0.442 | | 0.000 | 0.03** | 3.468 | 0.008 |
| Sociodemographic | Gender | 0.282 | 0.138 | 0.095 | 0.042 | | | |
| | Age | -0.149 | 0.069 | -0.101 | 0.030 | | | |
| | Educational level | 0.220 | 0.177 | 0.059 | 0.215 | | | |
| | Context of living | 0.145 | 0.091 | 0.075 | 0.112 | | | |
| Step 2 | (Constant) | 3.497 | 0.565 | | 0.000 | 0.073*** | 5.019 | < 0.001 |
| Sociodemographic | Gender | 0.384 | 0.137 | 0.129 | 0.005 | | | |
| | Age | -0.192 | 0.068 | -0.130 | 0.005 | | | |
| | Educational level | 0.207 | 0.175 | 0.055 | 0.236 | | | |
| | Context of living | 0.125 | 0.090 | 0.065 | 0.162 | | | |
| Consumer Sustainability Consciousness | Labelling Peer Pressure | 0.029 | 0.077 | 0.021 | 0.709 | | | |
| | Sense of Retribution | 0.123 | 0.080 | 0.099 | 0.128 | | | |
| | Circular Economy | 0.151 | 0.079 | 0.120 | 0.057 | | | |
| Step 3 | (Constant) | 5.097 | 0.584 | | 0.000 | 0.168*** | 9.979 | < 0.001 |
| Sociodemographic | Gender | 0.296 | 0.132 | 0.100 | 0.025 | | | |
| | Age | -0.142 | 0.065 | -0.096 | 0.030 | | | |
| | Educational level | 0.212 | 0.166 | 0.056 | 0.201 | | | |
| | Context of living | 0.097 | 0.085 | 0.050 | 0.254 | | | |
| Consumer Sustainability Consciousness | Labelling Peer Pressure | 0.074 | 0.074 | 0.055 | 0.316 | | | |
| | Sense of Retribution | 0.064 | 0.077 | 0.051 | 0.407 | | | |
| | Circular Economy | 0.153 | 0.075 | 0.121 | 0.043 | | | |
| Personality traits | Food Neophobia | -0.467 | 0.104 | -0.224 | 0.000 | | | |
| | Disgust sensitivity | -0.277 | 0.101 | -0.137 | 0.006 | | | |

** $p < 0.01$; *** $p < 0.001$

**Table 3**
Hierarchical Multiple Linear Regression models explaining attitude towards eggs from hens fed insect larvae reared on agroindustrial by-products (ATT_LAB).

| ATT_LAB | Variables | Unstandardized coefficients (B) | Std.Error B | β | Sign. | $R^2$ | F | Sign. Model |
|---|---|---|---|---|---|---|---|---|
| Step 1 | (Constant) | 4.389 | 0.478 | | 0.000 | 0.037** | 4.300 | 0.002 |
| Sociodemographic | Gender | 0.285 | 0.150 | 0.089 | 0.057 | | | |
| | Age | -0.137 | 0.074 | -0.086 | 0.066 | | | |
| | Educational level | 0.412 | 0.192 | 0.101 | 0.032 | | | |
| | Context of living | 0.197 | 0.099 | 0.093 | 0.047 | | | |
| Step 2 | (Constant) | 2.802 | 0.614 | | 0.000 | 0.075*** | 5.158 | < 0.001 |
| Sociodemographic | Gender | 0.389 | 0.149 | 0.121 | 0.009 | | | |
| | Age | -0.180 | 0.074 | -0.113 | 0.015 | | | |
| | Educational level | 0.397 | 0.190 | 0.097 | 0.037 | | | |
| | Context of living | 0.176 | 0.097 | 0.084 | 0.070 | | | |
| Consumer Sustainability Consciousness | Labelling Peer Pressure | 0.034 | 0.084 | 0.023 | 0.681 | | | |
| | Sense of Retribution | 0.110 | 0.087 | 0.081 | 0.210 | | | |
| | Circular Economy | 0.166 | 0.086 | 0.121 | 0.054 | | | |
| Step 3 | (Constant) | 4.464 | 0.636 | | 0.000 | 0.162*** | 9.577 | < 0.001 |
| Sociodemographic | Gender | 0.300 | 0.144 | 0.093 | 0.038 | | | |
| | Age | -0.128 | 0.071 | -0.080 | 0.072 | | | |
| | Educational level | 0.402 | 0.181 | 0.098 | 0.027 | | | |
| | Context of living | 0.147 | 0.093 | 0.069 | 0.116 | | | |
| Consumer Sustainability Consciousness | Labelling Peer Pressure | 0.081 | 0.080 | 0.056 | 0.311 | | | |
| | Sense of Retribution | 0.048 | 0.084 | 0.036 | 0.566 | | | |
| | Circular Economy | 0.168 | 0.082 | 0.122 | 0.041 | | | |
| Personality traits | Food Neophobia | -0.496 | 0.113 | -0.219 | 0.000 | | | |
| | Disgust sensitivity | -0.277 | 0.110 | -0.126 | 0.012 | | | |

** $p < 0.01$; *** $p < 0.001$

($R^2$=0.037, $F = 4.300$, $p = 0.002$). Among these, level of education ($B = 0.412$, $p = 0.032$) and context of living ($B = 0.197$, $p = 0.047$) emerged as significant predictors, suggesting that higher education levels and residence in city positively influenced attitude towards eggs from hens fed insect larvae reared on agroindustrial by-products. Gender ($B = 0.285$, $p = 0.057$) and age ($B$ = -0.137, $p = 0.066$) showed no significant impact, as opposed to HMLR for ATT_L. Including the CSC questionnaire domains in the second step improved the model's explanatory power ($R^2$=0.075, $F = 5.158$, $p < 0.001$). In this model, gender ($B = 0.389$, $p = 0.009$), age ($B$ = -0.180, $p = 0.015$), and education ($B = 0.397$, $p = 0.037$) resulted significant predictors, but not the context of living ($p = 0.070$). Among the CSC domains, Circular Economy ($B = 0.166$, $p = 0.054$) was very close the significance level, suggesting that promoting circular economy principles may enhance attitudes toward products derived from hens fed insect larvae reared on agroindustrial by-products. The inclusion of personality traits in the third step further enhanced the model's predictive power ($R^2$=0.162, $F = 9.577$, $p < 0.001$). In this final model, gender ($B = 0.300$, $p = 0.038$) and level of education ($B = 0.402$, $p = 0.027$) remained significant, while age ($p = 0.072$) and context of living ($p = 0.116$) lost significance. Furthermore, the CE domain ($B = 0.168$, $p = 0.041$) became a statistically significant predictor, confirming its importance in shaping consumers' attitude. As for ATT_L, Food Neophobia ($B$ = -0.496, $p < 0.001$) emerged as a strong negative predictor, indicating that higher levels of neophobia are strongly associated with reduced acceptance of insect-derived products. Disgust sensitivity ($B$ = -0.277, $p = 0.012$) was also considered as a significant negative predictor. These results are consistent with previous results by Laureati et al. (2016), who reported that age, gender, cultural background and food neophobia significantly affect the willingness to adopt insects in animal feed. Furthermore, Menozzi et al. (2021) reinforced these insights by showing that gender and education play an important role in influencing consumers' attitudes and willingness to pay for food products from insect-fed animals.

### 3.1.4. *Effect of individual variables on attitude towards and willingness to try, buy, consume regularly circular eggs*

The questionnaire results highlighted a positive attitude (mean value higher than the midpoint of the seven-point scale) toward eggs from hens fed insect larvae, both when the larvae were reared on agroindustrial by-products and when no such specification was provided. The mean scores for ATT_L (5.8 ± 1.5) and ATT_LAB (5.6 ± 1.7) were no significantly different ($p > 0.05$). In terms of behaviour intentions, participants demonstrated a high WTT_L (6.1 ± 1.5) and WTT_LAB (5.9 ± 1.7). Similarly, the WTB these eggs, although slightly lower (5.9 ± 1.5 and 5.7 ± 1.7, respectively), obtained high values, suggesting that the initial consumers' interest could potentially translate into purchase behaviour. The WTC showed the lowest mean scores, even if remaining above the scale midpoint (5.5 ± 1.8 and 5.3 ± 1.8, respectively). For both eggs from hens fed insect larvae and from hens fed insect larvae reared on agroindustrial by-products, the mean values of WTC variables were significantly lower than WTT and WTB ($p < 0.05$). However, according to Student's t-test results, no significant differences between the two egg types considered were observed for all dependent variables ($p > 0.05$). Overall, the results showed positive attitude towards and positive purchase intentions for both eggs from hens fed insect larvae and fed insect larvae reared on agroindustrial by-products. Nonetheless, although consumers were open in experimenting with such products, they were less open in the long-term integration of these products into their diet habits. This discrepancy may be attributed to several factors. Indeed, the consumers' willingness to try a new product indicates an exploratory attitude that frequently results in hypothetical bias (Hofstetter et al., 2013), whereas regular consumption of sustainable products involves stronger behavioural commitment, likely influenced by taste, price, perceived health benefits, trust in the production process or social norm (Vermeir and Verbeke, 2006).

Table 4 shows the impact of sociodemographic characteristics, CSC domains, personality traits levels, knowledge about hens' typical diet on ATT, WTT, WTB and WTC for both eggs from hens fed insect larvae and fed insect larvae reared on agroindustrial by-products.

*3.1.4.1. Sociodemographic characteristics.* Sociodemographic factors played a key role, with younger individuals, males and those with higher educational level demonstrating a high positive attitude toward both *circular eggs*. Males exhibited significantly higher scores in ATT and WTB than females toward eggs from hens fed insect larvae ($p < 0.05$). Male participants' higher attitudes toward *circular eggs* indicates that men are generally more open to sustainable food products. However, in literature there are contrasting opinion related to the gender disparity in sustainable attitudes and behaviours (Cela et al., 2024; Lu et al., 2024). Nonetheless, since women typically handle the majority of household purchases (D'Souza and Taghian, 2017), findings from this study

**Table 4**
Effect of sociodemographic characteristics, Consumer Sustainability Consciousness, personality traits and knowledge about hens' typical diet on ATT, WTT, WTB, WTC.

| Variable | Eggs from hens fed insect larvae | | | | Eggs from hens fed insect larvae reared on agroindustrial by-products | | | |
|---|---|---|---|---|---|---|---|---|
| | ATT_L | WTT_L | WTB_L | WTC_L | ATT_LAB | WTT_LAB | WTB_LAB | WTC_LAB |
| *Gender** | | | | | | | | |
| Male | 6.0$^{a}$ | 6.3$^{a}$ | 6.1$^{a}$ | 5.7$^{a}$ | 5.8$^{a}$ | 6.1$^{a}$ | 5.8$^{a}$ | 5.5$^{a}$ |
| Female | 5.7$^{b}$ | 6.0$^{a}$ | 5.8$^{b}$ | 5.4$^{a}$ | 5.5$^{a}$ | 5.8$^{a}$ | 5.6$^{a}$ | 5.2$^{a}$ |
| *Age* | | | | | | | | |
| 18-30 years | 5.9$^{a}$ | 6.3$^{a}$ | 6.0$^{a}$ | 5.6$^{a}$ | 5.7$^{a}$ | 6.0$^{a}$ | 5.7$^{ab}$ | 5.4$^{a}$ |
| 31-45 years | 5.9$^{a}$ | 6.1$^{ab}$ | 6.0$^{a}$ | 5.6$^{ab}$ | 5.7$^{a}$ | 5.9$^{ab}$ | 5.8$^{a}$ | 5.5$^{a}$ |
| 46-60 years | 5.7$^{ab}$ | 6.16$^{a}$ | 6.0$^{a}$ | 5.4$^{ab}$ | 5.5$^{a}$ | 6.0$^{a}$ | 5.8$^{ab}$ | 5.2$^{a}$ |
| $\geq$ 61 years | 5.4$^{b}$ | 5.7$^{b}$ | 5.4$^{b}$ | 5.1$^{b}$ | 5.3$^{a}$ | 5.5$^{b}$ | 5.3$^{b}$ | 5.0$^{a}$ |
| *Educational level* | | | | | | | | |
| Low education | 5.6$^{a}$ | 5.9$^{a}$ | 5.7$^{a}$ | 5.3$^{a}$ | 5.2$^{b}$ | 5.7$^{a}$ | 5.4$^{a}$ | 5.2$^{a}$ |
| High education | 5.8$^{a}$ | 6.8$^{a}$ | 6.0$^{a}$ | 5.5$^{a}$ | 5.7$^{a}$ | 6.0$^{a}$ | 5.8$^{a}$ | 5.4$^{a}$ |
| *Context of living* | | | | | | | | |
| City | 6.0$^{a}$ | 6.4$^{a}$ | 6.2$^{a}$ | 5.8$^{a}$ | 5.8$^{a}$ | 6.2$^{a}$ | 6.0$^{a}$ | 5.6$^{a}$ |
| Town | 5.8$^{a}$ | 6.0$^{b}$ | 5.8$^{b}$ | 5.4$^{ab}$ | 5.6$^{ab}$ | 5.9$^{ab}$ | 5.7$^{ab}$ | 5.3$^{ab}$ |
| Village/rural context | 5.7$^{a}$ | 6.0$^{b}$ | 5.8$^{b}$ | 5.3$^{b}$ | 5.4$^{b}$ | 5.7$^{b}$ | 5.5$^{b}$ | 5.1$^{b}$ |
| *Knowledge about hens' typical diet* | | | | | | | | |
| Omnivorous diet | 6.0$^{a}$ | 6.3$^{a}$ | 6.2$^{a}$ | 5.7$^{a}$ | 5.8$^{a}$ | 6.2$^{a}$ | 6.0$^{a}$ | 5.6$^{a}$ |
| Exclusively vegetal diet | 5.2$^{b}$ | 5.4$^{b}$ | 5.1$^{b}$ | 4.7$^{b}$ | 5.0$^{b}$ | 5.3$^{b}$ | 5.0$^{b}$ | 4.5$^{b}$ |
| Unsure | 5.3$^{b}$ | 5.7$^{b}$ | 5.3$^{b}$ | 4.9$^{b}$ | 4.9$^{b}$ | 5.2$^{b}$ | 5.1$^{b}$ | 4.7$^{b}$ |
| *Labelling Peer Pressure* | | | | | | | | |
| Low | 5.5$^{b}$ | 5.8$^{b}$ | 5.6$^{b}$ | 5.1$^{b}$ | 5.3$^{b}$ | 5.5$^{b}$ | 5.3$^{b}$ | 5.0$^{b}$ |
| Medium | 5.9$^{a}$ | 6.2$^{a}$ | 6.0$^{a}$ | 5.5$^{a}$ | 5.7$^{a}$ | 6.1$^{a}$ | 5.8$^{a}$ | 5.4$^{ab}$ |
| High | 5.9$^{a}$ | 6.2$^{a}$ | 6.1$^{a}$ | 5.7$^{a}$ | 5.7$^{a}$ | 6.1$^{a}$ | 5.9$^{a}$ | 5.6$^{a}$ |
| *Sense of Retribution* | | | | | | | | |
| Low | 5.4$^{b}$ | 5.9$^{b}$ | 5.6$^{b}$ | 5.3$^{b}$ | 5.3$^{b}$ | 5.7$^{b}$ | 5.4$^{b}$ | 5.1$^{b}$ |
| Medium | 5.8$^{a}$ | 6.1$^{ab}$ | 5.9$^{ab}$ | 5.5$^{ab}$ | 5.6$^{ab}$ | 5.9$^{ab}$ | 5.7$^{b}$ | 5.3$^{b}$ |
| High | 6.1$^{a}$ | 6.3$^{a}$ | 6.2$^{a}$ | 5.8$^{a}$ | 5.9$^{a}$ | 6.2$^{a}$ | 6.1$^{a}$ | 5.7$^{a}$ |
| *Circular Economy* | | | | | | | | |
| Low | 5.5$^{b}$ | 5.9$^{b}$ | 5.6$^{b}$ | 5.3$^{a}$ | 5.3$^{b}$ | 5.7$^{b}$ | 5.3$^{b}$ | 5.1$^{a}$ |
| Medium | 5.8$^{ab}$ | 6.1$^{ab}$ | 6.0$^{ab}$ | 5.5$^{a}$ | 5.6$^{ab}$ | 5.9$^{ab}$ | 5.8$^{a}$ | 5.4$^{a}$ |
| High | 6.1$^{a}$ | 6.3$^{a}$ | 6.1$^{a}$ | 5.7$^{a}$ | 5.9$^{a}$ | 6.1$^{a}$ | 5.9$^{a}$ | 5.5$^{a}$ |
| *Food Neophobia* | | | | | | | | |
| Low | 6.2$^{a}$ | 6.5$^{a}$ | 6.3$^{a}$ | 6.0$^{a}$ | 6.1$^{a}$ | 6.4$^{a}$ | 6.1$^{a}$ | 5.8$^{a}$ |
| Medium | 5.9$^{a}$ | 6.2$^{a}$ | 6.0$^{a}$ | 5.5$^{b}$ | 5.7$^{b}$ | 6.0$^{a}$ | 5.8$^{a}$ | 5.4$^{b}$ |
| High | 5.2$^{b}$ | 5.4$^{b}$ | 5.4$^{b}$ | 5.0$^{c}$ | 5.0$^{c}$ | 5.2$^{b}$ | 5.1$^{b}$ | 4.8$^{c}$ |
| *Disgust Sensitivity* | | | | | | | | |
| Low | 6.0$^{a}$ | 6.3$^{a}$ | 6.1$^{a}$ | 5.9$^{a}$ | 5.9$^{a}$ | 6.2$^{a}$ | 6.0$^{a}$ | 5.8$^{a}$ |
| Medium | 5.8$^{a}$ | 6.1$^{a}$ | 5.9$^{a}$ | 5.4$^{b}$ | 5.5$^{b}$ | 5.8$^{b}$ | 5.6$^{b}$ | 5.2$^{b}$ |
| High | 5.4$^{b}$ | 5.7$^{b}$ | 5.5$^{b}$ | 5.1$^{b}$ | 5.3$^{b}$ | 5.6$^{b}$ | 5.4$^{b}$ | 5.0$^{b}$ |

ATT= attitude; WTT= willingness to try; TB= willingness to buy; WTC= willingness to consume regularly.
Different letters in the same column indicate significant difference according to Tukey's post-hoc test ($p < 0.05$).
*only data from male and female participants were considered, as the other two gender categories had limited representation.

suggested that is crucial to focus on them in order to promote campaigns that support sustainable practices and eco-friendlier food products. This gender difference was not observed for any of the considered variables when the information that larvae were reared on agroindustrial by-products was provided ($p > 0.05$). Indeed, men's attitude was diminished when additional information about the use of agroindustrial by-products as rearing substrate for larvae was introduced. Indeed, this negative perception associated with the use of by-products may be attributed to a perceived reduction in the quality of the final product. Negative perceptions can potentially be mitigated by reframing the narrative to emphasize the circular economy benefits and their lack of compromise on product quality (Aschemann-Witzel et al., 2022).

Regarding the eggs from hens fed insect larvae, younger participants (18-30) showed significantly ($p < 0.05$) higher ATT, WTT, WTB and WTC scores compared to older participants ($\geq$ 61 years). These findings were in line with those reported in previous studies, suggesting that younger consumers are generally more inclined to explore novel and sustainable food sources (Gidaković et al., 2024; Yadav and Pathak, 2016), probably because they have been exposed to more environmental education and have greater responsibility for solving sustainability issues. This generational gap was not noticed when taking into account eggs from hens fed insect larvae reared on agroindustrial by-products. Indeed, the inclusion of agroindustrial by-products as rearing substrate reduced the behavioural intentions among young consumers, potentially due to concerns about food safety and unnaturalness (Rao et al., 2021).

Participants with higher education level (degree, master or PhD) exhibited more positive attitude than those with lower education ($p < 0.05$), but only for eggs from hens fed insect larvae reared on agroindustrial by-products. Therefore, educational level emerged as another key factor in shaping consumers' attitudes, with more educated participants demonstrating a greater understanding and positive attitude toward sustainability-oriented innovations, as also confirmed by previous studies (Giacalone and Jaeger, 2023). This is probably due to the fact that environmental knowledge and awareness are correlated with higher education levels, which help individuals to understand the broader implications of sustainable practices in food production. Nonetheless, no significant effect ($p > 0.05$) of educational level on WTT, WTB and WTC was observed in both scenarios (eggs from hens fed insect larvae and fed insect larvae reared on agroindustrial by-products) demonstrating that, regardless educational background, practical barriers like perceived risk or lack of familiarity may still discourage the complete acceptance of *circular eggs*.

Context of living significantly affected ATT, WTT, WTB and WTC in both scenarios ($p < 0.05$), with individuals from cities (> 70.000 inhabitants) showing higher scores than individuals from rural areas (< 10.000 inhabitants). The higher positive attitude of participants living in

cities, compared to those living in rural areas, may be explained by the greater exposure of urban individuals toward sustainable and innovative food practices, as well as by a higher likelihood that urban consumers will find more easily insects-based foods in the market. Furthermore, participants from rural areas exhibited more conservative attitudes, reflecting traditional dietary habits and scepticism toward unconventional food production methods (Siddiqui et al., 2022).

*3.1.4.2. Knowledge about hens' typical diet.* The impact of consumers' knowledge about the hens' typical diet on ATT, WTT, WTB, WTC was also evaluated. The role of consumers' knowledge about hens' typical diet emerged as another pivotal factor. Consumers who stated that hens have an omnivorous diet consistently showed statistically higher scores in all the dependent variables than the "Exclusively vegetal diet" group of consumers ($p < 0.05$). These findings suggested that if consumers already perceive hens as naturally omnivorous and capable of consuming larvae, their attitudes and purchasing intentions toward such practices are more favourable, minimizing biases typically associated with innovative or "unconventional" technologies. From a marketing and educational perspective, emphasizing the fact that these practices mimic the hens' natural dietary patterns could strengthen consumer trust in the product and increase the willingness to purchase eggs from sustainable supply chains.

*3.1.4.3. Consumer sustainability consciousness.* Concerning LPP domain, the majority of participants belonged to the medium group (43.6 %), indicating that a major percentage of participants had moderate level of awareness about peer pressure in relation to sustainability labelling. Nonetheless, over a quarter of respondents (26.1 %) belonged to the low group, placing little value on the sustainability labels. A similar pattern emerged for the SR domain: the medium group included almost half of the participants (47.4 %), while the low and high groups included 28.3 % and 24.3 % of the participants, respectively. The CE domain showed a slightly different trend, with the high group accounting for a more substantial proportion of participants (33.6 %) compared to the other domains. However, the relatively smaller low group (25.9 %) suggested that it is crucial to better encourage consumers' involvement with recycling or waste reduction principles. Overall, among the three CSC domains evaluated, the CE domain had the strongest positive impact on attitudes, indicating a greater consumers' interest in sustainable practices that align with the 3Rs principles (reduce, reuse, recycle) and the concepts of the circular economy. Participants with high LPP and SR scores showed significantly higher ATT, WTT, WTB and WTC values ($p < 0.05$) across both scenarios, emphasizing the role of social and ethical aspects in shaping consumers' behaviour. The same trend occurred for the CE domain. However, no significant differences ($p > 0.05$) were observed in WTC across CE groups in both scenarios, indicating that factors other than a general awareness of sustainability may be necessary for encouraging people to include such products in their regular diet.

*3.1.4.4. Personality traits.* Participants were divided into three groups separately based on their level of FN and DS. Approximately 45 % of the subjects demonstrated a medium level of FN (FN score between 19 and 32), while about 29 % and 26 % belonged to the groups with low (FN score $\leq 18$) and high (FN score $\geq 33$) levels of FN, respectively. In terms of food DS, 42 % of subjects had a medium (DS score between 21 and 29) level of DS, whereas 28 % and 30 % belonged to the low (DS score $\leq 20$) and high (DS score $\geq 30$) level of DS, respectively. In this study, food neophobia and food disgust sensitivity were strong negative predictors, with high levels of these personality traits reducing attitude toward, willingness to try, buy and consume regularly both *circular eggs*. These results confirmed that these personality traits are a barrier to the adoption of innovative practices, consistent with findings from previous studies in the literature (Bazoche and Poret, 2021; Laureati et al., 2016; Mustapa and Kallas, 2023). These results highlighted the necessity to focus on communication strategies to avoid negative attitudes towards eating insects or food by-products, as well as to prevent rejection by individuals with high food neophobia and disgust sensitivity. These barriers might be minimized with interventions such as sensory exposure and products tasting, in order to increase the consumers' familiarity, or with a transparent communication about the benefits to both animal welfare and environment, emphasizing the safety, naturalness and sustainability of insect-based feeding practices.

### 3.1.5. Willingness to pay a premium for circular eggs

Price sensitivity emerged as a factor influencing consumer behaviour. Approximately 59.0 % and 60.1 % of participants indicated unwillingness to pay any premium for eggs from hens fed insect larvae and larvae reared on by-products, respectively. However, 38.4 % and 37.5 % of participants expressed willingness to pay up to 50 % more for these two types of eggs, respectively, highlighting a potentially valuable market segment. These findings supported those of earlier research focusing on the factors affecting consumers' willingness to pay for insect-fed poultry products (both meat and eggs) (Tiboldo et al., 2024), suggesting that although consumers' opinions of larvae-based feeding practices were generally favourable, price is still a significant barrier for broader adoption. Nevertheless, the market segment of consumers who are willing to pay over 50 % more could be a chance for focused marketing strategies that target consumers who care about sustainability and the environment as part of their purchasing behaviour. To obtain a more detailed understanding of price sensitivity, future research should explore a broader range of price increases, incorporating smaller increments of 10, 20, 30 and 40 %. A more moderate price increase could potentially result in a higher percentage of consumers willing to pay a premium for *circular eggs*, thus eventually leading to increased adoption of this sustainable product. Moreover, future efforts might investigate strategies to reduce production costs or to improve perceived value in order to reach more consumers and expand the market sales.

## 3.2. Sensory analysis

### 3.2.1. Liking

Sensory analysis provided valuable insights into the characteristics driving consumers' acceptability of *circular eggs*. Results from liking evaluation are reported in Table 5. The egg sample with the highest overall liking score was the hard-boiled Circular sample (6.4 ± 1.8), followed by poached Circular egg (6.4 ± 1.9), poached Control egg (6.2 ± 2.0) and hard-boiled Control egg (6.1 ± 1.7). However, all samples did not statistically differ in overall liking ($p > 0.05$).

Different letters in the same column indicate significant difference ($p < 0.05$), following pairwise comparison using Tukey's post-hoc test. Two-way ANOVA results showed a significant impact of feeding on liking scores, with significant higher mean values ($p < 0.05$) for the Circular sample compared to the Control on the liking scores of the following sensory attributes analyzed: overall appearance, yolk colour, albumen colour, yolk flavour, overall flavour and yolk texture. Therefore, all appearance-related attributes were significantly influenced by feeding, whereas no significant different scores among samples for overall odour were observed, indicating that the feeding method had no adverse effects on the aroma of the eggs. Indeed, as also reviewed by Sverguzova et al. (2021), the insect-larvae-based feed had an impact mainly on the sensory quality of the egg yolk, improving the tocopherols, lutein, β-carotene and total carotenoids content, thus leading to a more intense yolk colour. Since yolk colour is often associated with freshness and quality and is considered one of the most important egg quality parameter for consumers (Rondoni et al., 2020), the higher liking score for overall appearance could be mainly attributed to a more intense yolk colour in the egg samples from insect-larvae-based hens. Moreover, the non-significant differences in overall odour scores indicated that the feeding method had no adverse effect on the aroma of the

**Table 5**
Average liking scores of egg samples.

| Sample | Yolk colour | Albumen colour | Overall appearance | Overall odour | Yolk flavour | Albumen flavour | Overall flavour | Yolk texture | Albumen texture | Overall texture | Overall liking |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Circular_hard-boiled | 6.5 $^{b}$ | 6.8 $^{a}$ | 6.3 $^{a}$ | 6.2 $^{a}$ | 6.5 $^{a}$ | 6.3 $^{a}$ | 6.6 $^{a}$ | 6.1 $^{b}$ | 6.2 $^{a}$ | 6.3 $^{a}$ | 6.4 $^{a}$ |
| Circular_poached | 7.0 $^{a}$ | 5.9 $^{b}$ | 5.8 $^{b}$ | 5.4 $^{b}$ | 6.8 $^{a}$ | 6.0 $^{ab}$ | 6.5 $^{a}$ | 7.1 $^{a}$ | 5.7 $^{b}$ | 6.4 $^{a}$ | 6.4 $^{a}$ |
| Control_hard-boiled | 5.6 $^{c}$ | 6.5 $^{a}$ | 5.8 $^{b}$ | 6.0 $^{a}$ | 6.0 $^{b}$ | 6.2 $^{a}$ | 6.3 $^{a}$ | 5.6 $^{c}$ | 6.3 $^{a}$ | 6.0 $^{a}$ | 6.1 $^{a}$ |
| Control_poached | 6.8 $^{ab}$ | 5.7 $^{b}$ | 5.6 $^{b}$ | 5.2 $^{b}$ | 6.5 $^{a}$ | 5.9 $^{b}$ | 6.2 $^{a}$ | 7.0 $^{a}$ | 5.5 $^{b}$ | 6.4 $^{a}$ | 6.2 $^{a}$ |

eggs, in line with findings from previous studies (Al-Qazzaz et al., 2016; Bejaei and Cheng, 2020; Dalle Zotte et al., 2019). Finally, both yolk and albumen texture were rated higher for Circular samples, indicating that the insect-based feed did not negatively impact the egg's structural integrity. Furthermore, analysing the effect of feeding on the WTE, WTB and WTC the sample, a significant difference was found for WTB ($p < 0.05$) but not for WTE and WTC ($p > 0.05$). In particular, consumers were more open to buy eggs derived from circular feeding methods.

Results from two-way ANOVA, studying the effect of the cooking method (hard-boiled vs poached) on liking, highlighted a significant impact ($p < 0.05$) on the following attributes: overall appearance, yolk colour, albumen colour, overall odour, yolk flavour, albumen flavour, yolk texture and albumen texture, but not on overall liking ($p > 0.05$). In particular, the poached egg samples were scored significantly higher for yolk-related attributes such as yolk colour, flavour and texture. On the other hand, the hard-boiled eggs were rated significantly higher in albumen-related attributes, such as albumen colour, flavour and texture, as well as in overall appearance and overall odour. Nonetheless, the cooking method did not have a significant effect on the WTE, WTB and WTC ($p > 0.05$).

### 3.2.2. *Sensory properties and drivers of liking of circular eggs*

Fig. 2 shows the results from CATA test, representing the frequency of selection of each attribute for each sample. CATA results showed that, in terms of appearance characteristics, "intense yellow egg yolk" was predominantly associated with samples derived from the Circular feeding practice and poached cooking method. Regarding taste, "umami" was the most frequently cited attribute, particularly in poached samples. Flavour profiles were significantly influenced by the cooking method: hard-boiled eggs were described as having a "sulphurous" note, whereas poached eggs were perceived as "buttery". Texture attributes indicated that the predominant differences among samples were primarily attributable to the cooking method. Indeed, the most frequently reported textural characteristics for hard-boiled eggs included "spongy", "firm", "gritty" and "dry". In contrast, poached eggs were predominately described with the attributes "soft", "watery" and "smooth". According to the results of the Cochran's Q test applied to the CATA data, significant differences of usage frequency among egg samples were found in all the sensory attributes ($p < 0.05$), except for "salty" and "bitter" (Table S3).

Correspondence analysis and penalty-lift analysis further revealed specific attributes that influenced overall acceptability. The Correspondence Analysis biplot (Fig. 3A) showed the relationships between the significant sensory attributes and the egg samples. The total variance explained by the first two factors was 98.47 %, with F1 and F2 accounting for 89.68 % and 8.79 %, respectively. The samples were well discriminated along the first factor based on cooking method and along the second factor based on hens' feeding type. In particular, it was observed that the differences between the two samples, Control and Circular, appeared to be less pronounced for the poached eggs, whereas the hard-boiled cooking method highlighted greater differences between Control and Circular samples. In general, poached eggs tended to amplify yolk-related attributes, such as flavour and texture, while hard-boiled eggs accentuated differences in albumen characteristics. These results were consistent with the idea that poaching, a gentler cooking method, is useful in preserving the natural sensory qualities of the egg yolk (Vaclavik et al., 2021). Indeed, hard-boiling resulted in whiter and more uniform appearance due to the complete coagulation of albumen proteins (Vaclavik et al., 2021). Overall, the sensory differences between Circular and Control eggs were more pronounced in hard-boiled samples. This indicated that the particular features provided by insect-based feeding practices can be either emphasized or hidden by cooking

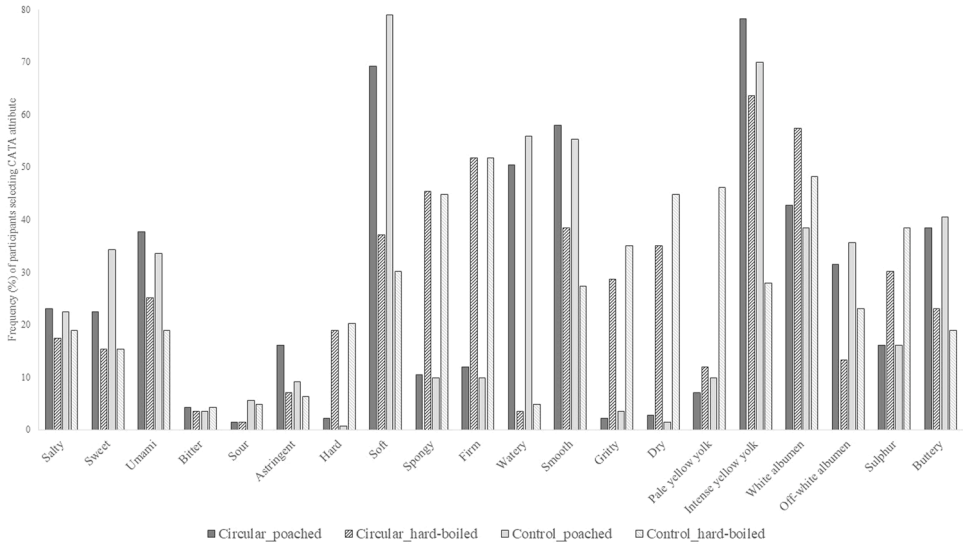


**Fig. 2.** Selection frequency of Check-All-That-Apply (CATA) attributes for each sample. Data are expressed as the percentage of participants who selected each attribute relative to the total sample size ($n = 143$).

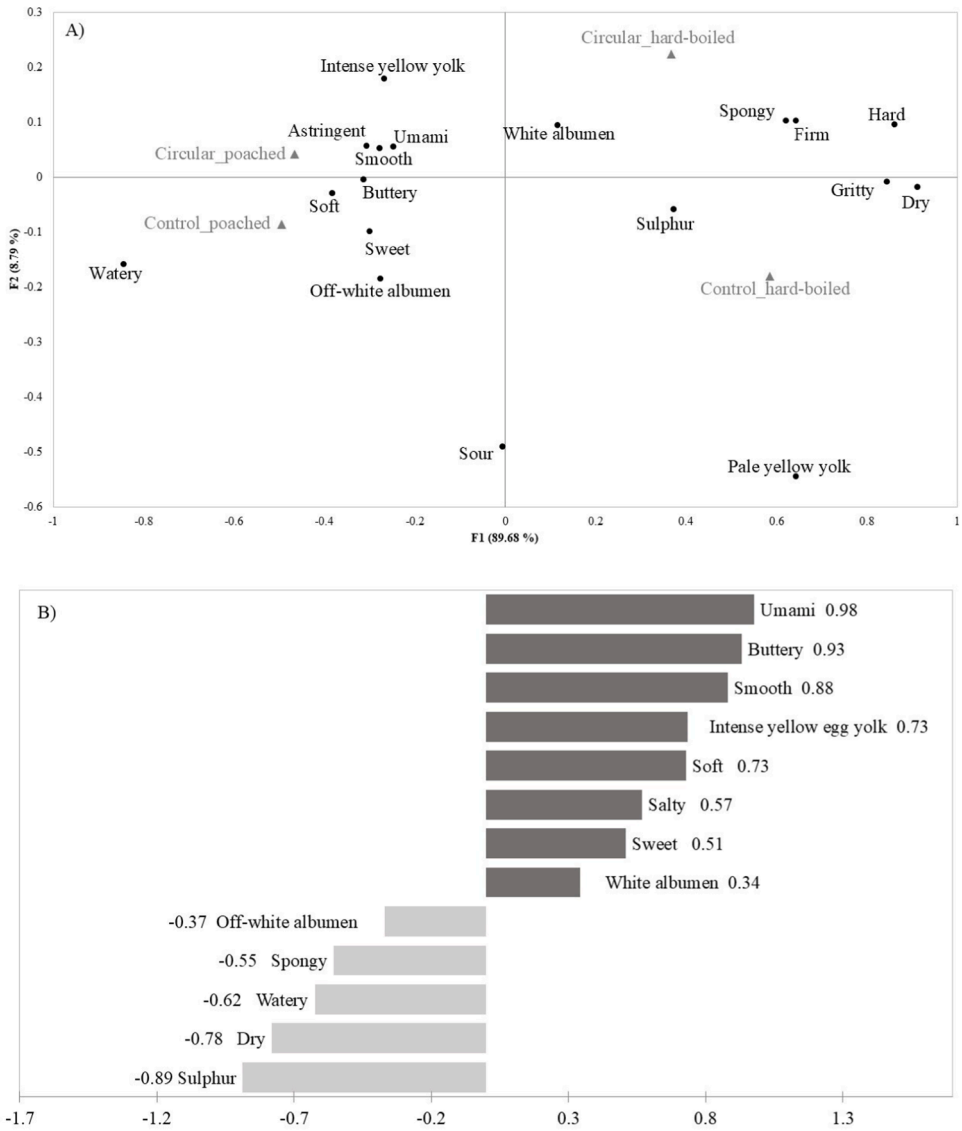


**Fig. 3.** A) Correspondence Analysis biplot showing the relationship among the Check-All-That-Apply sensory attributes and egg samples; B) Penalty-Lift Analysis chart showing the sensory attributes with a significant mean impact on overall liking.

techniques. According to Cochran's Q test and multiple pairwise comparisons using the Critical Difference (Sheskin) procedure, a significant difference in yolk colour perception was observed ($p < 0.05$) for the Control sample based on the cooking method. Specifically, hard-boiled Control eggs were predominantly associated with the attribute of pale-yellow yolk, whereas the Control sample cooked as poached eggs was more frequently associated with an intense yellow yolk. In contrast, no significant differences in yolk colour were observed between the two cooking methods (hard-boiled and poached) in the Circular sample. Additionally, the attribute "sweet" was more frequently associated ($p < 0.05$) with the poached Control sample compared to the corresponding poached Circular one, potentially due to differences in sensory properties influenced by the feeding system.

Penalty-Lift Analysis was conducted to individuate the sensory attributes with a positive or negative impact on the overall acceptability of the product. As showed in Fig. 3B, "umami", "buttery", "smooth", "intense yellow egg yolk", "soft", "salty", "sweet" and "white albumen" were positive drivers of acceptability, increasing the overall liking score by 0.34 to 0.98 points. All these positive drivers were strongly associated to the circular-fed and poached egg sample, suggesting that this combination of feeding and cooking method allowed to enhance the consumers' acceptability. Moreover, according to Al-Qazzaz et al. (2016), the BSFL-based hens' diet increased the glutamic acid content of their eggs, which in turn improved the taste liking score. Therefore, this also could explain the high umami taste perception in poached Circular eggs and the high overall liking. Conversely, "off-white albumen", "spongy", "watery", "dry" and "sulphurous" were identified as negative drivers, decreasing the overall liking score by 0.37 to 0.89 points.

## 4. Practical implications

To enhance consumers' acceptability and bridge the gap between willingness to try and regular consumption of *circular eggs,* several strategies can be used by food producers, policymakers and marketers. First, it is important to provide clear information about the safety and the environmental advantages of the insect-based feed in order to increase consumers' trust and to reduce perceived risk, by also emphasizing hens' natural insect-based diet. Second, recommendation by food scientists, nutritionists or industry experts could support the development of communication strategies targeting consumers with less involvement with sustainability. These strategies should also aim to address food neophobia and disgust sensitivity, as well as to reduce

negative preconceptions about the perceived loss of product quality associated to the use of agroindustrial by-products as rearing substrate. Third, it is necessary to increase product familiarity by sensory evaluations and then repeated exposure must be carried out so that consumers can understand that the sensory quality of the product is not compromised. Finally, price incentives, such as reduced costs for eco-friendly products, may help with both initial purchase decisions and following market adoption of these "circular" products.

## 5. Conclusion

This study demonstrated that *circular eggs,* derived from hens partially fed with black soldier fly larvae reared on agroindustrial by-products, were not only environmentally friendly but also accepted by consumers, both in terms of attitudes and sensory perception. Younger, highly educated and environmentally engaged individuals were more inclined to accept *circular eggs,* while personality traits such as food neophobia and disgust sensitivity negatively influenced consumers' attitude towards such sustainable products. Although willingness to try *circular eggs* was high, regular consumption and willingness to pay a premium remained constrained by concerns related to price, naturalness and trust in production processes. Despite this, results from the consumers' test showed that *circular eggs* were accepted and that the sensory characteristics of final product were not particularly different from those of conventional eggs.

Further research could extend the framework provided by this study by investigating how consumers' sensory perceptions and purchase decisions are affected by information on the insect-based feeding practices. In fact, providing information about the nutritional composition of insect-fed eggs may boost consumers' trust and improve the perceived value, especially among health-conscious consumers. Therefore, combining nutritional, sensory and technological analyses in future investigations could provide a more comprehensive evaluation of *circular eggs* and may also help promote their market integration. Moreover, analysing a lower substitution rate of black soldier fly larvae in hens' feed could help reduce production costs and thus retail prices, which would enhance market potential of *circular eggs*.

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## Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this work the authors used ChatGPT (free version) in order to revise the English of some sentences so as to improve the readability of the manuscript. After using this tool/service, the authors reviewed and edited the content as needed and take full responsibility for the content of the published article.

## Data availability

The data that support the findings of this study are available from the corresponding author upon request.

## Ethical statement

The study was conducted in accordance with the ethical guidelines of the Declaration of Helsinki and received approval from the Ethics Committee of the University of Gastronomic Sciences in Pollenzo (Ethics Committee Proceedings n.5/2024). Informed consent was obtained by participants prior completing survey and prior sensory evaluation.

## CRediT authorship contribution statement

**Nazarena Cela:** Writing – original draft, Visualization, Validation, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Chiara Nervo:** Writing – original draft, Validation, Resources, Methodology, Investigation, Conceptualization. **Marco Meneguz:** Writing – review & editing, Resources, Project administration, Funding acquisition, Conceptualization. **Carola Mileto:** Writing – review & editing, Project administration, Funding acquisition. **Cecilia Padula:** Writing – review & editing, Project administration, Funding acquisition. **Luisa Torri:** Writing – review & editing, Supervision, Resources, Project administration, Methodology, Investigation, Funding acquisition, Conceptualization.

## Declaration of competing interest

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

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## Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.fufo.2025.100773.

## Data availability

Data will be made available on request.

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