



*Research article*

## Reimagining beef: Consumer attitudes and acceptance of upcycled animal feed

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**Abstract:** Increasing environmental and ethical concerns are driving the transition toward more sustainable livestock production systems. However, consumer acceptance remains a critical and underexplored bottleneck, particularly for beef from animals fed agro-industrial by-products. In this context, we investigated Italian consumer attitudes and acceptance of beef derived from cattle fed hazelnut skins (HSs), a by-product of the hazelnut processing industry classified as waste under EU regulation, representing a novel circular economy application. An online survey (CAWI) was administered to 900 Italian beef consumers in 2023. Principal Component Analysis (PCA) identified five attitudinal patterns: *Conscious and Confident*, *Food Neophilic*, *Environmentally Concerned*, *Animal Nutrition Concerned*, and *Food Neophobic*. K-means cluster analysis on PCA scores yielded five consumer segments, characterized by socio-demographic variables and attitudes toward novel foods. Age and sensitivity to sustainability significantly predicted acceptance of HS-fed beef. The *Informed, Curious, and Concerned* segment (24%) reported the highest acceptability (mean = 5.58/7) and environmental sustainability scores (mean = 5.83/7). The *Informed Meat-Eaters* segment (14.2%) showed the strongest health benefit perceptions (mean = 5.13/7). Older consumers, concentrated on the *Sustainable and Selective* cluster, showed more moderate acceptance, moderated by food neophobia. We are some of the first to examine consumer segmentation in the context of beef from farms fed with by-products in Italy. Our findings provide actionable guidance for differentiated communication strategies across consumer segments and inform policymakers on promoting circular food systems.

**Keywords:** alternative feed; consumer segmentation; food industrial by-product; sustainable beef; food neophobia

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## 1. Introduction

Over the last decade, diverse environmental, economic, and social challenges have exposed structural vulnerabilities of global food systems, highlighting the urgent need to enhance their sustainability [1].

One major area of concern relates to animal-derived products, particularly meat, due to the growing awareness tied to its resource demands and ethical implications [2]. In Europe, this has led to increasingly strict environmental and climate regulations, parallel to a shift in consumers' eating habits, with many people opting to cut back on the most impacting meats, especially beef. As a result, its yearly production has dropped by 5% across Europe and by 20% in Italy between 2022 and 2023. These data, together with a negative trend projected toward 2035, make beef one of the most critical sectors of the meat industry [3,4].

Nonetheless, the sector is a substantial contributor to food security through its provision of protein, energy, and essential micronutrients from fibrous feeds that cannot be directly consumed by humans [5]. It also plays a vital role in sustaining rural communities and national identities across Europe and, for these reasons, its importance cannot be overlooked [6].

The long-term resilience of the beef industry depends on its capacity to adapt to evolving societal expectations and market demands by providing high-quality, nutrient-dense meat products through practices that prioritize environmental sustainability and animal welfare [2,7,8].

In Europe, researchers focused on the feed industry as a key area for meeting these growing expectations. Feed production can account for up to 70% of total expenses, and is responsible for significant environmental issues, deforestation, biodiversity loss, and competition for resources between food and feed systems [9]. Therefore, finding sustainable solutions is essential for the future of livestock and food systems [10]. One extensively studied approach is the inclusion of alternative feed sources, such as insects, marine algae, and by-products from the food industry [11,12]. Among them, food by-products are particularly promising, as they reintroduce components of the food supply chain that would otherwise be discarded as 'waste' [13]. In this context, examples of growing relevance for the scientific sector include brewers' spent grain, olive pomace, citrus pulp, grape pomace, and hazelnut skins (HSs), the latter being our focus of this study [14–18].

Their employment in the feed sector alleviates the competition for key ingredients, such as cereal grains, while reducing the industry's environmental footprint without compromising the safety or the nutritional value of the final product [10,19,20].

Among these by-products, HSs represent a particularly compelling case study. From a regulatory standpoint, HSs are the only by-product of the hazelnut processing chain classified as 'waste' under EU feed legislation [19], as opposed to other fractions that retain 'feed material' status. Their re-evaluation as a functional feed ingredient therefore represents a paradigmatic application of the cradle-to-cradle principle within the agro-industrial food system and aligns directly with the objectives of the EU Farm to Fork Strategy and the Circular Economy Action Plan [21].

From the animal nutritional perspective, the inclusion of HS in ruminant and monogastric diets has been validated across experimental trials. Studies on dairy cows [22], lactating ewes [23], pigs [24],

and lambs [25] consistently report an absence of adverse effects on animal health and productive performance. Moreover, HS inclusion has been associated with improvements in the fatty acid profiles of derived products, a reduction in atherogenic saturated fatty acids, and increases in vaccenic and oleic acids, recognized as health-promoting lipids. These nutritional benefits, if effectively communicated, may constitute an additional driver for consumer acceptance.

In accordance with the EU legislative definition, food products obtained from animals fed an alternative diet fall under the category of novel foods, together with plant-based novel foods and meat protein alternatives [21]. The literature presents extensive research on the nutritional, technological, and safety aspects associated with the consumption of these foods, yet little attention has been given to consumers' perceptions and acceptance of meat products derived from alternative feed materials [18,26,27]. Despite the promising zootechnical and nutritional evidence for HS-fed beef, no researcher to date has examined how consumers perceive and evaluate this product. This gap is critical, as consumer attitudes strongly influence market adoption and, ultimately, the development of sustainable food systems [28,29].

To date, many researchers have focused on insects [30–32], as well as on aquatic and plant-based alternatives in animal feed and human food [33,34]. Findings show that consumer acceptance strongly varies across cultures: Western consumers tend to value environmental and health benefits, whereas Asian consumers emphasize taste and familiarity [35]. Similarly, studies on algae and other aquatic foods highlight the central role of sensory attributes and culinary traditions, with higher skepticism reported in countries with more established food cultures, such as France, compared to Germany and the Netherlands [36–38].

Regarding meat products obtained from agro-industrial by-products, only limited evidence exists. Studies stress the importance of improving public understanding of these innovations [39–40], which agrees with efforts made for other types of novel foods [41–43]. Consumer acceptance, shaped by factors, including food neophobia, environmental identity, and trust in food systems, constitutes the determinant of whether a sustainable innovation reaches the commercial scale [44–46]. Understanding these dynamics for HS-fed beef is therefore essential not only for the hazelnut by-product valorization chain, but as a transferable model for the broader category of agro-industrial by-product-fed livestock products. By identifying key consumer segments and understanding what drives the acceptance of beef obtained from animals fed an agro-industrial by-product such as HS, this research aims to serve as a valuable model to understand the fundamental mechanisms regulating the market of novel foods.

Our objectives of the study can therefore be summarized as follows:

- 1) Identification of distinct consumer attitudes toward novel foods based on variables such as food neophobia, frequency of beef consumption, green self-identity, awareness of food waste and animal feeding practices, perceived meat quality, and commitment to reducing food waste.
- 2) Analysis of consumers' perceptions and acceptance of beef derived from animals fed HSs, as a model for novel foods. This will involve examining factors, such as product quality, food safety, and the economic, environmental, and health benefits associated with this type of meat.
- 3) Assessment of the effect of socio-demographic factors on consumer opinions and preferences regarding sustainable livestock feeding practices.

The findings are intended to help industry stakeholders and policymakers develop strategies that align with consumer expectations and promote more sustainable food systems.

## 2. Materials and methods

### 2.1. Data collection

From September to November 2023, a consultancy company conducted data collection using the Computer Assisted Web Interviewing (CAWI), enabling us to guarantee a balanced and representative sample. Participation was voluntary and anonymous. No personal identifiers were collected, and all data were processed in accordance with the General Data Protection Regulation (GDPR) [47]. Criteria for inclusion were consent for data use, minimum age of 18 years, and the regular consumption of beef products. Prior to completing the survey, each respondent was presented with a standardized disclosure sheet describing: (i) The scientific purpose of the study; (ii) the voluntary and anonymous nature of participation; (iii) the procedures for data storage and use; and (iv) the right to withdraw at any stage without consequence. Respondents provided their informed consent via an electronic signature embedded in the CAWI platform before accessing the questionnaire. No monetary compensation was provided.

The conduction of this study was approved by the University Bioethics Committee of the University of Turin (Ref-GD/169873/2023) and followed the ethical standards defined by the Declaration of Helsinki.

### 2.2. Participants

The final study sample composed 900 meat consumers and was representative of the Italian population from a socio-demographic perspective [48]. The sample was balanced in terms of gender and was primarily composed of individuals aged 31 to 59 years (60%). Most participants had a medium level of education, with over half (54.44%) holding a secondary school diploma. Income levels were concentrated in the mid-range brackets, with nearly 70% earning between €1,001 and €4,000 per month. Most were employed, particularly in the private sector (41.78%), indicating a working-age, economically active population with moderate educational attainment.

### 2.3. Questionnaire

A total of 950 surveys were completed (response rate = 94.74%), 50 of which (5.55%) were eliminated due to missing data or for not fulfilling the quality checks (straight-lining).

The questionnaire was developed in English and pre-tested by consumer science experts, whose approval was followed by the Italian translation by bi-lingual native speakers. As reported in the literature [49,50], translated surveys might present new comprehension problems consequent to the translation process. Due to this, a pre-test of the Italian version was conducted, involving five individuals external to the project and leading to minor modifications to the questions, phrasing, and response options. Participants were asked questions in relation to socio-demographic features, food neophobia, meat consumption habits, and individuals' perceptions and expectations toward meat produced from beef cattle fed HS as part of the feed formula. The investigated variables were decided through literature research targeting the most relevant traits involved in consumers' decision-making process in the context of novel foods to understand and provide a quantification of their role [51,52]. The final instrument comprised seven construct sections plus a socio-demographic module, as summarized in Table 1.

**Table 1.** Summary of questionnaire constructs, validated sources, number of items, and internal consistency.

Construct	Validated source	N items	Scale	Cronbach's $\alpha$	Interpretation
Food neophobia/Neophilia	Food Neophobia Scale [53,54]	10 (5 neophilia + 5 neophobia)	7-pt Likert	0.95	Excellent
Weekly beef consumption frequency	Study-specific	1	3-pt ordinal	N/A	N/A
Consumer green self-identity	[55]	2	7-pt Likert	$r = 0.89$	Good
Awareness of food waste reduction	[55]	4	7-pt Likert	0.75	Acceptable
Concern about food waste reduction	[55]	3	7-pt Likert	0.80	Good
Awareness of animal feeding methods	Adapted from [55]	4	7-pt Likert	0.81	Good
Concern about animal feeding methods	Adapted from [55]	3	7-pt Likert	0.82	Good
Acceptability of HS-fed beef	[56,57]	3	7-pt Likert	0.83	Good
Organoleptic trait perceptions	[58]	7	7-pt Likert	0.71	Acceptable
Health benefit & risk perceptions	[59,60]	10	7-pt Likert	0.83	Good
Economic sustainability	[61]	2	7-pt Likert	0.67	Borderline†
Environmental sustainability	[62]	3	7-pt Likert	0.71	Acceptable
Animal welfare perceptions	[63]	3	7-pt Likert	0.77	Acceptable

† The economic sustainability scale ( $\alpha = 0.67$ ) falls slightly below the conventional 0.70 threshold (Nunnally, 1978; Hair et al., 2019). Given the exploratory nature of this study and the theoretical importance of economic perceptions in novel food acceptance, this two-item scale was retained. Readers should interpret findings for this subscale with appropriate caution. Reliability thresholds used:  $\alpha \geq 0.70$  = acceptable;  $\alpha \geq 0.80$  = good;  $\alpha \geq 0.90$  = excellent [64].

All Likert-type items were assessed on a seven-point scale ranging from 1 (Strongly disagree) to 7 (Strongly agree). The complete list of items per construct is reported in Supplementary Table S1.

Finally, the Sociodemographic characteristic investigated gender, age, region of origin, educational level, employment and marital status, household size, and monthly average income.

A translated version of the questionnaire is reported in Section S2 of the Supplementary Materials.

#### 2.4. Principal Component Analysis and Clustering

Principal Component Analysis (PCA) was performed on the 27 attitudinal items to reduce the dimensionality of the dataset and identify underlying attitudinal patterns among consumers. The suitability of the data for PCA was verified using the Kaiser–Meyer–Olkin (KMO) measure of sampling adequacy and Bartlett’s test of sphericity. Components with eigenvalues greater than 1 were retained according to the Kaiser criterion. To improve interpretability, a Varimax orthogonal rotation was applied. Items with factor loadings above  $\pm 0.35$  were considered significant for the interpretation of each component. For each respondent, component scores were calculated, representing the individual position on the extracted principal components. These component scores were subsequently used as input variables for the cluster analysis to segment consumers according to their attitudinal profiles. The number of clusters was determined using a two-stage procedure. First, a Two-step cluster analysis (SPSS v.29) was run on the five PCA factor scores, using the Bayesian Information Criterion (BIC) as the automatic selection criterion (maximum clusters tested: 15; distance measure: Euclidean). The Two-step algorithm suggested  $k=6$  as the optimal solution. However, examination of the six-cluster solution revealed that the sixth cluster did not provide a meaningfully distinct attitudinal profile. Therefore, a K-means cluster analysis was subsequently performed with  $k = 5$ , which yielded a more parsimonious and theoretically interpretable segmentation. The BIC values for each tested cluster solution are reported in Table S3 of the Supplementary Material. Subsequently, the k-means clustering method was applied using the component scores to assign respondents to homogeneous consumer segments [65].

A Multivariate Analysis of Variance (MANOVA) was then employed to identify potential differences among clusters in perceptions of acceptability, organoleptic traits, health benefits, economic and environmental sustainability, animal welfare, and risks associated with meat products obtained from beef cattle fed HSs as part of their feed. Post-hoc Tukey's multiple comparison tests were also conducted. This approach enabled us to simultaneously test for multivariate differences among clusters (independent variable) across correlated outcome variables (dependent variables), accounting for their intercorrelations and reducing the risk of Type I error [66,67].

Finally, an alluvion plot was used to depict the relationship between cluster membership, some socio-demographic characteristics (gender, age, and geographic affiliation), and consumer meat acceptability, comparing three levels (high, medium, and low). Starting from the mean score obtained for each of the three items measuring acceptability ("I am interested in buying meat from beef cattle fed HSs as part of the feed formula", "It is a good idea to buy meat from beef cattle fed HSs as part of the feed formula", "Buying meat from beef cattle fed HSs as part of the feed formula is important to me"), we considered the high level of acceptability to be a mean score higher than 6, the medium level to be between 4 and 6, and the low level to be a mean score lower than 4. All statistical analyses were performed using SPSS (version 29.0), with an alpha level of 5% considered.

### 3. Results

#### 3.1 Consumer attitudes toward new foods

Results from the PCA enabled to identify five new variables (Principal Components-PCs), each representing a consumer's attitudinal pattern and perception profile toward meat products obtained from beef cattle fed HSs as part of the feed formula (Table 2). The presented PCs explained the 65.2% of the total variance and were retained in accordance with the Kaiser criterion (eigenvalue > 1) [66]. Each component was named in accordance with the attitudinal pattern described by the significance of the values.

**Table 2.** Varimax rotated PCA: Attitudinal patterns toward novel foods based on food neophobia, familiarity with food waste, and animal nutrition (n = 900). Items are grouped by construct. Non-significant loadings (<|0.35|) are indicated by —. The negative loading for beef consumption frequency reflects an inverse association with the environmentally concerned component and is reported for interpretive completeness; this item is not part of an attitudinal scale.

Variables	PC1 Conscious & confident	PC2 Food neophilic	PC3 Environmentally concerned	PC4 Animal nutrition concerned	PC5 food neophobic
<i>Food neophilia</i>					
I frequently try new and different foods	—	0.800	—	—	—
I like foods originating from other countries	—	0.787	—	—	—
When eating out, I will try new foods	—	0.827	—	—	—
I will eat almost anything	—	0.670	—	—	—
I like to try new ethnic restaurants	—	0.784	—	—	—
<i>Food neophobia</i>					
I do not trust new foods	—	—	—	—	0.696
If I do not know what is in a food, I will not try it	—	—	—	—	0.736
I find unfamiliar foods too strange to eat	—	—	—	—	0.664
I am afraid to eat things I have never tried before	—	—	—	—	0.712
I am very selective about what I will eat	—	—	—	—	0.580

*Continued on the next page*

Variables	PC1 Conscious & confident	PC2 Food neophilic	PC3 Environmentally concerned	PC4 Animal nutrition concerned	PC5 food neophobic
<i>Green self-identity</i>					
I think of myself as an environmentally conscious consumer	—	—	0.570	—	—
I consider myself very concerned about environmental issues	—	—	0.628	—	—
<i>Consumer awareness—Food waste reduction</i>					
I feel that I know a lot about food waste reduction	0.664	—	—	—	—
Compared to my family, I know a lot about food waste reduction	0.641	—	—	—	—
Compared to my friends, I know a lot about food waste reduction	0.682	—	—	—	—
Compared to experts, I know a lot about food waste reduction	0.792	—	—	—	—
<i>Consumer concern—Food waste reduction</i>					
Food waste reduction is important to me	—	—	0.794	—	—
I am concerned about food waste reduction	—	—	0.759	—	—
Food waste reduction is very important to me	—	—	0.761	—	—
<i>Consumer awareness—Animal feeding methods</i>					
I feel that I know a lot about what animals are fed	0.809	—	—	—	—
Compared to my family, I know a lot about what animals are fed	0.837	—	—	—	—
Compared to my friends, I know a lot about what animals are fed	0.843	—	—	—	—
Compared to experts, I know a lot about what animals are fed	0.790	—	—	—	—
<i>Consumer concern—Animal feeding methods</i>					
What animals are fed is important to me	—	—	—	0.805	—

*Continued on the next page*

Variables	PC1 Conscious & confident	PC2 Food neophilic	PC3 Environmentally concerned	PC4 Animal nutrition concerned	PC5 food neophobic
I am concerned about what animals are fed	—	—	—	0.799	—
What animals are fed is very important to me	—	—	—	0.825	—
<i>Beef consumption frequency</i> †					
How many times per week do you usually eat beef?	—	—	-0.382	—	—
<i>Cronbach's α</i>	0.87	0.95	0.79	0.89	0.90
<i>Explained variance (%)</i>	27.8	16.6	11.7	4.8	4.4

KMO = 0.887. Bartlett's test of sphericity:  $\chi^2 = 15037.253$ ,  $p < 0.001$ . Total explained variance: 65.2%.

† Beef consumption frequency is a single behavioral item, not an attitudinal scale. Its negative loading on PC3 indicates an inverse association between higher beef consumption frequency and the environmentally concerned attitudinal profile, and is reported for interpretive completeness only.

The first PC, named “Conscious and confident” (explained variance 27.8%) identifies a consumer attitudinal profile characterized by a high level of confidence in their knowledge of animal nutrition and food waste reduction. The PC 2 (“Food neophilic”, explained variance 16.6%) describes a curious and adventurous consumer attitudinal profile, characterized by active research for new foods (“When eating out, I will try new foods”, loading value=0.827; “I frequently try new and different foods”, loading value = 0.800) with no culinary or geographical limitations. On the other hand, PC 5, “Food neophobic” (explained variance 4.4%), identifies a neophobic attitude toward preparations on which consumers have limited knowledge in terms of composition (“If I do not know what is in a food, I won't try it”, loading value = 0.736) and/or sensory traits (“I am afraid to eat things that I have never had before”, loading value = 0.712).

PC 3, the “Environmentally concerned” pattern (explained variance 11.7%) represents an attitudinal pattern with a strong green self-identity and high awareness toward food waste reduction. This profile is also defined by a negative correlation with the beef-consumption frequency factor (loading value = -0.382), suggesting an association with a dietary pattern marked by limited or no meat consumption.

Finally, the consumption pattern called “Animal nutrition concerned” (explained variance 4.8%) describes a consumer attitude marked by great concern over animal nutrition, but without a parallel influence from factors regarding knowledge on animal feeding methods. Additionally, no significant influences were found regarding awareness or knowledge of food waste reduction or sustainability in general.

### 3.2 Consumers' profile

The cluster analysis identified five consumer groups (Table 3). Each cluster was named in accordance with the weight of each PC on the group definition reflecting the sum of specific attitudes.

**Table 3.** Final clusters definition: Weight of each consumer attitude toward new foods derived by the PCA in cluster definition.

Principal component	Informed, not concerned (n = 174, 19.3%)	Informed, curious & concerned (n = 216, 24.0%)	Informed meat-eaters (n = 128, 14.2%)	Sustainable & selective (n = 216, 24.0%)	Sustainable & adventurous (n = 166, 18.0%)
Conscious & confident (PC1)	+0.10	+0.50	+0.98	-0.89	-0.33
Food neophilic (PC2)	-0.50	+0.32	+0.55	-0.49	+0.35
Environmentally concerned (PC3)	-1.04	+0.28	-0.05	+0.35	+0.66
Animal nutrition concerned (PC4)	-0.47	+0.54	+0.31	+0.56	-0.22
Food neophobic (PC5)	-0.16	-0.97	+1.27	+0.41	-0.11
<i>F-value (p &lt; 0.001 for all)</i>	156.96	55.24	210.77	196.36	225.45

The socio demographic characteristics of the obtained clusters are described in Table S4 in the supplementary materials.

**Table 4.** Differences in perceptions across the five consumer clusters: MANOVA results and cluster means (n = 900).

Dependent variable	Informed not concerned	Informed curious & concerned	Informed meat-eaters	Sustainable & selective	Sustainable & adventurous	F	p	Partial $\eta^2$
Acceptability	4.21	5.58	5.43	4.80	4.55	50.48	<0.001	0.18
Organoleptic traits	4.13	4.90	5.17	4.40	4.32	47.79	<0.001	0.17
Health benefit perceptions	4.14	4.54	5.13	4.28	4.13	47.94	<0.001	0.17
Risk perceptions	4.34	5.51	5.32	4.90	4.83	34.51	<0.001	0.13
Economic sustainability	4.09	4.67	5.05	4.29	4.36	27.85	<0.001	0.11
Environmental sustainability	4.29	5.83	5.49	5.32	5.25	61.88	<0.001	0.22
Animal welfare perceptions	4.10	4.53	5.09	4.17	4.10	46.17	<0.001	0.17

Multivariate test (Pillai's Trace):  $F(28, 3568) = 18.74, p < 0.001, \text{partial } \eta^2 = 0.13$ .

All univariate F-tests:  $df = (4, 895)$ . Post-hoc pairwise comparisons: Tukey HSD,  $\alpha = 0.05$ . Cluster means are reported on a 7-point scale (1 = Strongly disagree, 7 = Strongly agree).

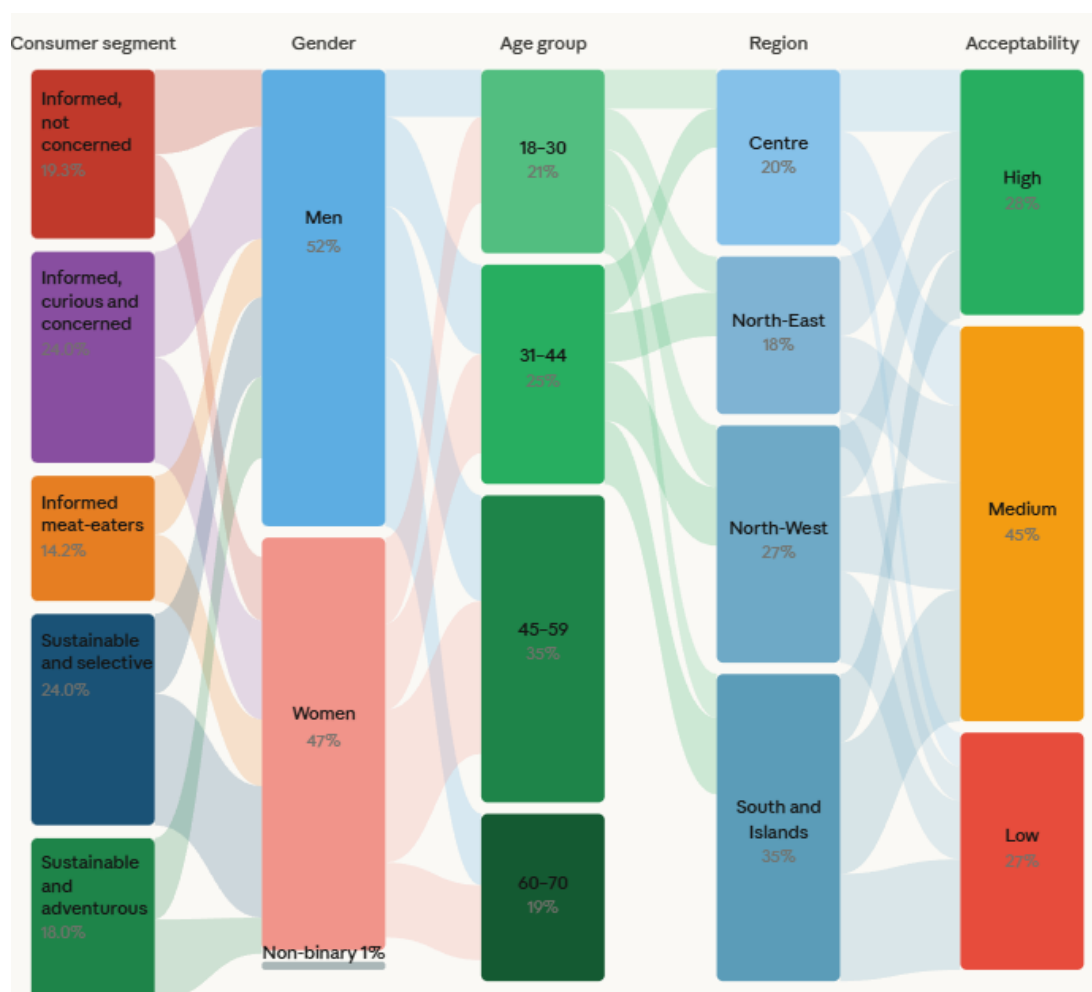
The first cluster, called “Informed, not concerned” (19.3 % of the total sample), was defined positively only by the first attitudinal profile (PC1, “Aware and informed”), and negatively by all the other four models, particularly PC3 (“Environmentally concerned”) (Table 3). These consumers were characterized by a strong self-reported knowledge of food systems but minimal concern for sustainability. They showed moderate acceptance of new meat products (mean score = 4.21), emphasizing environmental factors (mean score = 4.29) over economic considerations (mean score = 4.09) (Table 4). This cluster presented a balanced socio-demographic profile, with significant representation from the South and Islands (37.93%) and the Northwest (22.99%). Consisting of mostly men (62.64%), the group was relatively balanced in terms of age, with higher percentages in the 31–44 and 45–59 age groups (29.31% and 30.46%, respectively), and a smaller percentage of younger adults (18–30 years, 26.44%) (Figure 1).

The second group, labeled “Informed, curious, and concerned”, accounted for 24% of the total sample (Table 3). This group was interested in environmental and food system issues. Moreover, this group was the most open to sustainable meat products, placing a high value on environmental sustainability and reducing food waste. In fact, its members reported the highest acceptability (mean score = 5.58) and environmental sustainability (mean score = 5.83) scores compared to the other groups. They also presented a relatively higher appreciation for organoleptic characteristics, with a mean score of 4.90 (see Table 4). This cluster was positively defined by all the identified consumer attitudes, except for the PC5, related to “Food neophobia”. This group was quite heterogeneous in terms of geographic origin, with a significant concentration of middle-aged individuals, particularly aged 31–44 years (30.09%) and 45–59 years (35.65%) (see Figure 1).

Cluster 3 was named “Informed meat eaters” and accounted for 14.2% of the total sample. These consumers reported high acceptability (mean score = 5.43), parallel to the belief of strong health benefits (mean score = 5.13) and safety perceptions (mean score = 5.05) (Table 4). High scores were also reported for economic sustainability (mean score = 5.05) and organoleptic traits (mean score = 5.17). Attitudes were positive across four of five profiles, with the only negative aspect being PC3, which was negatively correlated with beef consumption. The group was mostly from the South and Islands (47.66%) and with a predominantly female composition (53.13%).

The fourth cluster, called “Sustainable and selective” (24%), were very concerned about sustainability but picky about novel foods. Its composition consisted mostly of older people (more than 70% made up from individuals aged between 45 to 70 years old) with a moderate level of acceptance of sustainable innovations. Overall, it averaged 4.80, with 5.32 for environmental sustainability. It rated economic sustainability at 4.29 and had a notable score of 4.90 for risk perceptions. However, its focus on health benefits (4.28) and taste qualities (4.40) was lower compared to Clusters 2 and 3 (Table 4). This group was positively influenced by the factors PC3, PC4, and PC5, relating to consumer concerns about environmental sustainability, animal feed management, and a cautious attitude toward new foods.

On the other hand, the “Sustainable and adventurous cluster” (18%) consisted of consumers who balanced their sustainability concerns with a curiosity for trying new foods. They showed moderate acceptance (mean score = 4.55) but did not strongly favor any particular aspect. Participants in this group had moderate to low expectations regarding health benefits (4.13) and environmental sustainability (5.25), especially when compared to the other clusters (see Table 4). The characteristics of this cluster were positively defined by PC2 and PC3, highlighting a consumer profile that was environmentally conscious and curious (refer to Table 2). This group had an even distribution across age ranges and a notable representation from the North-West (32.50%) (Figure 1).



**Figure 1.** Socio-demographic characteristics and acceptability levels of the five consumer clusters ( $n = 900$ ). The alluvial plot displays the flow of respondents across five dimensions (left to right): consumer segment, gender, age group, geographical area, and acceptability level. The width of each ribbon is proportional to the number of respondents sharing that combination of characteristics. Acceptability levels are defined from the mean score across three items: High = mean score  $> 6$ ; Medium = mean score between 4 and 6; Low = mean score  $< 4$  (7-point Likert scale). Consumer segment labels: (1) Informed, not concerned (19.3%); (2) Informed, curious, and concerned (24.0%); (3) Informed meat-eaters (14.2%); (4) Sustainable and selective (24.0%); and (5) Sustainable and adventurous (18.0%). Gender categories: Men, Women, Non-binary. Age groups: 18–30, 31–44, 45–59, and 60–70 years. Geographical areas: Center, North-East, North-West, South, and Islands.

#### 4. Discussion

In this research, we provide a detailed overview of Italian consumer profiles concerning the consumption of beef obtained from animals fed HS in terms of acceptability, economic and environmental sustainability, and perceptions of their organoleptic traits, health benefits, risks, and animal welfare implications. With these results, we aim to offer insights into the dynamics shaping consumer attitudes toward novel foods.

#### *4.1. Consumption attitudes toward new foods*

Consumer demands in the food industry are changing, with a growing focus on products that are healthier, more sustainable, and ethically produced [68]. Because of this, companies are required to not only adapt their product offerings, but also to reconsider how such values shape consumers' preferences. One common approach to tackling this challenge is examining the attitudes that make up a consumer's profile [69]. This kind of analysis has been applied to various fields, including fashion, cutting-edge technologies, and food products [70]. The food industry has focused on key factors such as perceptions of sustainability, animal welfare, and human nutrition [71–74]. This study is the latest in a series of similar research projects in other sectors. Our aim is to examine the changing food landscape by looking closely at the attitudes of Italian consumers toward new food options.

The first consumer profile, labeled 'conscious and confident', displayed a strong sense of assurance regarding livestock nutrition and minimizing food waste. In general, Italian consumers are quite comfortable with the concept of cattle nutrition, probably because it is so ingrained in the country's agricultural and culinary traditions [75,76]. However, their level of awareness and confidence regarding food waste aligns with that found in other studies [77].

Two opposing views on trying stood out among the key attitudes: PC2 and PC4.

PC2 was characterized by curiosity and openness and a willingness to embrace and enjoy new culinary experiences (food neophilia). In contrast, PC4 was more cautious, hesitating to try unfamiliar foods due to concerns about ingredients or taste (food neophobia). These patterns are well-documented in research examining how consumers embrace food innovation while maintaining traditional culinary knowledge [78–81]. Moreover, PC3, known as 'environmentally concerned', represented consumers who are dedicated to reducing food waste and often prefer a low- or no-meat diet. This viewpoint aligns with the findings of Wakefield and Axon [77], who noted that this trend is gaining traction due to a commitment to sustainability and an increasing awareness of the environmental impact of livestock farming. Although their research was based in the UK, the authors believe that their insights are applicable worldwide, particularly in developed countries such as Italy, where tackling food waste poses a significant challenge. In contrast, PC4, labeled 'Animal nutrition concerned', focused on animal nutrition but seemed to lack a solid understanding of effective feeding practices for animals. Unlike PC3, this group did not demonstrate much awareness of issues such as reducing food waste or promoting sustainability. Few researchers have compared this mindset, as most researchers looking into animal nutrition tend to focus on companion animals [82] or delve into livestock welfare and environmental issues [83–86].

#### *4.2. Italian consumers' profiles*

Understanding consumer behavior is crucial for the future of the food industry, particularly in dynamic markets such as Italy. Consumers can be categorized based on factors such as neophobia, frequency of beef consumption, green identity, and awareness of food waste and animal feeding practices through cluster analysis. Companies can use this information to create targeted marketing campaigns, improve product positioning and increase consumer engagement. Moreover, policymakers can develop initiatives that promote public health and environmental sustainability [87]. We identified five distinct consumer groups. The 'Informed, curious, and concerned' and 'Informed meat-eaters' clusters in particular stood out for their embrace of innovative foods. 'Informed, curious, and

concerned' consumers were recognized for their curiosity and strong environmental awareness, a finding that aligns with other research [88–90]. In contrast, the 'Sustainable and selective' cluster exhibited more restrained acceptance and a more discerning approach, which is consistent with studies indicating that older consumers often resist dietary modifications [91]. One possible reason for this trend is that older adults may feel that their choices will not significantly affect the future [92]. Therefore, it is crucial to develop communication strategies that integrate sustainability into familiar food traditions [93]. Some interesting gender differences were also observed between the clusters, with the exception of 'Sustainable and adventurous'. Consumers who were informed but not worried were mostly male. Moreover, consumers who were informed, curious, and worried, as well as meat-eaters who were interested in the environment and sustainability. This disconnect could stem from a lack of education on how to implement sustainable practices [94]. Furthermore, research suggests that women are generally more engaged in sustainable consumption habits, while men often prioritize practical factors such as price and convenience [95–98].

### 4.3. Implications for the meat industry

The results have concrete and differentiated implications for industry stakeholders and policymakers aiming to promote the adoption of sustainable feed innovations in the Italian meat market.

#### 4.3.1. Segment-specific communication strategies

**Informed, curious, and concerned consumers (24%):** This segment reported the highest acceptability and environmental sustainability scores. Communication strategies targeting this group should emphasize verified sustainability claims and third-party ecolabeling (e.g., EU circular economy certification marks). Campaigns should make explicit the link between HS feed use and waste reduction targets; for instance, quantifying the tons of hazelnut by-product diverted from landfill per ton of beef produced. Digital channels and sustainability-oriented retail platforms (e.g., organic food stores, farm-to-table subscription boxes) are likely the most effective touchpoints for this audience.

**Sustainable and selective consumers (24%, predominantly 45–70 years):** This older, more cautious segment showed moderate acceptability and high food neophobia. For this group, sustainability messaging should be embedded within familiar cultural and culinary frameworks rather than presented as innovation. Communication should emphasize continuity with Italian pastoral tradition and quality of animal husbandry, rather than the novelty of the feeding practice. Point-of-sale materials and trusted institutional endorsements (e.g., agricultural consortia, PDO bodies) would be more effective than digital campaigns. The term 'upcycled feed' should be avoided in favor of 'natural by-product of Italian hazelnut production'.

**Informed meat-eaters (14.2%):** This segment showed strong health benefit perceptions and high acceptability. Marketing messages should foreground the improved fatty acid profile of HS-fed beef (documented reduction in atherogenic lipids, increase in oleic and vaccenic acids), potentially framing the product as functionally superior rather than merely sustainable. Collaboration with nutritionists and health communicators could amplify reach within this group.

**Informed, not concerned (19.3%):** This predominantly male group had self-reported knowledge but low sustainability concern. Economic arguments, demonstrating price competitiveness with conventional beef through supply chain efficiency, are the most promising lever. Transparent pricing

strategies and cost-benefit comparisons at point of sale may shift purchasing behavior in this segment more effectively than environmental appeals.

**Sustainable and adventurous (18%):** This younger segment (overrepresented among 18–30-year-olds) balanced openness to novelty with environmental awareness but shows moderate and undifferentiated perceptions across attributes. Innovation-oriented messaging, highlighting the cutting-edge nature of circular feed systems and the role of the consumer as an agent of food system change, is most likely to engage this cohort. Social media campaigns, influencers' partnerships in the food-sustainability space, and QR-code-accessible supply chain transparency tools are recommended.

#### 4.3.2. Policy recommendations

At the regulatory level, our findings support three concrete policy directions. First, the European Commission should consider extending the scope of circular economy quality labels to include livestock products derived from approved by-product feed ingredients, enabling clearer market differentiation and consumer-facing communication. Second, national public health and agricultural extension agencies should invest in consumer literacy programs explicitly addressing agri-food circularity, explaining, in accessible language, what by-product feeding involves, why it is safe, and how it benefits the food system. Our findings suggest that knowledge, not merely environmental concern, is a key predictor of acceptance, underscoring the value of science-based public communication. Third, fiscal instruments (e.g., reduced VAT rates on certified circular beef products, subsidized feed certification costs for small producers) could accelerate uptake among producers, lowering the cost barrier that limits consumer access.

#### 4.3.3. Label saturation caveat

A critical consideration for industry and policymakers is the risk of sustainability label proliferation. Italian consumers navigate a complex landscape of quality marks (PDO, PGI, organic, Rainforest Alliance, carbon footprint labels, etc.). Adding a 'circular feed' label without adequate simplification and communication risks confusion rather than clarity, particularly for segments already characterized by information overload. We therefore recommend that any new labeling scheme be developed within EU quality frameworks rather than as a standalone system, and that it be subject to consumer testing before market deployment.

### 4.4. Limitations

Limitations of this study can be attributed to practical and technical factors.

Performing the data collection exclusively among Italian consumers may limit the transferability of our findings to other cultural or geographical settings where consumers' attitudes toward meat production and its sustainability may differ. From a technical perspective, the use of PCA and subsequent cluster analysis, while valuable for identifying consumer profiles, represents a statistical simplification of highly complex behaviors and cannot fully capture the dynamic and context-dependent nature of food choices. Moreover, we relied on self-reported measures, especially in terms of sensorial perceptions. For more robust conclusions concerning consumers' acceptance toward these parameters, a dedicated sensory analysis would be advised for future studies.

## 5. Conclusions

In this study, we address a research gap by exploring how Italian consumers perceive meat from animals fed recycled by-products, particularly HS. The analysis classifies attitudes into demographic and attitudinal groups, revealing that acceptance of these innovative foods varies significantly. Factors such as age, gender, environmental beliefs, and food neophobia influence these attitudes. The results emphasize the need for tailored communication strategies: For older or more traditional consumers, it is crucial to integrate sustainability into culinary practices, while younger and more adventurous audiences may respond better to messages highlighting innovation and environmental benefits. Furthermore, a focus on cost-effectiveness may resonate with more practical or cautious consumers. Ultimately, understanding these consumer profiles is essential to promote the acceptance of sustainable food innovations to ensure the resilience of the meat industry and to support the transition to circular food systems.

### Use of AI tools declaration

The authors declare they have not used Artificial Intelligence (AI) tools in the creation of this article.

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### Author contributions

Elena Diaz Vicuna: Data curation, Investigation, Visualization, Writing - original draft; Valentina Maria Merlino: Supervision, Data curation, Conceptualization, Methodology, Software, Validation, Formal analysis, Writing - review & editing, Supervision. Stefano Massaglia: Writing - review & editing; Jatziri Mota-Gutierrez: Writing - review & editing, Methodology; Claudio Forte: Funding acquisition, Project administration, Resources, Writing - review & editing; Simone Blanc: Conceptualization, Methodology, Supervision, Validation, Writing - review & editing.

All authors have read and agree to the final version of the manuscript.

### Conflict of 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.

## Supplementary description

**S1.** Full item list of the employed constructs in the consumer survey.

**S2.** Questionnaire.

**Table S3.** BIC values for automatic cluster number selection using the Two-step cluster analysis (SPSS v.29). The asterisk (\*) indicates the number of clusters automatically selected by the algorithm based on the minimum BIC. The final solution adopted in the study ( $k = 5$ , highlighted in green) was selected based on BIC criterion combined with theoretical interpretability of the cluster profiles.

**S4.** Socio-demographic characteristics of the five identified clusters.

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