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Sustainable food waste management in supermarkets

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ABSTRACT

Food waste represents a significant burden to waste management systems, exacerbating food insecurity and contributing to global pollution, climate change, and biodiversity loss. Supermarkets bear partial responsibility for food waste, yet their sustainability efforts could also contribute to a solution. The present work aims at evaluating a sustainable approach to food waste management within supermarkets. To this end, we conducted a multi-criteria analysis, incorporating the perspectives of academic experts and 505 Italian consumers. Experts deemed residual value apps the most sustainable solution for food waste management in supermarkets, while also emphasising the influence of price and brand image. The consumer analysis corroborated these results. Specifically, consumers expressed a willingness to pay 36 % less for a bag of goods set to expire within 2–3 days, which increased to 60 % for goods set to expire within 24 h. The findings point to opportunities for mutual benefit between consumers and suppliers when food waste is effectively managed in store, thereby highlighting the need for further, product-focused research.

1. Introduction

The literature emphasizes the critical role played by the circular economy (CE) in food production and consumption for achieving SDG 12 (i.e., Sustainable Consumption and Production) (Zhang et al., 2022). In this context, the food industry is progressively embracing CE principles (Springle et al., 2022; Van Schoubroeck et al., 2022) and actively engaging stakeholders in sustainability endeavours (Azapagic et al., 2016; D'Adamo, 2022). However, an expanding global population and modern dietary habits still represent primary drivers of unsustainable food systems (Mokrane et al., 2023).

Food loss and waste (FLW) represents a significant impediment to establishing sustainable food systems. Food loss refers to the reduction in the mass or nutritional value (quality) of food intended for human consumption. Conversely, food waste, as defined by the FAO, refers to food fit for human consumption that has been discarded, regardless of whether it has exceeded its expiration date or spoiled (HLPE, 2014). In 2017, global FLW from supply chain and waste management systems contributed 9.3 Gt of CO_2 equivalent, accounting for approximately half of the annual greenhouse gas (GHG) emissions from the global food system (Zhu et al., 2023b). The FAO's Food Loss Index remained relatively stable between 2016 (13 %) and 2020 (13.3 %), though with significant geographic disparities: sub-Saharan Africa reported the highest losses, at 21.4 %; while Europe and North America reported the lowest losses, at 9.9 % (FAO, 2023). According to the UNEP's Food Waste Index Report, 931 million tonnes of food were generated in 2019, corresponding to 17 % of global food production: households accounted for 61 %, food service for 26 %, and retail for 13 % of this total (UNEP, 2021).

To effectively combat FLW, it is crucial to comprehend why food is discarded and to identify optimal mitigation strategies throughout the food supply chain (Magalhães et al., 2021). Although a sufficient volume food is produced for the global population, excessive wastage leaves one in every nine people malnourished (Matthew, 2020), emphasising the need for appropriate consumption practices (Masud et al., 2019). Several analyses have quantified the environmental impact of food waste (Shafiee-Jood and Cai, 2016), primarily associated with acidification and eutrophication (Scherhaufer et al., 2018), as well as water overconsumption (Reutter et al., 2017). The reduction of food waste requires actions to be taken along the supply chain, personal shifts in behaviour, promotion of the CE and advertising campaigns (Varese et al., 2023). In this context, some authors have identified strategies

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linked to: (i) the reduction and replacement of animal products, (ii) changes in food preferences, (iii) the reduction of food waste, (iv) the consumption of suboptimal foods and (v) food sharing (Funk et al., 2021).

The complexity of FLW management implies that it should be approached from multiple perspectives (Sharma et al., 2023). From a policy standpoint, taxes could be applied to tackle excessive food waste (Ananno et al., 2021), though any prevention policy must encompass the entire food supply chain, engaging all relevant stakeholders (Jeswani et al., 2021). On the consumer side, there is a growing tendency to reduce consumption of animal products (i.e., meat, milk derivatives) and minimise waste (Aschemann-Witzel, 2018), as well as an increasing preference for regional and seasonal products (Garnett, 2011). For retailers, various strategies can be adopted. The organic fraction of municipal solid waste holds promise as an energy resource for sustainable production (D'Adamo et al., 2023b), and analyses have shown the potential for harnessing waste from food industries to generate energy in expired food energy chains, as well as using supermarket discards for charitable initiatives (Bartocci et al., 2020). Monitoring supermarket discards – particularly with respect to meat and bread waste – is also essential for identifying other potential solutions, such as separating waste packaging from food content, utilising bread for animal feed (Brancoli et al., 2017) and implementing reverse logistics programmes for the collection of unsold products (Weber et al., 2023). Innovative business models, including in-house catering services (Shamaeva, 2020) and cooperation between retail and charity organizations (Bilska et al., 2018), present additional opportunities.

Digital technologies may play a vital role in supporting waste management in supermarkets by identifying products close to expiration and implementing dynamic pricing models to prevent their waste (Aschemann-Witzel, 2018; de Souza et al., 2021). The digital landscape has also empowered consumers with choices and tools. Notable among these is the Too Good to Go (TGTG) app, which allows producers to sell their leftovers to consumers as an alternative to throwing them away (Vo-Thanh et al., 2021).

The sustainability of supermarkets has emerged as a significant theme in the recent literature, addressing both consumer and retailer aspects. With regard to the former, research has proposed that consumers should reduce the frequency of their shopping trips by purchasing food for multiple meals at one time (Cortesi et al., 2023). On the side of retailers, a survey indicated that cost-saving messages and emotional appeals may increase the likelihood that food is sold before it expires. Nevertheless, specific handling practices are required for certain product categories, such as fresh foods (Aschemann-Witzel, 2018), considering also the higher environmental impact of meat, fish, rice and cheese compared to vegetables (Jeswani et al., 2021).

The present study aimed at identifying sustainable solutions for mitigating food waste in supermarkets, guided by two key research objectives (RO):

RO1. to evaluate the most sustainable strategic approaches for managing food waste in supermarkets, based on the views of academic experts; and.
RO2. to analyse consumer behaviour related to food waste, particularly with respect to their product choices for items nearing expiry and their willingness to pay (WTP) for these products.

To achieve these objectives, we employed a multi-criteria decision analysis (MCDA) to evaluate various alternatives for retailers to combat food waste, as informed by a survey administered to academic experts and an online survey administered to Italian consumers. The data were subjected to statistical analysis, thus providing useful insights based on different socioeconomic variables.

Following this introduction, Section 2 describes the methodology of the study, while Section 3 presents the results related to the two ROs. Finally, in Section 4, we propose ideas aimed at improving sustainability with respect to supermarket food waste.

2. Methods

The study employed two distinct methodologies: MCDA to evaluate academic perspectives (RO1) and an online survey to gather diverse consumer perspectives (RO2).

2.1. Multi-criteria decision analysis

MCDA is a robust methodology that is recognised in the literature for its ability to assess multiple and conflicting alternatives, particularly in the context of SDG 12 (Appolloni et al., 2021; Phillis et al., 2021). Its logic consists of a number of steps, as follows: (i) identification of a goal; (ii) identification of relevant alternatives to achieve this goal; (iii) identification of appropriate criteria to measure the performance of these alternatives; (iv) selection of experts; (v) expert verification of the proposed criteria and alternatives; (vi) assignment of weights to the criteria, irrespective of the considered alternative; (vii) assignment of values to each alternative for individual criteria; (viii) aggregation of weights; (ix) aggregation of values; and (x) identification of the most effective alternative, according to the sustainability value (see also Siskos et al., 2016). In the present study, we used an nxn matrix, with a row vector consisting of n columns (1,n) multiplied by a column vector consisting of n rows (n,1). The row vector described the weights of the criteria, while the column vector proposed the values attributed to the alternatives for each criterion. The sustainability value, representing a metric of sustainability performance, was the product of these vectors.

2.1.1. Description of alternatives

Efforts to reduce food waste in supermarkets involve the adoption of more sustainable alternatives to disposing of all waste (without differentiation) in landfills. Our approach considered that products at risk of becoming food waste could be handled within supermarkets through: (i) in-house catering, (ii) external catering for social and charitable purposes, (iii) sale at residual value through apps such as TGTG or (iv) waste collection and the management of municipal solid waste (MSW) for the production of energy and other products (e.g., digestate) (Table 1). Subsequently, we calculated the sustainability value of each of these alternatives .

2.1.2. Description of the criteria

The selection of criteria was informed by the need to consider both potential revenues and relative costs, in line with typical strategic considerations. To facilitate this, 10 criteria were chosen for an analytic hierarchy process (AHP) (Saaty, 2008). However, if >10 criteria had been deemed important, the local-global priority method could have been used (D'Adamo, 2022). Table 2 lists the criteria employed, along with their descriptions.

2.1.3. Selection of experts

The quality of AHP relies on the proper selection of experts to minimise subjectivity in the analysis (Tsyganok et al., 2012). In the present study, academics (D'Adamo, 2022) were chosen based on their

Table 1
List of food waste management alternatives.

Number	Alternative	Description
A1	Landfill	Total product waste
A2	In-house catering	Reuse of products through in-house catering
A3	Residual value app	Distribution of products through a residual value app (e.g., TGTG)
A4	Charity organizations	Distribution of products to charitable services (i.e., external catering)
A5	Energy	Allocation of products to public utilities for MSW collection (e.g., energy production)

Table 2
List of criteria employed in the analysis.

Criteria	Alternative	Description
C1	Costs of control	Costs for monitoring the condition of food products
C2	Advertising costs	Costs associated with publicizing the initiative and informing consumers
C3	Perception of product quality	Consumer perception of product quality
C4	Costs of product recovery and management	Costs of sorting and managing expiring products after checking
C5	Benefits from new market segments	Benefits of entering alternative markets that leverage the circular economy
C6	Social responsibility	Ethical and moral responsibility
C7	Brand image	Impact of the business initiative on consumer perception
C8	Resistance to change	Apprehension regarding the consequences of the initiative
C9	Coopetition with stakeholders	Strategic efforts to foster collaboration among normally competing companies to achieve common benefits
C10	Price	Selling price of expiring products when adopting the initiative

expertise in sustainability and the food industry, as determined by their publication records in the Scopus database and their research experience of at least 10 years. An email introducing the project aim and methodology was sent to an initial group of experts meeting this criteria, with the further notification that only the first 10 experts to positively respond would be invited to participate. Table S1 (in the supplementary file) presents the final set of 10 experts, alongside their profiles (i.e., roles, countries of reference, years of experience). Of note, 30 % were female.

In line with a previous work (D'Adamo, 2022), an initial screening was conducted with two of these experts, involving an online meeting (approximately 1 h in duration) to introduce them to the criteria and alternatives and invite any suggestions. Improvements were made to the criteria and alternatives on the basis of their feedback. To collect pairwise comparisons, we sent an Excel file containing a description of the methodology to the experts and scheduled online meetings to clarify the content of the inquiries and to provide further explanation, where necessary. The survey was conducted at two different time points: first to collect criteria weights and subsequently to collect criteria values. Data collection occurred between February and March 2023. The experts were also informed that their input would be considered valid only if the allocation of their weights was deemed suitable in accordance with the consistency ratio (CR), which was automatically calculated in the Excel file.

2.1.4. Aggregation of weights

We used a 10 × 10 matrix, correlating with the number of criteria considered. For the identification of weights, each expert assigned a score between 1 and 9 (Table S2), following the literature (Saaty, 2008). A normalized approach was necessary to complete the analysis (Subramoniam et al., 2013). Pairwise comparisons were performed for all criteria until the matrix was completed. The analysis was then considered valid when the CR, calculated as the ratio of the consistency index (CI) to the random inconsistency (RI), did not exceed 0.10 (Saaty, 2008) (Table S3). The CI was calculated as $(\lambda_{max}\text{-n})/(\text{n-1})$, with λ_{max} representing the inner product of the row vector containing the column sums and the Eigen vector matrix and n representing the number of criteria. RI was evaluated in line with Saaty (2008), based on the number of criteria used (Table S2).

The matrix was considered complete when 44 values were aggregated and no inconsistencies were found in the expert analyses. Tables S4–S13 report the anonymised weights provided by experts (with no association with the expert identification numbers reported in Table S1). For example, expert 1 (E1) identified criterion C10 (price) as the most significant, with a relative weight of 0.171; and criterion C4 (costs of product recovery and management) as the second most significant, with a relative weight of 0.148. Consequently, these two criteria collectively assumed a relative weight of 31.9 %. In contrast, expert 2 (E2) identified criterion C5 (benefits from new market segments) as the most significant, with an average value of 0.236. Thus, the analysis proceeded by combining the different relevance levels attributed by experts.

2.1.5. Aggregation of values

The second phase of the survey involved the same experts as the previous phase, but in this phase they were not asked to fill out an AHP but to assign a value to each alternative. For this purpose, we used weights ranging from 1 (*worst*) to 10 (*best*), to allow for greater variability relative to a 5-point scale (Appolloni et al., 2021). Fifty responses were provided by each expert, given the 5 alternatives for each of the 10 criteria considered. During this phase, there was no indicator of analytical consistency. Expert 1 (E1) assigned the highest value to alternative A5 (energy), but not to all criteria. Expert 5 (E5) assigned the highest value to alternative A3 (residual value app), but again, not to all criteria. Thus, expert choices seemed to be based as much on the relevance they assigned to the generic alternatives as the importance they attributed to each criterion. Tables S14–S23 report all scores.

2.2. Online survey

The online survey employed a behavioural approach based on the transdisciplinary taxonomy proposed by Sovacool et al. (2018), combining different techniques from the fields of economics and psychology. The literature highlights both the advantages and the potential risks associated with web-based surveys (Menegaki et al., 2016). In the present study, we designed and administered a structured questionnaire to a significant sample of Italian consumers (D'Adamo et al., 2023a), using Google Forms. The main objective of the questionnaire was to understand respondents' attitudes toward sustainability concerning food waste, with a specific emphasis on supermarkets. To mitigate potential biases associated with online surveys and to ensure the representativeness of the sample, we utilised different social media platforms and email communication to reach an optimal number of participants.

The questionnaire comprised 17 items, which had been pre-validated by experts in a pilot study. Items were organized into four sections. The first section focused on socio-demographic data, while the second related to consumer behaviour concerning food waste and the purchase of food products nearing expiry. The third section sought consumer views on food waste management in supermarkets and the factors that would encourage them to purchase food products nearing expiry. The findings from this section were compared with the results of the AHP. Finally, the fourth section pertained to consumers' WTP and their economic choices concerning products nearing expiry in supermarkets.

The complete questionnaire is provided in the Supplementary File. Factors influencing companies' decisions to reduce food waste were investigated using a Likert scale, and the economic value of products was determined using a payment card. A total of 505 valid responses were collected during the data collection period (i.e., March 2023). The study purpose was described at the outset of the questionnaire, and respondent anonymity was guaranteed. The relationships among variables were assessed using descriptive statistics and various analytical methods (e.g., ANOVA, Kruskal-Wallis test).

3. Results

This section is divided into two parts, corresponding to RO1 and RO2. The first section, dedicated to RO1, describes the evaluation of weights and values associated with criteria and alternatives to determine the most suitable strategy for ensuring sustainable food waste management in supermarkets. RO2 is discussed in the second section,

which focuses on the findings from the online customer survey.

3.1. Sustainable food waste management in supermarkets

3.1.1. Evaluation of criteria weights

In the initial phase of the analysis, our aim was to aggregate the weights obtained from various experts, as the CR confirmed the consistency of their evaluations. Table S24 reports the weights associated with the criteria. Notably, 7 out of the 10 experts identified C10 (i.e., price) as the most critical criterion. In contrast, experts E2 and E4 assigned the most importance to entry into new markets (C5), and expert E3 gave weight to brand image (C7).

Fig. 1 illustrates the row vector in which each expert's input is given equal importance. The average weights indicate that, overall, the criterion that received the highest score was C10, with an average weight of 0.169. This finding underscores the importance of considering the price of expiring goods from a producer/entrepreneur perspective, as this may directly affect the probability and viability of the considered initiatives.

Following C10 were criteria C7 and C5, with average weights of 0.142 and 0.133, respectively. Brand image reflects how customers perceive a product or business, based on their interactions and experiences with the brand. Benefits from new market segments derive from strategic choices made by entrepreneurs, typically to maximize added value by appealing to customers in multiple segments. Collectively, these three criteria accounted for approximately 45 % of the total weight.

On the other hand, experts rated criterion C2 (advertising costs) as the least relevant to the 'typical producer', giving it an average score of 0.045.

3.1.2. Evaluation of alternatives according to the criteria

The second step of the analysis involved aggregating the values assigned to each alternative based on the analysed criteria. The distribution of values revealed that value 7 was the most frequently attributed, at 17.8 %, followed by 6, at 16.4 %. Values in the range of 6–10 accounted for 80.4 % of the responses (Fig. S1). The lowest value, 1, was selected for alternative A1 by 56 % of respondents, while the highest, 10, was selected for alternative A3 by 41 % of respondents. Additionally, 28 % of respondents attributed the value of 9 to alternative A5, while the values of 7 and 6 were selected by 34 % and 27 % respondents for alternatives A2 and A4, respectively see (Table S25).

The average value was calculated, with equal weight given to each expert (Table 3). Initially, we identified the criterion with the highest value for each alternative. For instance, C8 (resistance to change) was considered the most relevant criterion for alternative A1, while criterion C5 (benefits from new market segments) took precedence for alternatives A2 and A3. For alternative A5, C9 (coopetition with stakeholders) was the primary criterion. Criteria C6 (social responsibility) and C7 (brand image) were considered most relevant for alternative A4. Finally, criterion C8 (resistance to change) was most relevant for alternative A1.

In the case of in-house catering (A2), experts suggested that supermarkets should consider the benefits of reusing food waste generated by their primary activities, which could result in economic advantages. They applied a similar reasoning to residual value apps (A3), such as TGTG, which they linked to economic opportunities. Lastly, they saw the donation of products to charitable services (A4) as an alternative that could potentially improve brand image, from a corporate social responsibility perspective. Finally, coopetition with other stakeholders was considered essential for recovering energy (A5) from food waste.

Further analysis involved identifying the maximum and minimum values for each criterion and their associated alternatives. The results indicated that residual value apps (A3) received the highest values for five criteria (C2, C5, C6, C7, C10), and the energy (A5) alternative received the highest values for four criteria (C1, C3, C4, C9). Two maximum values were also recorded for the alternative associated with charity organizations (A4) (C6, tied with A3; C8). In contrast, landfill disposal (A1) consistently received the lowest score across all criteria.

3.1.3. Sustainability value analysis for each alternative

The final step in the MCDA was to aggregate the weights (Fig. 1) and values (Table 3) to identify the most sustainable production alternative for reducing food waste in supermarkets. Table 4 presents the ranking of these alternatives in addition to a baseline scenario characterised by average weights (with all criteria given equal relevance). Notably, the ranking varied depending on the weights assigned to the criteria, emphasising the relevance of the AHP approach (although the first two positions and the final position did not change).

The results confirmed the results of the value analysis, with alternatives A3 and A5 once again excelling. In particular, residual value apps (A3) stood out with a score of 7.93 out of 10. While this alternative performed exceptionally well on five criteria, its performance on other criteria was relatively lower. The AHP analysis revealed that the gap in performance between A3 and A5 (energy) was significant (0.62), with 0.57 of this difference attributed to performance on the first three criteria (C10, C7, C5) (Fig. 2).

This result indicated that criteria C10, C7 and C5 had a substantial influence on the final result for alternatives A3 (55 %) and A5 (49%). The influence of these criteria on alternatives A2 (52%) and A4 (48%) was also high. Furthermore, the top criteria for alternatives A3 and A5 were also the most consistent across the board. For alternative A4, criterion C7 was the most consistent value, while for alternative A2, criterion C10 consistently prevailed, ahead of criterion C5.

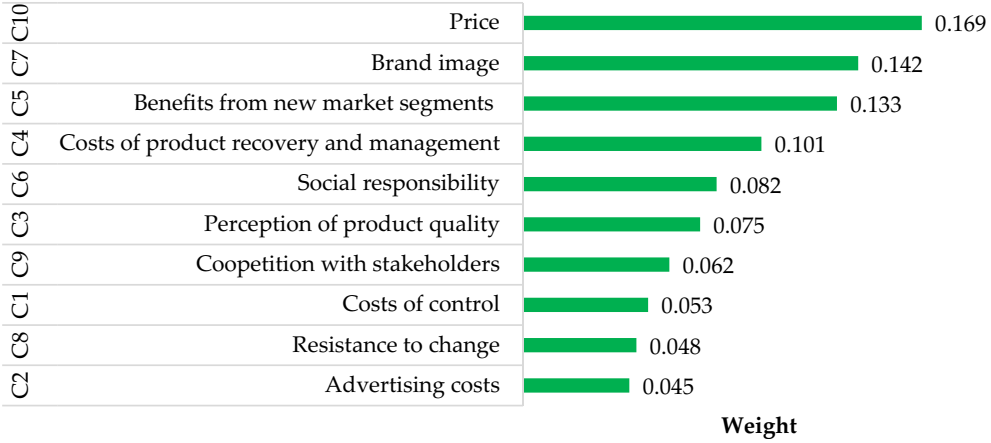

Fig. 1. Row vector – Average values of experts' weights.

Table 3
Aggregation of the expert values – Column vector.

	A1	A2	A3	A4	A5
C1	4.0	7.1	7.3	7.0	7.8
C2	1.8	7.6	9.2	7.5	7.4
C3	3.1	7.2	7.2	7.2	7.8
C4	3.1	6.8	7.5	7.0	7.9
C5	1.2	8.6	10.0	6.9	8.5
C6	1.1	7.5	9.0	9.0	8.5
C7	1.2	7.7	9.4	9.0	8.2
C8	4.8	6.8	5.8	7.7	7.2
C9	2.3	7.7	7.9	8.4	9.0
C10	1.5	8.5	9.8	6.5	7.6

Max value Min value

Table 4
Sustainability value.

Alternative	Sustainability value (different weights)	Ranking	Sustainability value (equal weights)	Ranking
A3	7.93	1	8.31	1
A5	7.31	2	7.99	2
A2	7.04	3	7.55	4
A4	6.88	4	7.62	3
A1	1.88	5	2.41	5

Max sustainable value Min sustainable value

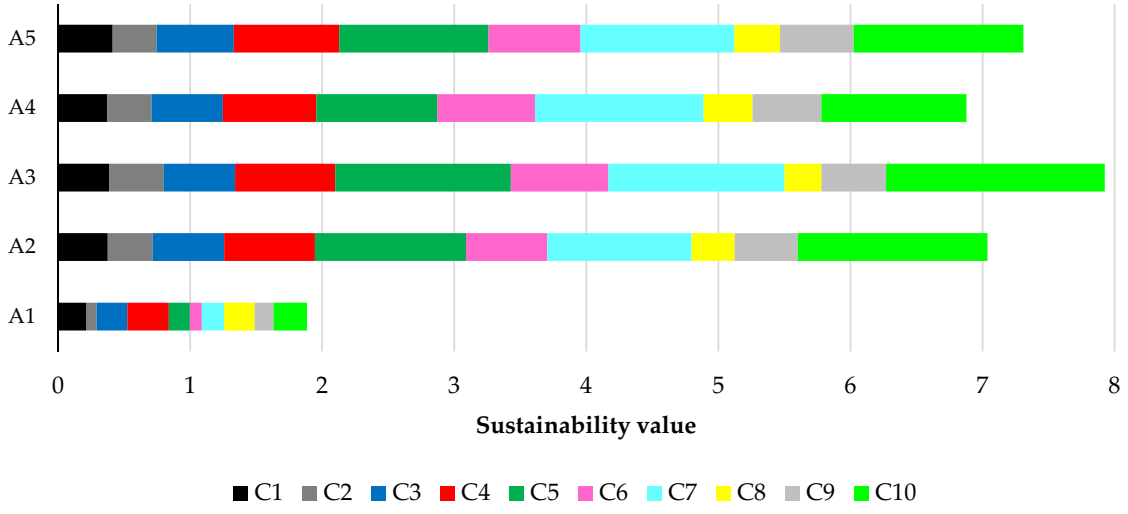

Fig. 2. Decomposition analysis – sustainability value.

Another significant finding was the emergence of four potential sustainable alternatives to landfill disposal, which received a rating of only 1.88. In more detail, this low value was associated with the three most relevant criteria, as well as criterion C6. The difference between alternative A1 (landfill disposal) and the second-ranked alternative A2 was more significant (0.62) than the difference between A2 and the alternative ranked fourth (A4).

These results suggest that residual value apps (e.g., TGTG) may help businesses reduce food waste, increase visibility and retain customers with sustainability awareness. This aligns with the existing literature (Vo-Thanh et al., 2021), and particularly previous research citing the potential of these apps as new business models (de Visser-Amundson, 2022; Zaman et al., 2021). In more detail, these apps may help companies reduce costs associated with the disposal of unsold food and improve their reputation in terms of corporate social responsibility (Aschemann-Witzel et al., 2022; Devin and Richards, 2018), by enabling them to derive value from products before they physically deteriorate. On these apps, consumers purchase products as they would typically, but at a lower selling price (Aschemann-Witzel, 2018; de Souza et al., 2021). Thus, the disposal decision is passed to the consumer. The second-place position of the energy alternative may be influenced by rising electricity and gas prices, particularly within countries that are dependent on imported energy (Bartocci et al., 2020; D'Adamo et al., 2023b).

However, achieving the sustainability goals of these alternatives in comparison to landfill disposal will require the involvement of

stakeholders across the food industry supply chain (Jeswani et al., 2021; Varese et al., 2023), with the aim of satisfying SDG 12 (Zhang et al., 2022). With this in mind, stakeholder engagement may be a key determinant of sustainability goals (Calabrese et al., 2021; D'Adamo, 2022).

3.2. Sustainable food waste consumption in supermarkets

3.2.1. Sample identity

Our consumer sample comprised 505 consumers who responded to all questionnaire items. This sample size is in alignment with previous research (Coderoni and Perito, 2020). Respondents' ages ranged from 17 to 87 years, with an average age of 38 years. While age was recorded as a continuous variable, we also categorised it into the following classes to explore its impact on our research questions: 18–24 years (27 %), 25–34 years (31 %), 35–44 years (7 %), 45–54 years (11 %), 55–64 years (19 %) and > 65 years (5 %) (Fig. S2). Female respondents accounted for 63.8 % of the sample, reflecting the common trend in Italy, where women make most of the food purchasing decisions. The study was conducted in Lazio, with 82.8 % of the respondents reporting their origin in central Italy; the rest were evenly distributed between northern and southern Italy (Fig. S3). Regarding educational qualifications, 9.5 % held a postgraduate degree, while 27.5 % had a master's degree and 28.3 % had a bachelor's degree. Most respondents had a diploma (31.3 %). The final sociodemographic item pertained to domestic partnership, revealing that 62 % lived with family members, 15 % lived with a partner, 10.3 % lived with roommates and 12.7 % lived alone (Fig. S4).

Online questionnaires are often affected by a sample bias characterised by an overrepresentation of younger and more educated people relative to the general population (Coderoni and Perito, 2020). To mitigate this risk, we posted the questionnaire on online platforms with a broad target audience (Perito et al., 2020). As a result, our sample did not appear to suffer from this bias. While a concentration of respondents in the central region of Italy was evident, this is consistent with the literature (Demartini et al., 2019).

3.2.2. Consumer behaviour related to food waste and the purchase of food products close to expiry

The data analysis presented in this section focuses on consumer views on food waste management in supermarkets. The relevant section of the questionnaire included three items, of which two were rated on a Likert Scale ranging from 1 to 5 (Fig. S5). While the mean values of Likert scales lack physical meaning, we report them here for the sake of comparison.

Responses to the question regarding disposal practices for expired food yielded a mean value of 2.53, with 48.9 % of respondents indicating 'rarely' and 35.4 % indicating 'sometimes'. These results suggest a moderately sustainable practice, which we should aim to further improve. With regard to the purchase of food products nearing expiry, 46.4 % reported doing so 'rarely' and 33 % 'sometimes', with a mean value of 2.38. These results did not indicate a sustainable food waste practice, but reflected consumer preferences.

A non-parametric Mann-Whitney *U* test revealed that the difference in behaviour between a randomly selected proportion of each group of respondents (i.e., those who threw away food nearing expiry and those who purchased food nearing expiry) was statistically significant ($p < 0.01$). A subsequent regression analysis to determine the potential relationship between each of these questions and age did not yield any statistically significant findings.

Further statistical analysis was conducted to explore the impact of socioeconomic variables on these questions (Figs. 3–4). Regarding gender, only male and female respondents were considered, due to the available number of responses. Men tended to dispose of slightly less food nearing expiry relative to women, but the difference was not statistically significant (2.5 vs. 2.6). In turn, women tended to buy products slightly closer to expiration; however, this difference also failed to reach statistical significance (2.3 vs. 2.5). Individuals aged 55 years and older tended to dispose of less food nearing expiry compared to those aged 25–54 years, who tended to engage in this behaviour occasionally. Of note, very young (under 25 years) respondents tended to demonstrate more sustainable behaviour compared to older respondents. Regarding the purchase of products nearing expiry, this practice was relatively rare across the sample, although younger respondents (18–34 years old) tended to engage in it more frequently, probably due to their lower incomes. As for the disposal of food nearing expiry, this behaviour increased in line with the number of people living together, particularly among those living with family members (the largest subgroup). This suggests that purchasing habits may be influenced by different consumption patterns within a household. In contrast, the purchase of products nearing expiry was more common among those living with roommates, likely due to lower income levels.

A Mann-Whitney U test revealed that the difference in responses between men and women regarding the disposal of food nearing expiry was not statistically significant ($p = 0.184$). However, for the question related to buying food nearing expiry, men were more likely to respond positively ($p = 0.045$). Fig. S6 presents the distribution of responses based on gender.

Interestingly, younger respondents were more likely to both dispose of food nearing expiry ($r_s = -0.1126$, $p < 0.05$) and purchase food

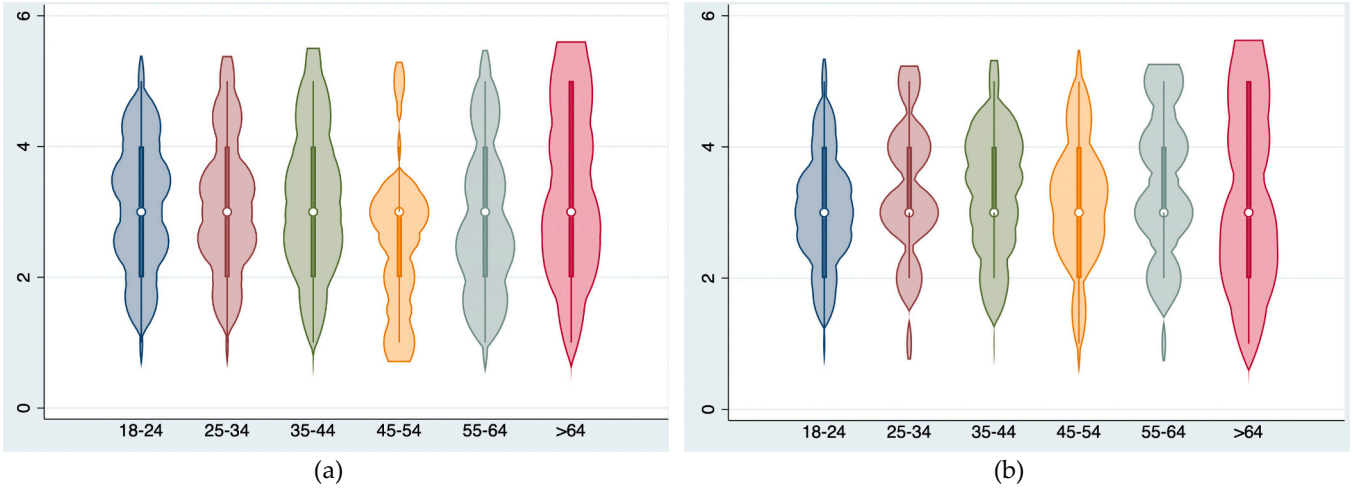

Fig. 3. Responses according to age class for the questions: (a)"Throwing away food close to its expiration date" and (b) "Buying food close to the expiration date" (1: never, 2: rarely, 3: sometimes, 4: often, 5: very often).

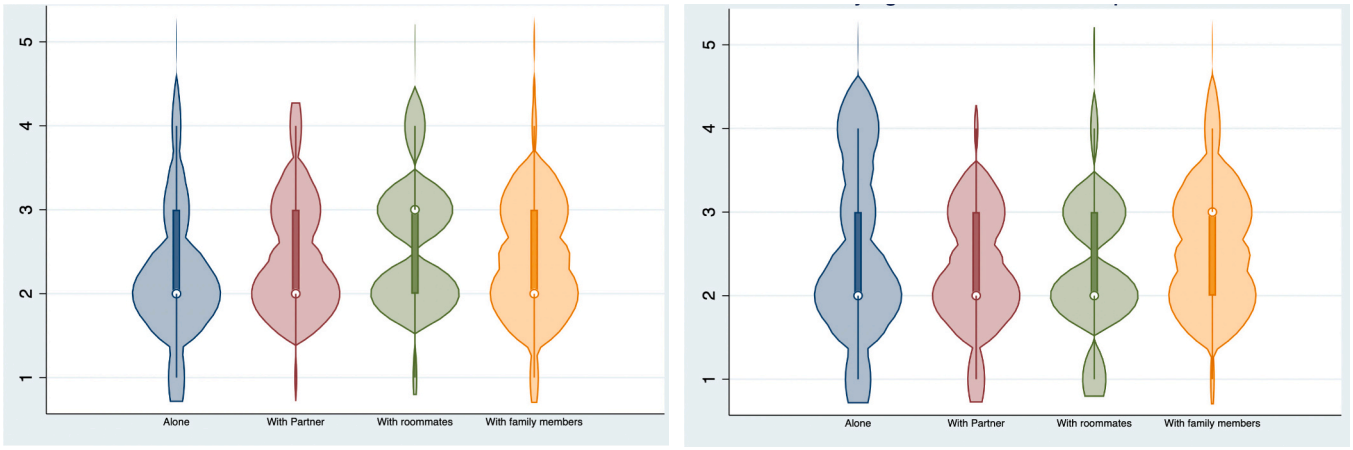

Fig. 4. Responses according to household composition for the questions: (a)"Throwing away food close to its expiration date" and (b) "Buying food close to the expiration date" (1: never, 2: rarely, 3: sometimes, 4: often, 5: very often).

nearing expiry ($r_s = -0.1163$, $p < 0.01$). While these findings may appear contradictory, a non-statistical correlation between responses to these questions ($r_s = 0.1163$, $p = 0.122$) indicated that respondents who exhibited positive behaviour in one area did not necessary do so in the other. Fig. 3 provides a visual representation of respondents' answers to these questions, according to Eurostat age classifications.

Based on the Kruskal-Wallis test ($\chi^2 = 13.11$, $p < 0.01$), responses for "Throwing away food close to its expiration date" had a mean rank score of 202.18 for individuals living alone, 242.66 for those living with a partner, 248 for those living with roommates and 266.73 for those living with family members. The Post-Hoc Dunn's test using a Bonferroni corrected alpha of 0.0083 indicated that the mean rank of those living with family members versus those living alone was statistically different. This means that families may be more likely to throw away food nearing expiry compared to households comprised of individual residents (see also Fig. 4a). However, there were no significant differences in responses to "Buying food close to the expiration date" ($\chi^2 = 5.83$, $p = 0.120$) with respect to different household compositions, as this item received a mean rank score of 267.62 for individuals living alone, 246.09 for those living with a partner, 290.26 for those living roommates and 245.5 for those living with family members (see also Fig. 4b).

The consumer tendency to avoid buying products close to expiry may be explained by the findings of a survey conducted by Censis (Center for Social Investment Studies), reporting that 60.7 % of the Italian population shops weekly. This likely explains the preference for products with longer viability.

In addition, the second part of the questionnaire asked about the categories of food that consumers most frequently threw away (Fig. 5).

The results indicated that 43 % of respondents tended to throw away milk and milk derivatives, while 40 % and 37 % tended to dispose of fruits and vegetables, respectively. These findings align with those reported in the literature (Aschemann-Witzel, 2018), and they may be explained by the speed with which the foods in question decompose (i.e., expire). As shown in Fig. 5, fish, which was the least frequently disposed, is typically intended for immediate consumption or, at most, consumption within 24 h. If this is not possible, it may be stored in the freezer for several weeks. The same situation applies to meat. Canned food, representing the second least disposed of food, likely owes its position to its extended viability.

In contrast, milk, milk derivatives, fruits and vegetables are usually stored in the refrigerator or pantry. Such products are prone to waste due to their tendency to be purchased in bulk. Consumers may therefore struggle to fully consume the products prior to their expiry. In addition, fruits and vegetables are particularly delicate and sensitive to changes in temperature and humidity.

3.2.3. *Consumer perspectives on food waste management in supermarkets and the factors that would encourage them to purchase food products nearing expiry*

The third part of the questionnaire was comprised of three items focused on consumer opinions about food waste in supermarkets, of which two reiterated the key questions highlighted in the AHP to identify convergences and divergences. The first question concerned consumer preferences for five alternatives (Table 1). A positive result for sustainability emerged, as almost none of the respondents (0.4 %)

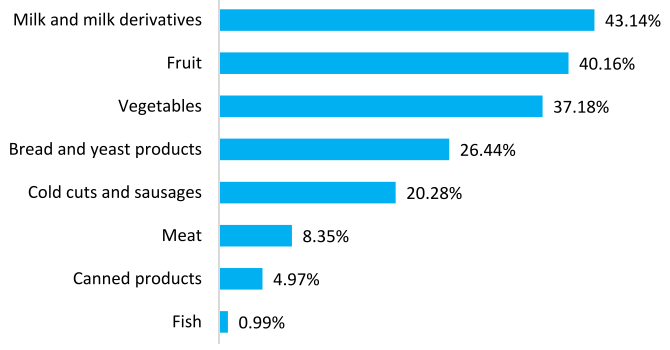

Fig. 5. Consumer responses to the question: "What types of foods do you happen to throw out most often?"

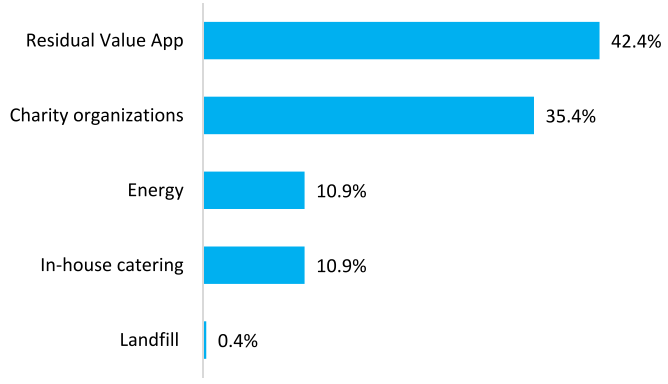

Fig. 6. Consumer responses to the question: "What do you think would be the best alternative for a supermarket to use products close to expiry?"

preferred the complete disposal of food products nearing expiry. Instead, almost all expressed a preference for sustainable alternatives (Fig. 6).

Notably, 42.4 % of respondents favoured the use of apps to sell these goods at discounted prices (i.e., residual value apps). Such apps would not only benefit consumers, but they would also represent an opportunity for entrepreneurs. This result aligns with the findings reported in Section 3.1.3. However, some differences emerged with regard to the other choices. Of note, the AHP methodology involved pairwise comparisons, and experts may have been more influenced by the potential impact of energy costs – not only on food waste, but also on the country as a whole. Consumers, on the other hand, tended to favour the sale of products to charitable services (35.4 %), perhaps because they considered this option ethically sound. A possible reason why this alternative did not achieve the first rank is that consumers perceived it as less convenient or profitable for entrepreneurs. Notably, the option of supermarkets using food nearing expiry for in-house catering received a lower rating from a sustainable perspective (10.9 %). Finally, the low value assigned to the energy aspect (10.9 %) could be attributed to less consumer awareness on the subject (D'Adamo et al., 2023b; Mazzanti et al., 2021).

Relative to experts, consumers opted more for sustainable solutions (i.e., source prevention, food recovery, repurposing) over anaerobic digestion. This result can be explained by two factors. First, the academic literature emphasizes energy considerations, particularly with respect to countries characterised by energy dependence (Cudjoe et al., 2023; Zhu et al., 2023a). Second, it is possible that consumers were guided by a pragmatic (versus ideological) approach, focused on minimising landfill usage. In fact, not all assumptions were verified: i) the distribution of surplus food to socially vulnerable people depends on structures in place to distribute products and the location of recipients in accessible locations; and ii) certain products (especially fruits and vegetables) cannot withstand long-distance travel due to the need for refrigeration. At this stage of the analysis, a cluster analysis aimed at shedding light on differences in preferences for sustainable alternatives to reduce food waste in supermarkets (Tables S25–27).

For the second question, respondents rated the 10 criteria using a Likert scale ranging from 1 to 5 (Fig. 7). A comparison with the results presented in Section 3.1.1 revealed that criteria C10 (price) and C7 (brand image) excelled in both analyses. Notably, the AHP methodology allowed for a more pronounced assessment of the criteria, resulting in a significant difference (0.124) between the criteria ranked first and last (0.169 vs. 0.045) (Fig. 1). In contrast, in the Likert scale analysis, this difference was only 0.023 (Fig. S7). This highlights the advantages of the AHP methodology. In the Likert scale analysis, where pairwise comparisons were not relevant, most criteria were rated as moderately relevant (approximating a value of 3). However, criteria C7 and C3 (perception of product quality) received ratings approaching 3.5. The only criterion that received a higher rating was C10, which achieved a value of 3.7 (placing it in the group with a value of 4). However, it is important to note that, while the mean value in a Likert scale lacks physical meaning, it may nonetheless serve as a valuable tool for comparing and classifying preferences.

The top-ranking criterion clearly emphasizes the importance of product selling price, which was also well-perceived by consumers. Thus, regardless of whether a product is nearing expiration, it must be affordable. The second-ranking criterion (brand image) holds significance because it encompasses brand positioning, personality and reputation. A company that successfully cultivates a positive image among its target market gains enduring credibility. Finally, the third-ranking criterion of C3 may have been motivated by growing awareness of the importance of a healthy, balanced diet. Consumers are increasingly prioritising fresh and seasonal foods, reducing their consumption of processed foods and paying closer attention to the origin of ingredients. Additionally, research has shown that a healthy diet may contribute to preventing many diseases (Scapaticci et al., 2021).

Upon closer inspection, the rankings reveal that, in addition to C3, C1 (costs of control) also received more attention from consumers than experts. In contrast, criterion C5 (benefits from new market segments) lost ground. These findings suggest that consumers might perceive this potential market segment as more associated with economic risks than potential benefits. Moreover, brand did not emerge as a preferable factor. This finding aligns with the previous results and indicates that, while retailers must consider brand image in their market positioning, consumers show little interest in this aspect when purchasing products nearing expiry.

Finally, the third item in this section asked consumers to select the factors that would encourage them to purchase products nearing expiry (Fig. 8). Discounted price (i.e., below market price) emerged as most significant, confirming the previous findings. In fact, four out of five consumers (79.5 %) selected this option. Other relevant factors, while less frequently reported, included actual product need (34.9 %), opportunity (31.2 %) and personal and social ethics (29.6 %). Factors such as quality control, time constraints in meal selection and brand preference did not appear to be significant. Respondents tended to identify a single overriding factor, despite the multiplicity of factors presented. Cluster analyses were also conducted at this stage of the work (Tables S28–30).

3.2.4. *Consumer WTP and economic choices regarding products nearing expiry in supermarkets*

The final part of the questionnaire, comprised of six items, explored the economic aspects of consumer preferences concerning products

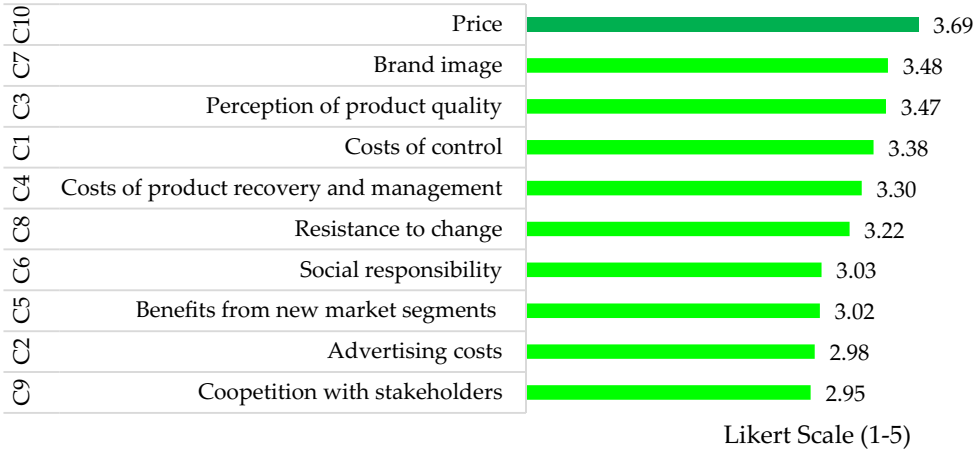

Fig. 7. Relevance of criteria for reducing food waste in supermarkets.

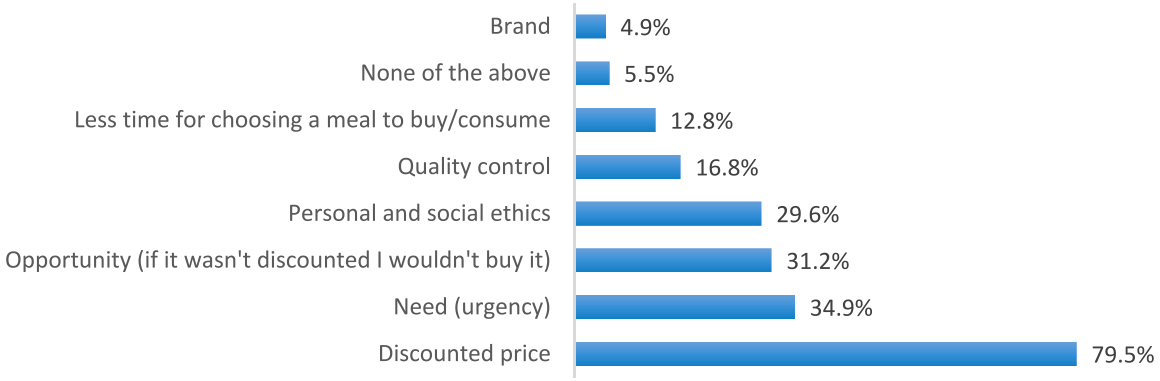

Fig. 8. Enabling factors for buying products nearing expiry.

nearing expiry. To gain deeper insight into consumer habits and intentions, two questions asked respondents to specify the appropriate discount percentage, in their opinion, for two products nearing expiry with different prices: one with a maximum price of 5 € and another with a maximum price of 10 €. The average response to the first question indicated a discount of 33.06 %, while for the product with the higher price, the average suggested discount was 35.84 % (Fig. S8). This reflected a small but statistically significant difference of 2.78 % ($t(504) = 5.876$, $p < 0.001$).

Respondent age was positively correlated with the first question ($r_s = 0.0979$, $p < 0.05$), but not the second ($r_s = 0.0792$, $p = 0.076$). Fig. 9 shows a clustered presentation of the different age groups, illustrating that older respondents tended to request higher discounts for the first product. Also for first product, women reported an average discount of 33.53 %, while men proposed an average discount of 32.12 %; this did not represent a significant difference ($t = 2.079$, $p = 0.150$). For respondents in a domestic partnership, the average values given for the first and second products were equal, showing no significant differences ($F = 0.3605$, $p = 0.7815$ and $F = 0.7176$, $p = 0.5418$, respectively). However, the average discount values varied across the different age groups, as follows

- Food price 5 €: 30 % (18–24 years); 32 % (25–34 years); 38 % (35–44 years); 37 % (45–54 years); 34 % (55–64 years); 34 % (>64 years).
- Food price 10 €: 33 % (18–24 years); 35 % (25–34 years); 39 % (35–44 years); 41 % (45–54 years); 37 % (55–64 years); 34 % (>64 years).

Similar variations were observed for gender (Fig. 10) and domestic partnership (Fig. 11):

- Food price 5 €: 34 % (female); 32 % (male).
- Food price 10 €: 37 % (female); 34 % (male).
- Food price 5 €: 34 % (living alone); 33 % (living with partner); 31 % (living with roommates); 33 % (living with family members).
- Food price 10 €: 38 % (living alone); 37 % (living with partner); 34 % (living with roommates); 36 % (living with family members).

The survey also assessed the consistency of the proposed percentage data against how consumers reported they would act if they were aware of the specific products inside a bag containing foods nearing expiry. Therefore, a 'typical bag' containing various products (e.g., ham, low-fat yogurt, two hamburgers, a package of salad) was outlined. The market value of this bag was calculated at approximately 10–12 €, based on a survey of supermarket data.

Three items were formulated to investigate respondents' WTP for this bag in three distinct scenarios: i) the products were not expiring; ii) the products were expiring in 2–3 days; and iii) the products were expiring in 24 h. The results showed that WTP for the first scenario was 10.8 € (Fig. 12). However, this value decreased to 6.9 € and 4.3 € for the second and third scenarios, respectively. Thus, given a spending level of 10 €, the expected discount for products nearing expiry was confirmed as 36 %, confirming the robustness of the previous results. However, when products were imminently expiring (i.e., within 24 h), the expected discount increased significantly, to 60 %.

An ANOVA revealed significant differences in the mean WTP values among all three groups, as shown in Fig. 12 ($F(2, 1512) = 338.1$, $p < 0.001$). Following this analysis, we conducted a cluster analysis (Table 5), with the results confirming the patterns observed previously

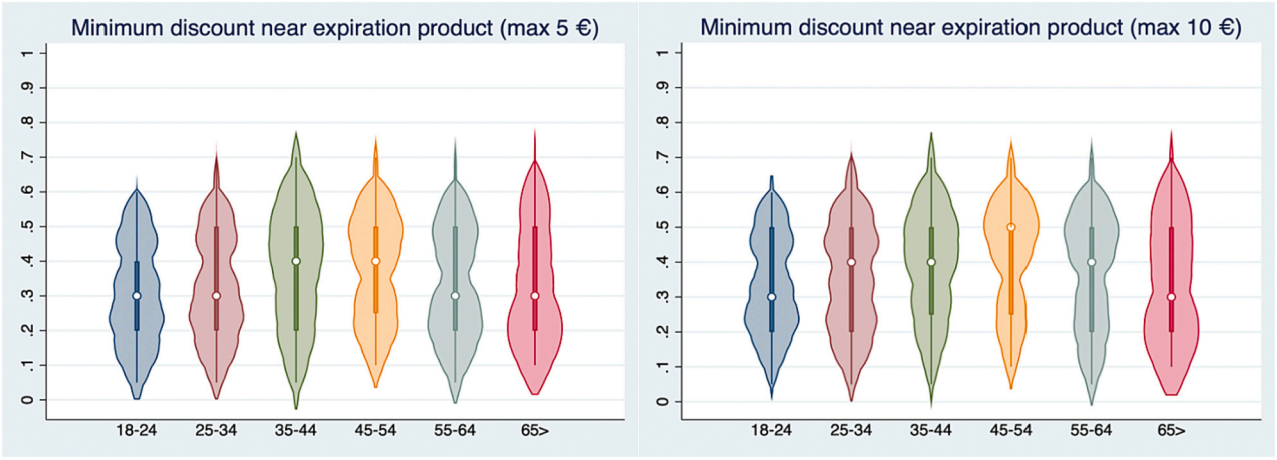

Fig. 9. Minimum percentage discount preferences based on age group.

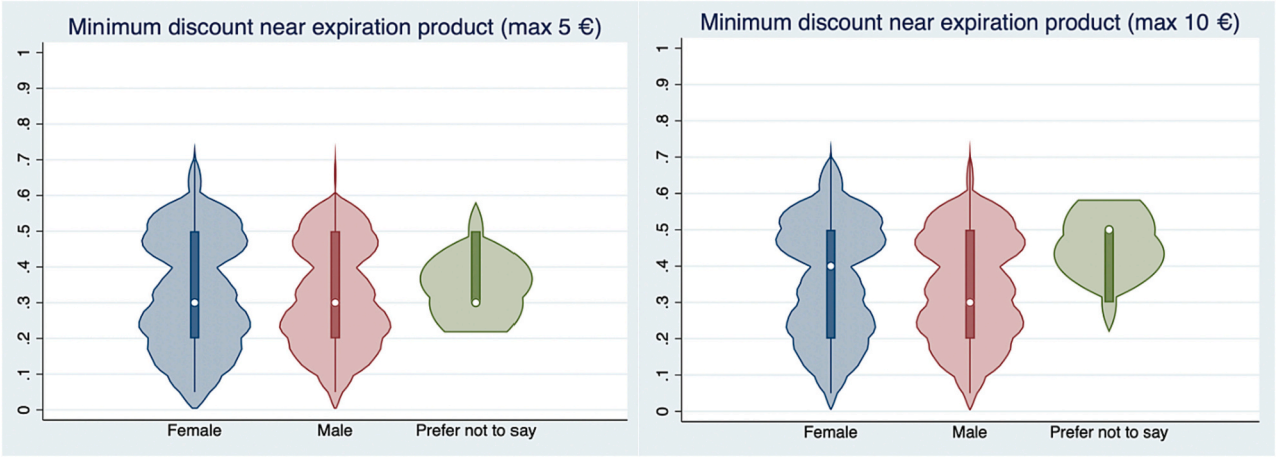

Fig. 10. Minimum percentage discount preferences based on gender.

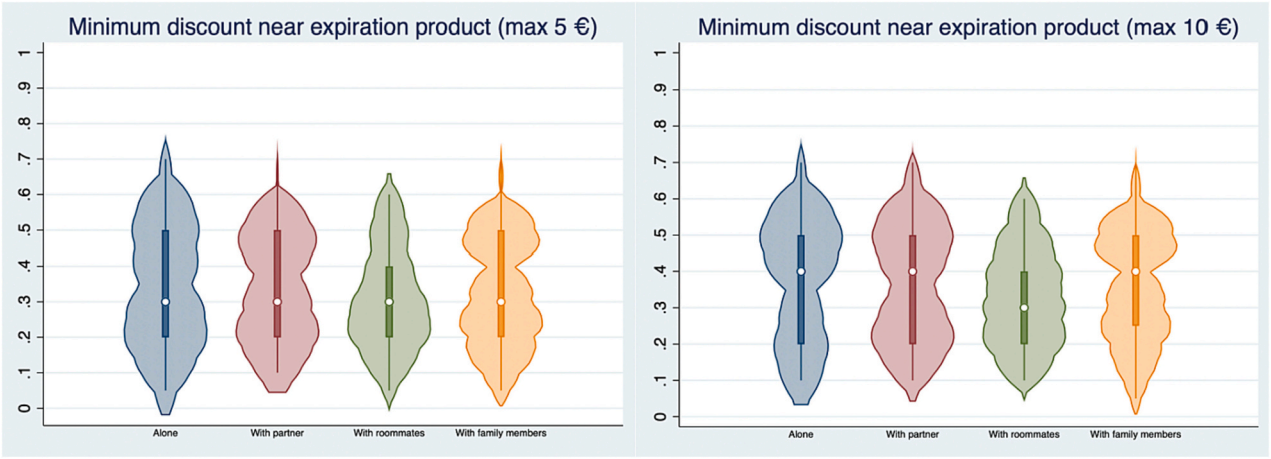

Fig. 11. Minimum percentage discount preferences based on domestic partnership.

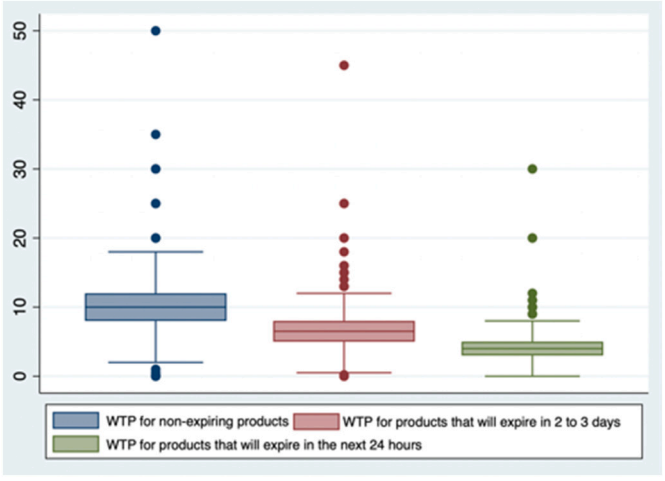

Fig. 12. WTP for products with different expiration dates. The following average values were obtained: a) WTP for non-expiring products of 10.8 €; b) WTP for products expiring in 2–3 days of 6.9 €; and c) WTP for products that expiring in 24 h of 4.3 €.

for all age groups (Figs. S9–S11). Notably, a bell curve was observed, indicating that the highest discounts were reported by respondents in the 45–54 year age range, at the values of 42 % and 68 % for products expiring in 2–3 days and 24 h, respectively. Conversely, the youngest age group (18–24 years) reported the lowest discount values, at 30 % and 55 %, respectively. Similar trends were observed in the other analyses, with women proposing slightly higher discounts relative to men, and those living with roommates proposing lower discounts relative to those living with a partner.

The final item asked respondents to choose among the three previously proposed bags containing foods with varying expiration dates (Fig. 13), using reference prices based on supermarket surveys:

- Bag 1: 2.99 € for products expiring within 24 h;
- Bag 2: 4.99 € for products expiring within 2/3 days;
- Bag 3: 9.99 € for products with no defined expiration date.

Notably, the observed WTP tended to be higher than our estimates. Specifically, it was approximately 8 % for products with no defined expiration date, and it increased significantly as the expiration window decreased (to 38 % and 44 % for bags 2 and 3, respectively). Consumers exhibited a strong preference for bag 2 (63 %) and a lower preference for bags 3 (19.4) and 1 (17.6 %). Thus, price seemed to represent an effective incentive for purchase, even when the discount rate was lower than expected.

Further analysis at the cluster level (Table 6) revealed additional differences. In terms of age, preference for bag 2 was consistent across all groups, but highest among the youngest age groups (25–34 years: 70 %; 18–24 years: 67 %) and lowest (45 %) among those aged 45–54 years.

Table 5
Percent reduction in WTP for products nearing expiry compared to products not nearing expiry.

Sample or variable	Group	WTP (versus WTP for products not approaching expiry) for products that will expire in		Statistical test (ANOVA)
		2–3 days	24 h	
Total		−36 %	−60 %	$F(2,512) = 338.1$, $p < 0.001$
Age	18–24	−30 %	−55 %	$F(2, 411) = 76.1$, $p < 0.001$
	25–34	−35 %	−58 %	$F(2, 468) = 155.4$, $p < 0.001$
	35–44	−39 %	−62 %	$F(2,102) = 66.8$, $p < 0.001$
	45–54	−42 %	−68 %	$F(2, 162) = 27.4$, $p < 0.001$
	55–64	−40 %	−65 %	$F(2, 282) = 61.7$, $p < 0.001$
	>64	−31 %	−57 %	$F(2, 72) = 7.2$, $p = 0.001$
Gender	Female	−36 %	−61 %	$F(2, 963) = 215.6$, $p < 0.001$
	Male	−35 %	−58 %	$F(2, 537) = 121.2$, $p < 0.001$
	No gender	−41 %	−66 %	$F(2, 6) = 2.4$, $p = 0.17$
Household composition	Alone	−36 %	−59 %	$F(2, 189) = 31.1$, $p < 0.001$
	With partner	−41 %	−62 %	$F(2, 225) = 54.5$, $p < 0.001$
	With family members	−35 %	−60 %	$F(2, 936) = 215.7$, $p < 0.001$
	With roommates	−33 %	−56 %	$F(2, 153) = 53.3$, $p < 0.001$

The latter age group presented the most complex pattern, with significantly higher preferences for the opposite bags of 1 and 3. With regard to younger respondents, the present results suggest that they sought an ideal compromise between product longevity and product price. In contrast, older respondents seemed to value either discount or longevity, and sought less of a compromise between these factors. In this respect, we might imagine that older consumers are more habitual with respect to their meals, whereas younger consumers may be driven by more last-minute decisions. Regarding gender differences (i.e., women versus men), women showed a strong preference for products with shorter expiration periods. Considering domestic partnership, those living alone or with roommates were more inclined toward bag 1 than bag 3, and the highest preference for bag 2 was observed among those living with family members.

Only a marginal statistical difference in bag selection was observed on the basis of gender ($\chi^2 = 5.9839$, $p = 0.051$) and domestic partnership ($\chi^2 = 8.450$, $p = 0.207$). The mean ages at which the highest preferences for bags 1, 2 and 3 were expressed were 37.6 years, 36.1 years and 43.2 years, respectively ($F(2,502) = 5.5474$, $p = 0.004$). Post hoc Tuckey comparisons showed no statistically significant differences for bag 1 versus bag 2 ($p = 0.712$) or bag 1 versus bag 3 ($p = 0.117$). However, there was a statistically significant difference in the average age (6.2 years) of those who preferred bag 3 to bag 2 ($p = 0.003$). To the best of our knowledge, no previous study has compared this set of choices.

Nonetheless, it is essential to acknowledge some limitations of the present work. In particular, the latter result indicates the potential utility of experimental field studies to complement online data and cross-country comparisons, in order to strengthen generalisability. Additionally, the inclusion of other categories of stakeholders (e.g., producers, politicians) in AHP studies would be helpful to identify any convergences and divergences of opinions. Finally, a product life cycle approach would be helpful to identify potential food waste management alternatives in supermarkets.

Table 6
Percentage distribution of choices for the different bags.

		Bag 1	Bag 2	Bag 3
Age	Entire sample	18 %	63 %	19 %
	18–24	17 %	67 %	15 %
	25–34	17 %	70 %	13 %
	35–44	11 %	63 %	26 %
	45–54	24 %	45 %	31 %
	55–64	18 %	56 %	26 %
	>64	16 %	60 %	24 %
	Female	16 %	61 %	23 %
	Male	20 %	66 %	14 %
Gender	No gender	33 %	67 %	0 %
	Alone	23 %	61 %	16 %
	With partner	18 %	55 %	26 %
	With family members	15 %	65 %	19 %
Household composition	With roommates	25 %	62 %	13 %

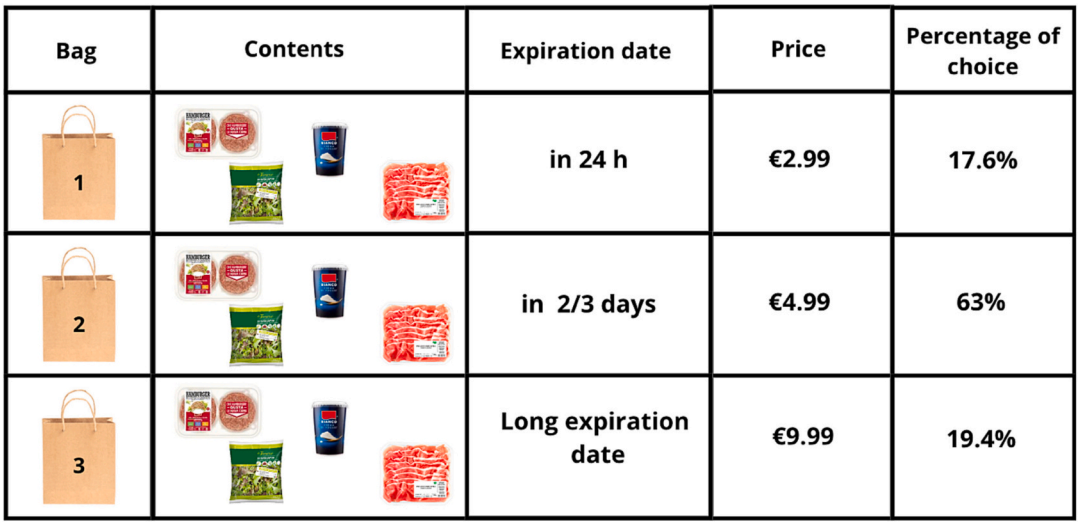

Fig. 13. Consumer preferences for three bags with varying expiration dates and discounts.

4. Conclusions

Food waste management is a critical concern, given the paradoxical situation in which individuals habitually dispose of unused food despite others dying of malnutrition. The present study has investigated food waste management in supermarkets from the perspective of sustainable production and consumption.

The results emphasise the strategic importance of selling expiring products through apps, indicating support for this approach from both academic experts and Italian consumers. Moreover, the direct sale of such products in stores is crucial, to ensure the normal flow of products from supermarket shelves to consumer homes. Differences in the opinions of experts and consumers emerged with respect to other alternatives aimed at mitigating food waste, with academic experts favouring conversion for energy purposes (linked to the strategic goal of energy independence) and consumers (particularly in the younger age ranges) preferring charitable initiatives. Both of these alternatives, in addition to the use of expiring products for in-house catering, were considered more sustainable than landfill disposal. Finally, both experts and consumers agreed that price and brand image were significant for reducing food waste in supermarkets.

The consumer analysis revealed that all consumers occasionally discarded of expired food, but older consumers did so only rarely. Similarly, although products nearing expiry were rarely purchased, younger consumers purchased them most frequently, driven primarily by the heavily discounted price. No gender-based differences in consumer habits emerged. The results also indicated a 36 % reduction in consumer WTP for a bag of products expiring in 2–3 days and a 60 % reduction for a bag of products expiring within 24 h. A significant percentage of respondents (approximately 63 %) preferred the compromise solution, choosing the discounted bag of products that was nearing expiry but not imminently expiring. In particular, this was a popular choice among those living with family members.

The present findings underscore the potential for effective food waste management in supermarkets. A strategic approach, also considering consumers' socioeconomic characteristics, may optimise the consumption of products nearing expiry, resulting in benefits for both consumers and suppliers. Future research could include field experiments, cross-country analyses and individual evaluations of products nearing expiry. However, the present study offers valuable insights for stakeholders aiming to address food waste and identify possible solutions for achieving SDG 12. A relevant goal should be to develop digital tools that allow supermarkets to identify and promote (i.e., through discounts) products nearing expiry, facilitating their selection by consumers shopping in-store or on an app. In this context, stakeholder engagement may play a crucial role in supporting sustainability goals.

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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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.spc.2023.11.005.

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