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Food waste heterogeneity among Spanish households: a quantile regression approach

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Abstract
Food waste is a global systemic issue that poses major threats in economic, social, and environmental sustainability. Recent policy efforts have primarily targeted households, as they are responsible for most food wasted. However, for these policies to be effective, they must account for household heterogeneity, recognizing that certain socioeconomic characteristics may influence differently depending on their level of waste. This study investigates the heterogeneous impact of socioeconomic characteristics on Spanish household food waste over the period 2018–2022, analysing households from minimal to substantial waste ratios. A quantile regression approach is applied to estimate the effects across the entire distribution of food waste, rather than focusing only on average effects. Results indicate that household characteristics influence food waste in a significant different way depending on their waste level. Moreover, product-level heterogeneity is also addressed, highlighting perishable products (fish and vegetables) as critical targets. Our findings point to the need for designing highly precise interventions, focusing on specific products and socioeconomic groups that contribute most to food waste.

Keywords: Food waste, Households, Quantile regression, Heterogeneity

Introduction
During the last decade, the world began to realize the harsh reality of the food loss and waste issue, which currently represents around 40% of total food production (WWF-UK 2021). This issue is expected to get worse in the coming future if projections of a growing population and increasing consumption are met by 2050 (FAO, 2009; Tilman et al. 2011; van Dijk et al. 2021).

Food is lost or wasted at every stage of the supply chain, and despite numerous conceptualizations and frameworks in the extensive food waste literature, a globally accepted definition remains elusive (e.g., Xue et al. 2017; Bellemare et al. 2017; Spang et al. 2019). This uncertainty makes it challenging to effectively investigate this systemic problem that affects society, especially those vulnerable demographic groups. In this sense, a distinction is often made between food loss, which refers to the accidental reduction in the quantity and quality of food before consumption, and food waste, which involves the intentional discarding of products fit for human consumption (Santeramo 2021).

Thus, household food waste generally encompasses discarded food, both unused and leftover, reflecting diverse disposal practices (Silvennoinen et al. 2015). Households emerge as the main contributors (e.g., Principato 2018), being responsible for 631 million tonnes in 2022 at global level, 60% of total wasted food (UNEP, 2024). In Europe, households generated roughly 53% of the 57.6 million tonnes of wasted food in 2022 (Eurostat 2022).

The impacts of food waste are multi-dimensional and extensive. When consumers waste food, the impact is even more significant than losses earlier in the supply chain, because so many resources go into getting food from the farm to our plates (Reynolds et al. 2020). In the environmental sphere, it has negative impacts on limited resources like water, land, and energy (e.g., Silvennoinen et al. 2022) and contributes to greenhouse gas emissions (UNEP, 2024). Additionally, food waste contributes negatively to food security and inequality (e.g., Geislar 2019; Santeramo 2021; Moghayer et al. 2024), imposes significant economic costs to households -such as family budget losses- (e.g., van der Werf et al. 2021), and raises ethical concerns, disproportionately affecting vulnerable demographic groups (e.g., de los Mozos et al. 2020).

Spain presents a particularly compelling case study due to the strong economic, social, and environmental implications of food waste. While it has the EU's lowest per capita food waste at just 26 kg/person (compared to the EU average of 68 kg/person in 2022), it is the seventh largest contributor overall, discarding 1.23 million tonnes in 2022 (Eurostat 2022). The consequences of this paradox are of great magnitude in Spain, where the agricultural sector is notably large, contributing 2.5% to the gross domestic product in 2024 compared to the EU average of 1.6% (Eurostat 2025a), and constantly faces intense resource constraints. In this sense, Spain shows one of the highest levels of water stress in the EU, with a Water Exploitation Index Plus of 8.8% compared to the 5.8% EU average (Eurostat 2025b), and with 30% of its agricultural land affected by degradation (Prăvălie et al. 2024). Adding to this, Spain faces significant social challenges, ranking fourth in the EU for population at risk of poverty or social exclusion (Eurostat 2025c), which increases the economic and food security implications of household food waste.

In response to this situation, Spanish institutions have not remained indifferent and have implemented measures aimed at preventing and reducing food waste. The most recent development in this field is the Law for the Prevention of Food Loss and Waste, approved in early 2025 (Spanish Government 2025). This law establishes a hierarchy of priorities for the management of food surpluses, promoting their use for human consumption through the signing of donation agreements with social organizations, also introducing a penalty system for those who do not comply with this regulation. In addition, the law includes several good practices, such as encouraging the sale of imperfect products, or adjusting the labelling of "best before" dates. Recent scoping reviews indicate that these retail-level interventions and food-rescue measures can indirectly shape household behaviour and outcomes and thus are relevant when considering complementary consumer-oriented policies (Olauson Barlas et al. 2025). The main goal of this Law is to reduce per capita food waste by 50% at the household and retail levels and by 20% in production and supply chains from 2020 to 2030, in line with international strategies, such as the European Green Deal and the Sustainable Development Goals (SDGs). Despite the significant progress, this law represents, and the strong measures it imposes on the different actors of the supply chain, there is a notable absence of specific actions aimed directly at the final consumer. This is paradoxical considering the major role that households play in food waste generation. It is therefore necessary to improve the understanding of food waste at the household level and its driving factors to provide new evidence supporting the development of complementary, targeted policies. This will help achieve established objectives and ensure more efficient, safe, just, and sustainable food systems.

To this end, the present study investigates how socioeconomic factors influence food waste across its entire distribution, from households with minimal waste to those with substantial waste levels, moving beyond insights derived from average effects. For this purpose, we use secondary microdata on household food waste and purchases in Spain from 2018 to 2022. Our empirical approach is motivated by the household production model originally developed by Becker (1965), which conceptualizes household activity as a production process where food waste constitutes a portion of foodstuff purchases (Lusk and Ellison 2017). Under this framework, a quantile regression approach is applied for the first time to investigate how socioeconomic status and other sociodemographic characteristics influence food waste across different distribution levels of food waste. Unlike traditional regression methods that primarily focus on average effects, our strategy provides a more complete picture of the underlying distribution of our variable of interest (Koenker and Hallock 2001). Moreover, the paper also considers product heterogeneity by disaggregating data by food group. This category-level analysis facilitates the identification of specific food groups that may yield valuable insights for designing targeted interventions to reduce household food waste, rather than merely identifying common drivers.

The remaining of the paper is structured as follows: Section 2 provides an overview of the existing literature of food waste at household level. Section 3 describes the data and offers an overview of the situation of household food waste in Spain. Section 4 outlines the methodology employed. Section 5 presents the results and discusses the findings. Section 6 concludes the research, provides the main political implications, highlights the limitations of our study, and identifies further potential venues of research.

Navigating the literature on household food waste

The fragmented literature on food waste in the context of private households reveals a vast and complex research landscape. Past studies have covered many aspects including quantification and compositional analysis (e.g., Reynolds et al. 2014; Bellemare et al. 2017; Delley and Brunner 2018; Withanage et al. 2021; Ammann et al. 2021; Amicarelli and Bux 2021), consumer behaviour analysis (e.g., Evans 2011; Parizeau et al. 2015; Tonini et al. 2023), the study of food waste reduction and prevention initiatives (e.g., Priefer et al. 2016; Reynolds et al. 2019; van Herpen et al. 2023; Stöckli et al. 2018; Goossens et al. 2019; Casonato et al. 2023), as well as the policy and legislative implications (e.g., Vittuari et al. 2015; Thyberg and Tonjes 2016; Condamine 2020), and the potential environmental impacts (e.g., Birney et al. 2017; Song et al. 2015; Slorach et al. 2020). Another relevant strand of literature focuses on the nexus between food waste and food security, showing a paradox where high levels of edible food waste in households coexist with the prevalence of food insecurity (e.g., Jereme et al. 2017). In this regard, some authors delve into the socioeconomic and demographic factors that influence food waste and food security, paying special attention to the link between income, food security, and waste (e.g., Althumiri et al. 2021; Fami et al. 2021; Diana et al. 2024).

Special efforts have been directed toward identifying the drivers of food waste, as evidenced in several recent state-of-the-art reviews (e.g., Hebrok and Boks 2017; Schanes et al. 2018; Vittuari et al. 2023). The current literature shows that there are numerous, complex, and interconnected factors (e.g., Secondi et al. 2015; van Geffen et al. 2016; Thyberg and Tonjes 2016; Lusk and Ellison 2017; Bravi et al. 2020) whose importance and predictability depend on the specific context of the analysis. These studies generally fall into three categories. The first considers psychological approaches, particularly rooted in consumer behaviour theories such as the Theory of Planned Behaviour (Ajzen 2002) or the Motivation-Opportunities-Abilities framework (e.g., MacInnis et al. 1991). The second strand takes an economic perspective, considering food waste as the result of optimal consumer decision-making. This includes the Becker's (1965) household production model (e.g., Lusk and Ellison 2017; Landry and Smith 2018), the production frontier model (Yu and Jaenicke 2020; Smith and Landry 2021), the consumer theory (e.g., Katare et al. 2017; Hamilton and Richards 2019; Drabik et al. 2019), or the so-called vignette method (Ellison and Lusk 2018).

Beyond these models, the third strand comprises a significant body of empirical studies exploring various determinants of household food waste, which are intended to capture the capacity of individuals to manage or deal with food waste. For instance, income often correlates with access to efficient storage solutions and different time endowments for food management (e.g., Parizeau et al. 2015), while the age of the main shopper may reflect accumulated experience in food management (e.g., Smith and Landry 2021; Quested et al. 2013a; Jörissen et al. 2015). Similarly, household size and the presence of children introduce complexities like diverse preferences and increased handling of perishable items, all of which directly bear on the household's ability to minimize waste (e.g., Parizeau et al. 2015; Quested et al. 2013b).

However, empirical findings on these determinants are often mixed and depend on the context (e.g., Stancu et al. 2016; Grasso et al. 2019; Cuffey et al. 2023). For instance, the relationship between income and food waste remains mixed, with some studies showing a positive correlation, while others suggest a negative or non-statistically significant relationship (e.g., Koivupuro et al. 2012; Stancu et al. 2016; Visschers et al. 2016). These inconsistencies underline the need for an analytical framework that examines how effects vary across the entire distribution of waste rather than focusing on average effects.

Despite the extensive and expanding research in this area, the field still faces broader obstacles. Findings are often heterogeneous and difficult to compare due to a wide collection of definitions and quantification approaches (Hoehn et al. 2023), diverse methodologies, and the variability across different regional and contextual factors. This complexity complicates the formulation of general conclusions (e.g., Parfitt et al. 2010; Roodhuyzen et al. 2017). These limitations highlight the need for more causal studies, preferably based on longitudinal data, to explain such contradictions (Corrado et al. 2019) and provide robust insights into underlying mechanisms. A significant challenge, as highlighted by Ellison et al. (2019), is the call to integrate pivotal economic research questions with high-quality data on food loss and waste, thereby contributing significantly to the global discourse on this topic. This implies the access to representative data of the total population, and the use of disaggregated data. Specifically, the literature has highlighted the need of data disaggregation by food category, as previous studies have mostly relied on aggregated data alone (Ananda et al. 2021). This is crucial because household food waste varies significantly across different food categories due to their unique characteristics, such as shelf life, packaging, price, or consumer behaviour. These differences further highlight the need for additional evidence on product heterogeneity to guide the design of tailored interventions to achieve food waste reduction targets.

Data

The statistical categorization for consumer food waste in Spain, established by the Ministry of Agriculture, Fisheries, and Food (MAPA), distinguishes between two main types: unused food waste and recipe waste. The former refers to food discarded in the same state; it was purchased without any preparation at home. The latter consists of leftovers from recipes or dishes that are discarded after being cooked or prepared, either because they were not finished or because they spoiled after being stored. Since unused food waste accounts for 78.5% of the total waste in Spain (MAPA 2022), it is the specific focus of the present study.

For this analysis, we used secondary microdata on household food waste and purchases in Spain from two panels supplied by the Kantar WorldPanel, covering the period from 2018 to 2022, and eight geographical regions that group Spanish provinces with relatively homogenous marketing characteristics: 'Metropolitan Area of Barcelona (MAB)', 'Metropolitan Area of Madrid (MAM)', 'rest of East (Aragón and rest of Catalonia)', 'Levante', 'Andalusia', 'North-West', 'North-Centre', and 'rest of Centre'.

The Kantar purchase panel comprises approximately 12,000 representative households of the total population of Spanish households, offering detailed information on food and beverage purchases across five food groups: 'meat', dairy', 'fish', 'vegetables', and 'other' food category that is a catch-all group including products like juices, fruits, or ready meals. The households are randomly selected by stratification based on the following criteria: socioeconomic status[1] ('low', 'middle-low', 'middle', 'high and upper-middle'), household size ('1–2', '3', '4', '5 or more'), presence of children ('yes', 'no'), and the age of the person responsible for shopping ('under 35', '35–49', 'over 50'). Participants use scanners to record every item bought, capturing data on types, quantities, and other relevant product features over extended periods.

For the same period, household characteristics, food groups, and regions, the Kantar Food Waste Panel offers information of 2,500 questionnaires from representative Spanish households, specifically tasked with recording their food waste. Participants maintain detailed diaries over designated periods, noting the types and amounts of food discarded as purchased, opened or unopened but not cooked, whether stored in the pantry, refrigerator, or freezer, irrespective of the reason for disposal (spoiled,

[1] Kantar defines socioeconomic status based on the following household characteristics: first, the occupation of all household members; second, general attributes of the living place such as size, location, and ownership, among others; third, household equipment; and last, the number and type of vehicles owned.

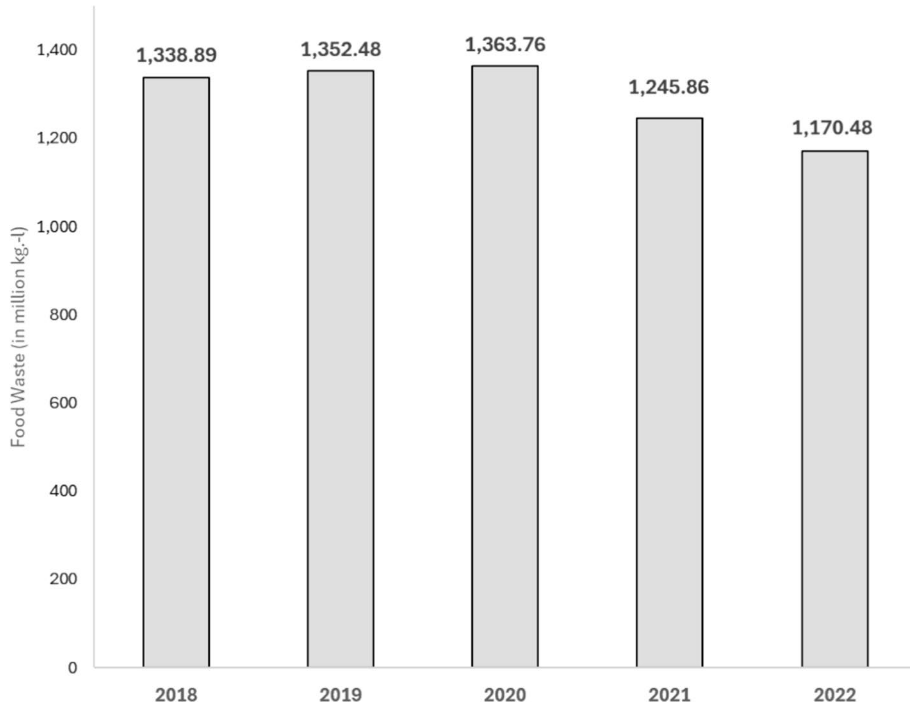

Fig. 1 Evolution of household food waste in Spain (2018–2022)

Table 1 Mean percentage of household food waste by category and year (2018–2022)

	2018 (%)	2019 (%)	2020 (%)	2021 (%)	2022 (%)	ANOVA test
Dairy	18.12	17.95	17.80	17.65	17.50	F(4) = 9.73 (0.000)
Fish	2.85	2.78	2.70	2.65	2.60	F(4) = 4.66 (0.001)
Meat	5.25	5.10	4.98	4.87	4.75	F(4) = 5.78 (0.000)
Other	61.48	61.99	62.52	62.98	63.45	F(4) = 7.55 (0.000)
Vegetables	12.30	12.15	12.00	11.85	11.70	F(4) = 3.34 (0.010)

Year columns report the annual mean shares of the total household food waste by food category. The last column reports the one-way ANOVA tests on the volume of waste by year for each food category. *F*-statistics are reported along with p-values in parentheses

prolonged fridge storage, not going to be consumed, etc.) during a reference week. This panel collects data periodically to ensure accurate logging of waste activities.

Figure 1 shows the evolution of total household food waste over the sample period. A small 2% increase is observed from 2018 to 2020, followed by a 14% decrease from 2020 to 2022, which could be attributed to changes in consumption and waste patterns during and after the pandemic.

Table 1 reports the annual mean shares of the total household food waste broken down by the four main food categories (dairy, fish, meat, vegetables, and "other"). It can be observed that the "other" category remains the largest throughout the period, rising slightly from 61.03% in 2018 to 62.11% in 2022. Dairy and vegetables rank second and third, averaging approximately 18% and 12%, respectively, while meat and fish both stay below 6% and 3%. All four main categories exhibit gradual downward

Table 2 Comparison of socioeconomic characteristics of the sample vs population

Variables	Categories	Household sample (%)	Household population (%)
Socioeconomic status	Low	24.27	26.20
	Middle-low	26.50	26.79
	Middle	29.47	30.70
	High and upper-middle	19.76	16.31
Age	−35	18.89	11.87
	35–49	40.35	31.15
	50+	40.77	56.97
Household size	1–2	32.70	56.65
	3	28.86	20.48
	4	25.01	17.24
	5 or more	13.43	5.62
Children	No	54.09	74.01
	Yes	45.91	25.99

Household population in Spain comprises all households across the Peninsula and the Balearic Islands, excluding the Canary Islands, Ceuta and Melilla. Value reported is the mean for the period 2018–2022 and were provided by Kantar WorldPanel

trends over time, and formal ANOVA tests confirm that these year-to-year differences in mean are statistically significant.

Additionally, Table 2 shows a comparison of household characteristics of our dataset and the Spanish household population. The shares of the different categories in our sample closely mirror those observed in the overall population, evidencing the representativeness of the sample.

The first step in data management is to match both panels supplied by Kantar, in order to obtain the food waste ratio (FWR) by dividing the quantity of food not consumed and wasted by the food inputs purchased, as in Lusk and Ellison (2017). To do so, the two databases are scaled to the population level, thus obtaining the food purchases and waste of the total Spanish population, disaggregated by the aforementioned socioeconomic criteria: socioeconomic status, household size, presence of children, and age. Then, cross-referencing the information on these characteristics, the FWR is obtained for the different household profiles in Spain[2], for eight geographical areas, 5 years, and five food groups, leading to a total of 5,718 observations.

The unconditional distribution of FWR across food groups and household socioeconomic characteristics is illustrated in Fig. 2 using violin plots, which presents key distributional insights into the location of central point (median), scale (dispersion), and shape (density and skewness). The figure offers visual evidence that highlights the heterogeneity in food waste across households' characteristics. The figure is organized into four panels. In each one, the Y-axis represents the endogenous variable FWR, and the X-axis displays distributions over several food groups, broken down by each specific household characteristic.

Panel a) details the FWR by socioeconomic status. It shows that households with lower socioeconomic status ('low' and 'middle-low') consistently exhibit not only higher

[2] As an example, our reference household profile for estimation is characterized by a low socioeconomic status, with a responsible for shopping under 35, without children and with 1–2 members.

median waste, but also wider and more right-skewed distributions, particularly for meat and fish products. Panel b) shows that households with children tend to have higher and more variable food waste ratios. This is visible as the violins for this group are taller and more dispersed across most food categories compared to households without children. Panel c) reveals a clear age association. Households with members under 35 consistently tend to display distributions with higher medians and longer upper tails, indicating both higher waste ratios and greater variability compared to older age groups. This pattern is consistent across most food groups and systematically decreases in older groups. Finally, panel d) shows that FWR increases with household size. The violins for larger households (e.g., 4, 5+) are visibly taller and wider, especially for meat and fish products, highlighting a pronounced increase in both the median and the overall variability of waste as the number of members grows.

Methodological approach

Our empirical approach is motivated by Becker's (1965) household production framework, in which households combine purchased inputs and time to produce final consumption goods, in this case, meals. In this context, food waste can be interpreted as the proportion of purchased food that is discarded, explicitly representing a residual inefficiency in this transformation process (Lusk and Ellison 2020). Households, when making purchases, often anticipate that a proportion of the purchased food will be discarded (Katare et al. 2017), which can be determined by a set of socioeconomic variables. This approach is consistent with recent applications in the food waste literature that adopt the household production model as a conceptual framework (e.g., Lusk and Ellison 2020), without necessarily estimating a structural production function. In this framework, we assume that the decisions over purchasing and consumption are exogenous.

Let $x_{i,p,r,t}$ denote the volume of food purchased by household type i of product p, in region r and year t, and let $z_{i,p,r,t}$ represent the (unobserved) volume of food effectively consumed or transformed into meals. Then, the households' food waste ratio (FWR) is given by:

$$\mathrm{FWR}_{i,p,r,t} = \frac{x_{i,p,r,t} - z_{i,p,r,t}}{x_{i,p,r,t}} \tag{1}$$

while the theoretical model implies that this residual depends on prices, wages, time allocation, and household productivity, our data do not contain direct measures of these factors. Hence, as in previous empirical studies (e.g., Lusk and Ellison 2020; Yu and Jaenicke 2020), we model the observed food waste ratio as a function of the observable

(See figure on next page.)

Fig. 2 Distribution of food waste ratio (FWR) across food category and household characteristics. *Note*: Violin plots display the estimated kernel density of the FWR within each group. The violin width indicates observation density, the white dot marks the median of the data, a box indicating the interquartile range, and spikes extending to the upper- and lower-adjacent values, as in standard box plots. The y-axis shows the FWR. The panels (**a**–**d**) correspond to socioeconomic status, presence of children, age groups and household size, respectively. The labels on the x-axis for socioeconomic status are abbreviated as follows: L (low), M-L (middle-low), M (middle), and H (high and upper-middle)

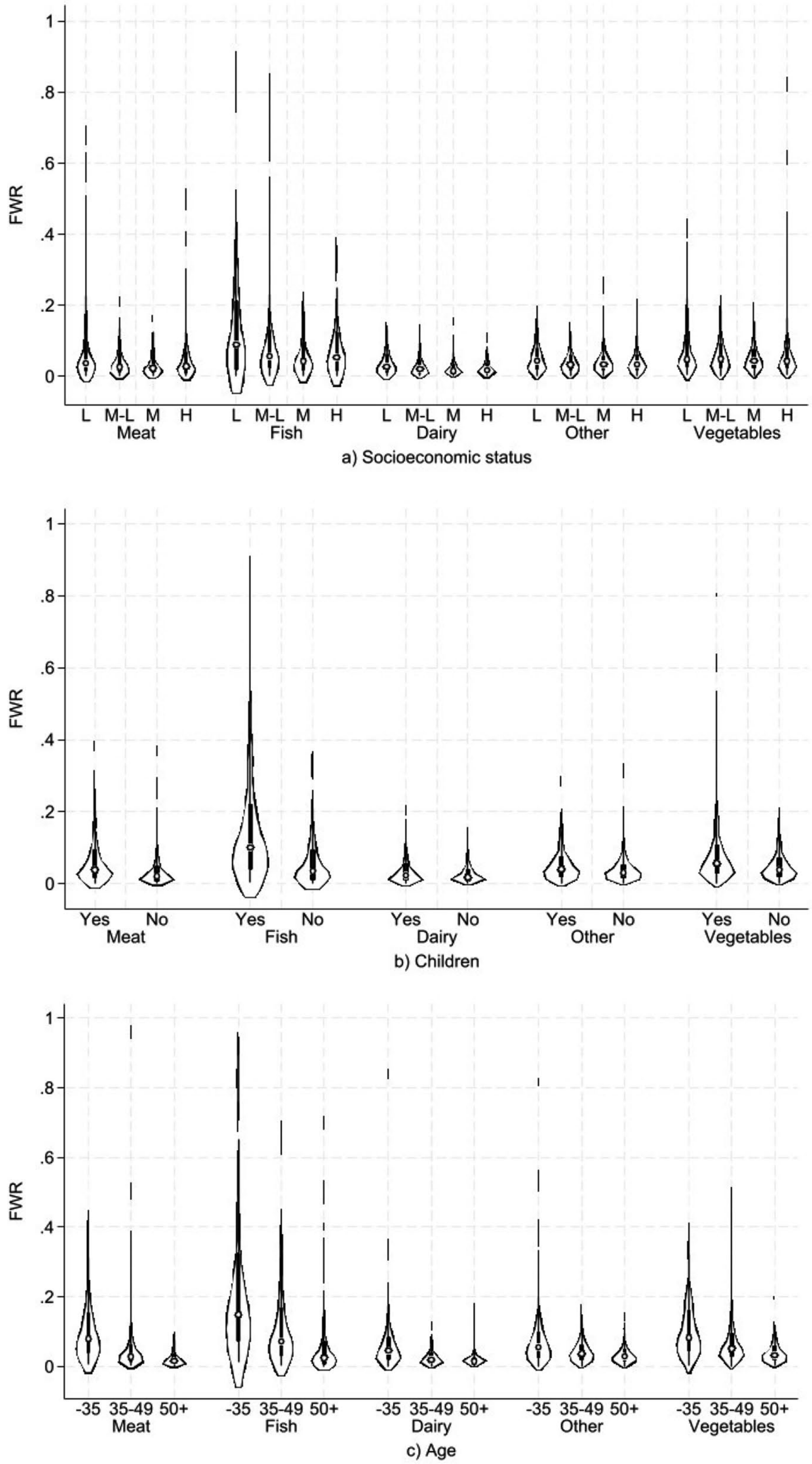

Fig. 2 (See legend on previous page.)

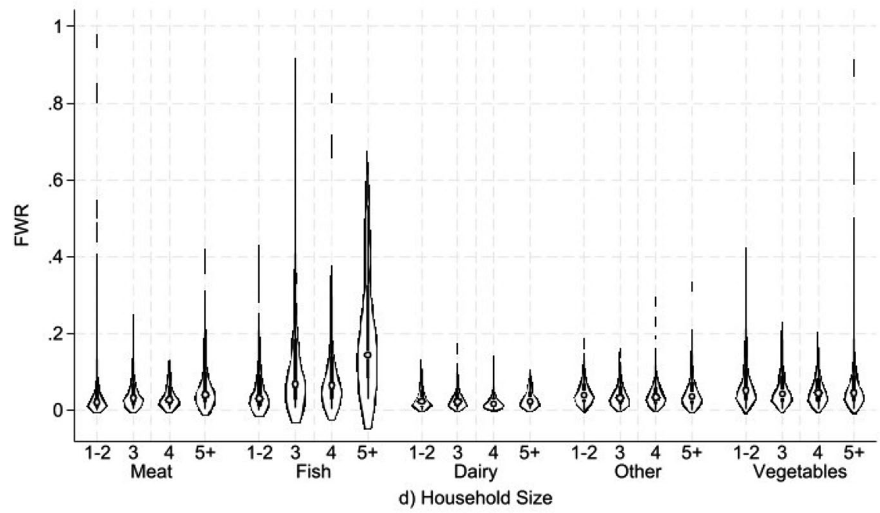

Fig. 2 continued

socioeconomic household characteristics, in order to capture the heterogeneity in productivity and time costs. Specifically, four household level socioeconomic variables are considered as determinants of this residual inefficiency: socioeconomic status, age of main shopper, presence of children, and household size. These variables may directly influence the behavioural nuances, such as varying food storage costs (e.g., Smith and Landry 2021; Bellemare et al. 2017), the intricacies of managing perishability (e.g., Hebrok 2018), and the impact of learning over time (e.g., Graham-Rowe et al. 2014; Nikolaus et al. 2018 on young adults' learning) that influence household's efficiency in food transformation.

Under this framework, the use of a quantile regression analysis (Koenker and Basset 1978) is a particularly suitable approach to estimate the relationship between the socioeconomic variables and the endogenous variable (FWR) at different points of the distribution. Recognizing that the insights derived solely from the conditional mean can offer an incomplete view, especially when dealing with heterogeneous impacts (Koenker and Hallock 2001), our approach moves beyond average effects. By considering a non-normal distribution rather than relying on just the conditional mean, we are able to better capture the heterogeneity in food waste behaviour across the conditional distribution. This procedure provides a more comprehensive understanding of how the effects of socioeconomic factors may vary across different levels of the outcome variable, including the tails.

Thus, for a given quantile, $0 < \tau < 1$, the conditional quantile function of our dependent variable can be written as:

$$Q_\tau\left(\mathrm{FWR}_{i,p,r,t}|X_{i,r,t}, Z_{p,r,t}\right) = X_{i,r,t}\beta(\tau) + Z_{p,r,t}\gamma(\tau) \tag{2}$$

where $t \in \{2018, 2019, 2020, 2021, 2022\}$, X is the vector of socioeconomic household characteristics, and Z contains additional control dummy variables such as indicators for years, regions and products in the sample. So, to study the effect of explanatory variables on different degrees of food waste ratio, the vectors of the coefficients, $\beta(\tau)$ and $\gamma(\tau)$, will be estimated at each of the following quantiles of the outcome variable: 10th (very low), 25th (low), 50th (median), 75th (high), and 90th (very high). It should be noted that the use of quantile panel estimators is not suitable with short panels as ours (with only 5 years) since the slopes of the quantiles cannot be identified. Hence, the model is estimated using a pooled quantile regression with clustered standard errors using an identifier that capture each region to control for potential heteroskedasticity, as proposed by Parente and Santos Silva (2016). Consequently, the estimated coefficients should be interpreted as conditional relationships that describe patterns of influence across the food waste distribution.

Furthermore, we have performed formal tests to assess heterogeneity of coefficients of Eq. 2. While the tests proposed by Koenker and Machado (1999) are standard, their direct application would not be appropriate in our case, as they were derived under *i.i.d.* or individual heteroskedastic errors and do not explicitly account for the clustered nature of our data. Therefore, to verify whether the effect of each socioeconomic characteristic differs across waste distribution, we perform a cluster-robust bootstrap test for equality of coefficients between representative quantiles. So, for each socioeconomic characteristic, we test the null hypothesis for the difference between the 10th and 90th quantiles ($H_0 : \beta_{0.9} - \beta_{0.1} = 0$). Therefore, the test statistic is as follows:

$$z = \frac{\hat{\beta}_{q_{90}} - \hat{\beta}_{q_{10}}}{\widehat{se}\left(\hat{\beta}_{q_{90}} - \hat{\beta}_{q_{10}}\right)} \to^{d} N(0,1) \quad (3)$$

where $\widehat{\beta}$ is the estimated coefficients from the quantile regression (Eq. 2) and *se* denotes the standard error of the regression calculated using 1000 bootstrap replications clustered by region (Parente and Santos Silva 2016).

Results and discussion

Descriptive statistics for our variable of interest (FWR), by quantiles, are summarized in Table 3. Overall, statistics show a significant decrease from 2018 to 2020, on average and across the entire distribution, followed by a small rebound in 2021, both on average and in those households with the highest levels of waste ratios. Then, the waste patterns seem to have stabilized in the last year of the sample. The increase in the FWR in the final 2 years of the sample contrasts with the reduction in total food waste observed during the same period in Fig. 1, an apparent paradox that can be explained by the fact that the reduction in purchases was proportionally greater. Moreover, Table 3 evidences the great heterogeneity in FWR over the different quantiles, with the 90th quantile almost doubling the 10th quantile in most years, which supports the suitability of the proposed methodological approach.

Table 4 reports the estimates for the pooled quantile regression (Eq. 2) and the pooled OLS model for comparison. To further evidence the heterogeneous effects across the distribution, we have also included Fig. 3 that clearly illustrates how coefficients evolve across quantiles. To formally test statistical significance of this heterogeneity, Table 5 shows the results of the heterogeneity test across quantiles (Eq. 3), which largely confirm our main hypothesis of heterogeneity, revealing that the impacts of most characteristics are not uniform across the waste distribution. Specifically, the tests show highly significant differences for drivers like age and the presence of children, as well as for most household size and socioeconomic groups. This general trend is not without exception, as the effects for "high and upper-middle" status and "3-member" household show more stability across the quantiles.

According to the coefficients of estimation presented in Table 5, the socioeconomic status of the household exhibits a strong relationship with food waste. Our findings are consistent with past studies that found a negative correlation between socioeconomic status and food waste (e.g., Stancu et al. 2016). Households classified as "middle-low", "middle", and "high and upper-middle" groups are consistently associated with a reduced impact on FWR compared to the reference group (low), especially at the higher quantiles. This suggests greater effectiveness in converting purchased food into actual consumption for these groups. For example, the three previous economic statuses (middle-low, middle, and high and upper-middle) show a reduction of 0.024, 0.028, and 0.008, respectively, at the highest quantile (90th) with respect to the reference group. In contrast, for the lowest quantile (10th), these coefficients indicate a smaller reduction (0.003, 0.002, and 0.002, respectively). This pattern indicates that lower-status households encounter greater difficulties in adopting more resource-efficient consumption practices. This outcome is potentially driven by factors highlighted in previous studies. These may include inadequate storage facilities and limited time allocated for food management (e.g. Parizeau et al. 2015), temporal constraints from busy work-life schedules (e.g., Jörissen et al. 2015) as well as lifestyles choices or how food is valued (e.g. Hebrok and Boks 2017). It is also worth noting the results for high-status households. While they systematically yields lower coefficients than for the reference group, this effect is statistically stable across the distribution. The stability of the high-status effect could reflect a balance between their greater purchasing power, potentially leading to higher waste, and increased awareness of sustainability or access to waste reduction strategies.

The estimated effects of the age variable are also relevant, with a negative effect found across all quantiles, increasing with upper quantiles. Households with a main shopper aged '35–49' or 'over 50' consistently exhibit lower FWR across all quantiles with respect to the reference group ('under 35'). The magnitude of this effect becomes more significant at higher waste ratio levels. For instance, for the over-50 group, the estimated coefficient becomes more negative, shifting from –0.008 at the 10th quantile to – 0.087 at the 90th quantile. This pattern indicates that the efficiency gains in converting purchased food into consumption associated with older age are particularly pronounced among

Table 3 Descriptive statistics of FWR by quantiles over the sample years

Year	N	Mean	10th quantile	25th quantile	50th quantile	75th quantile	90th quantile
2018	1202	.073	.010	.021	.042	.081	.156
2019	1256	.072	.009	.019	.040	.079	.164
2020	1119	.054	.007	.014	.031	.059	.113
2021	1074	.057	.006	.015	.030	.061	.132
2022	1067	.060	.007	.015	.030	.062	.127
2018–2022	5718	.063	.007	.016	.034	.069	.140

Levels of food waste ratio are defined as very low (10th quantile), low (25th quantile), median (50th quantile), high (75th quantile), very high (90th quantile) households experiencing high waste ratios. In line with past studies, this finding suggests that younger individuals may be more prone to wasting food (e.g., Bravi et al. 2020; Principato et al. 2015). On the contrary, older individuals tend to exhibit more experienced consumption patterns, which stands in contrast with the usual impulsive purchasing habits observed for the youngest (e.g., Kacen and Lee 2002; Duarte et al. 2013).

Table 4 Estimation results

Quantile regressions						OLS
	10th quantile	25th quantile	50th quantile	75th quantile	90th quantile	
Socioeconomic status						
Middle-low	−0.003*** (0.001)	−0.002** (0.001)	−0.004* (0.002)	−0.014*** (0.004)	−0.024*** (0.009)	−0.013*** (0.004)
Middle	−0.002*** (0.001)	−0.002*** (0.001)	−0.004*** (0.001)	−0.015*** (0.003)	−0.028*** (0.007)	−0.017*** (0.003)
High and upper-middle	−0.002** (0.001)	−0.001 (0.001)	−0.000 (0.002)	−0.003 (0.003)	−0.008* (0.004)	−0.005 (0.004)
Age						
35–49	−0.005*** (0.001)	−0.014*** (0.001)	−0.028*** (0.002)	−0.053*** (0.004)	−0.072*** (0.012)	−0.044*** (0.004)
Over 50	−0.008*** (0.001)	−0.019*** (0.002)	−0.036*** (0.004)	−0.063*** (0.008)	−0.087*** (0.018)	−0.046*** (0.005)
Children						
Yes	0.000 (0.000)	0.002 (0.001)	0.006** (0.002)	0.022*** (0.003)	0.061*** (0.006)	0.036*** (0.005)
Household size						
3 members	−0.002** (0.001)	−0.002* (0.001)	−0.003* (0.002)	−0.004 (0.004)	−0.002 (0.009)	−0.013*** (0.005)
4 members	−0.002*** (0.001)	−0.003** (0.001)	−0.004*** (0.001)	−0.009*** (0.002)	−0.010* (0.005)	−0.021*** (0.005)
5+members	−0.001 (0.001)	0.000 (0.002)	0.000 (0.003)	0.008 (0.007)	0.027*** (0.007)	−0.005 (0.006)
Product						
Fish	0.002 (0.001)	0.008*** (0.002)	0.023*** (0.004)	0.065*** (0.014)	0.198*** (0.038)	0.061*** (0.009)
Dairy	−0.002*** (0.001)	−0.003*** (0.001)	−0.006*** (0.002)	−0.015*** (0.004)	−0.032*** (0.007)	−0.019*** (0.004)
Other	0.003*** (0.001)	0.006*** (0.001)	0.009*** (0.002)	0.000 (0.003)	−0.015** (0.006)	−0.009** (0.004)
Vegetables	0.008*** (0.001)	0.012*** (0.001)	0.019*** (0.003)	0.024*** (0.004)	0.022* (0.012)	0.017*** (0.004)
Intercept	0.017*** (0.001)	0.035*** (0.002)	0.063*** (0.004)	0.118*** (0.007)	0.180*** (0.024)	0.094*** (0.006)
Goodness of fit	0.033	0.056	0.081	0.12	0.17	0.091
PSS test	−1.890*	−1.959*	−1.971**	−1.969**	−1.922*	−
Obs	5718	5718	5718	5718	5718	5718

***, ** and * denote statistical significance at 1%, 5%, and 10% levels, respectively. Control dummies for regions and years were included in all regressions but omitted in the table for simplicity. Clustered-errors are presented between parentheses as in Parente and Santos Silva (2016). The reference item is household profile characterized by: socioeconomic status is 'low', age is 'under 35', children is 'No', and household size is '1–2 members'. The reference food group is 'meat'. Goodness of fit is computed by pseudo-R^2 for quantile regressions as in Koenker and Machado (1999) and by R^2 for OLS. Pseudo-R^2 values reported for quantile regressions are not directly comparable to OLS R^2 and tend to be low in micro-level models focused on conditional quantiles; here inference relies on coefficient magnitudes across quantiles, their statistical significance and robustness checks, rather than on pseudo-R^2 alone. (Koenker and Machado 1999). PSS test, proposed by Parente and Santos Silva (2016), tests the null hypothesis of no intra-cluster correlation

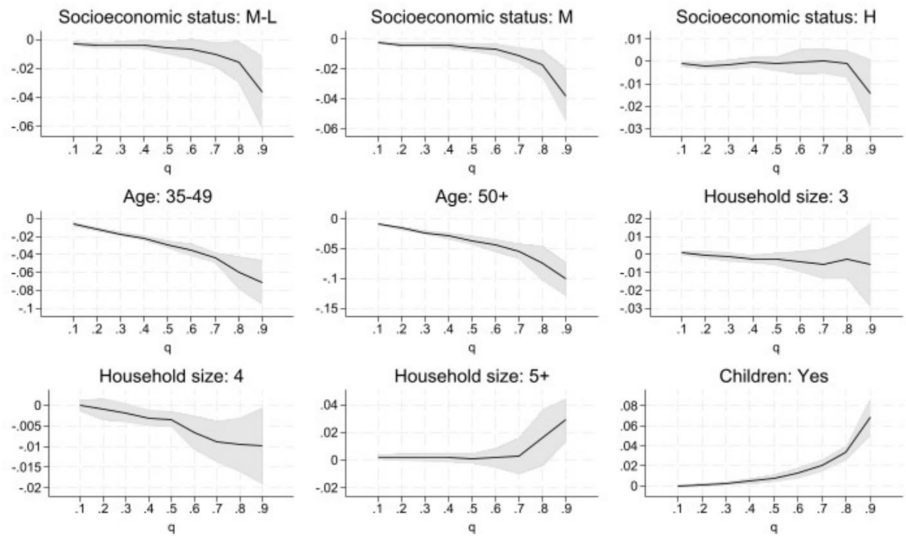

Fig. 3 Coefficient estimates across quantiles. *Note*: Label q denotes quantile and for socioeconomic status are abbreviated as follows: L (low), M-L (middle-low), M (middle), and H (high and upper-middle). 95% confidence intervals are represented with the shaded area and calculated using cluster-robust standard errors

Table 5 Heterogeneity tests across quantiles

Variable	*z*-statistic (10th vs 90th)
Socioeconomic status	
Middle-low	2.96 (0.00)
Middle	4.41 (0.00)
High and upper-middle	1.59 (0.11)
Age	
35–49	5.13 (0.00)
Over 50	5.55 (0.00)
Children	
Yes	6.50 (0.00)
Household size	
3 members	0.55 (0.58)
4 members	1.80 (0.07)
5 + members	3.37 (0.00)

The *p*-value of the test is two-sided $p - \text{value} = 2[1 - \Phi(|z|)]$, being Φ the cdf of the standard normal distribution. Errors calculated using 1,000 bootstrap replications

The presence of children in households shows a positive relationship with the FWR across all quantiles, with its intensity increasing at upper quantiles. While the effect is negligible at the lower quantiles (with estimates close to zero), it becomes statistically significant at the median (0.006) and grows substantially at the upper quantiles (0.022 at the 75th and 0.061 at the 90th). This is in line with evidence found in past studies (e.g., Parizeau et al. 2015; Kansal et al. 2022), suggesting that the presence of children tends to increase the waste ratio. In other words, households with children are more likely to exhibit higher inefficiency in converting purchased food into consumption, which may be attributed to the increased complexity and variability in consumption patterns associated with children.

Regarding the household size, the relationship exhibited with food waste is nuanced and complex. While larger households (3+members) show higher waste ratios in Fig. 3, our controlled analysis reveals that larger households tend to be more efficient at converting purchased food into actual consumption due to the presence of economies of scale, resulting in lower waste ratios, in line with previous research (e.g., Quested et al. 2013a). For example, three-member households exhibit negative coefficients across most quantiles. However, for this group, the effect is statistically homogeneous, as the test in Table 5, and shows no significant difference between the 10th and 90th quantiles ($p = 0.58$). Similarly, four-member households show a small reduction relative to the reference group (1–2 members), with a coefficient of −0.002 at the 10th quantile that increases up to −0.010 at the 90th quantile. In this case, we observe weak evidence of heterogeneity ($p = 0.07$), suggesting that their waste-reducing effect may be slightly stronger in high-wasting contexts. However, households with 5 or more members present a more intricate picture. In this case, the heterogeneity is highly significant ($p = 0.00$). Their impact is similar to that of smaller households at lower quantiles, but a significant positive effect (0.027) emerges at the 90th quantile. This may suggest that when the FWR is high, the benefits of economies of scale may even be reversed for the largest households. This intricate pattern could reflect increased logistical complexities or a broader range of consumption preferences in very large households.

Interestingly, food product matters. Our results first indicate that the FWR differs across food categories, and second, these estimates also vary across different quantiles. These two key insights highlight, on the one hand, the limitations of using conventional mean regression analysis, which tends to overestimate the effect (see the last column of Table 4), and on the other hand, the importance of considering product-specific heterogeneity.

Our findings reveal that 'fish' and 'vegetables' consistently have a positive effect, compared to the 'meat' category, thus increasing FWR regardless of the household's existing waste level. For example, 'fish' exhibits the highest positive effect at the 90th quantile with an estimated coefficient of 0.198, followed by 'vegetables' with a peak at the 75th quantile (0.024). Hence, fish is the most waste-intensive product, which may reflect issues like perishability and storage constraints. Vegetables show modest magnitudes compared to fish at upper quantiles but higher at lower quantiles. This finding reinforces existing evidence that vegetables are among the most wasted food items due to their perishability and limited storage life (e.g., Parfitt et al. 2010). Unlike fish, vegetables have a relatively lower unit cost, which might contribute to a lower perceived economic loss and, consequently, a higher likelihood of discarding them when they deteriorate due to over purchasing for instance (Ananda et al. 2022). On the contrary, dairy products consistently show a negative impact, suggesting that Spanish households show improved purchasing practices and managing close-to-expired labels associated to these products (Campbell and Feldpausch 2022). Finally, the 'other' food group produces mixed results. While a reduced positive effect is observed at lower and median quantiles, the impact becomes negative at the upper quantile (90th: −0.015). This may be a result of the composition of this food group which includes products with different degrees of perishability and management challenges (e.g., oil, fruits, snacks, and beverages).

Conclusions

This paper enhances the understanding of food waste at the household level and its driving factors, focusing on how socioeconomic factors influence food waste across its entire distribution, from households with minimal waste to those with substantial waste levels. To do so, an original dataset on purchases and food waste of representative Spanish households is exploited to investigate the heterogeneous impact of socioeconomic characteristics on household food waste ratios from 2018 to 2022. Rather than focusing solely on average-effect models, we apply a quantile regression approach to uncover that socioeconomic status, age of main shopper, presence of children, and household size each exert different impacts at different points of the waste distribution.

Our results confirm our main hypothesis: households with certain socioeconomic characteristics might respond differently depending on how much they waste. In general, most variables analysed exhibit increasing effects as we move toward higher quantiles, indicating that their impact is more pronounced among households with greater waste ratios. This pattern underscores the added value of our quantile regression approach, as it captures disparities that a conventional mean regression would overlook. Leveraging this richer information allows policymakers to design highly precise interventions, focusing on specific socioeconomic groups that contribute most to food waste.

We conclude that belonging to middle and middle-high socioeconomic groups, particularly those with higher recorded waste ratios, exhibits a more negative effect on food waste ratios compared to lower groups. This has clear implications in the context of food security, as enabling more vulnerable households to utilize their purchases more efficiently may reinforce money savings. Therefore, this pattern emphasizes the need for policies that specifically address economic disparities in waste practices.

Additionally, younger households, smaller households and those with children show higher waste ratios. These results highlight the need for targeted strategies for these groups, considering their potential for greater food waste creation and prioritizing new actions addressing overpurchasing to achieve substantial waste reductions. Notably, one of the variables with the highest impact is age. In today's digital era, social media platforms, which are especially popular among younger households and have been shown to strongly influence attitudes toward food waste reduction. These platforms can effectively promote sustainable practices such as healthy habits, improved meal planning, and creative repurposing of leftovers, thereby reducing household food waste and inspiring a collective sense of responsibility. This underscores the importance of studying the connection between digital content and food waste behaviours to design impactful interventions.

The heterogeneity among food products is also evident, with products such as fish and vegetables associated with higher waste levels. This highlights the challenges that households face when managing highly perishable food products, especially if they represent a lower cost, as it is the case of vegetable products. These results call for targeted interventions focused on improving storage, preservation, and supply chain management, and evidence the importance of policy strategies focused on consumer education campaigns.

In sum, our results provide valuable evidence for understanding household waste behaviours within the Spanish context. However, given that many high-income countries may share similar household waste patterns, our results may also hold broader relevance, particularly for other developed nations with comparable characteristics. In particular, in the Spanish case, our findings suggest that the Spain's 2025 Law for the Prevention of Food Loss and Waste could be strengthened by complementary household-oriented policies, since their ambitious targets and measures do not include consumer-level actions. For example, for younger groups, targeted digital campaigns—such as app-based expiry reminders or social media "leftover challenge" hashtags—can leverage online norms to curb impulsive overbuying. For households with children, integrating meal planning modules into school curricula and community cooking workshops can build parents' skills in portion sizing and creative reuse. Retailers, in turn, could pilot smaller portion packs and dynamic discounts on near-expiry fish and vegetables, directly addressing the product vulnerabilities we identified. Moreover, community-based initiatives such as municipal composting programmes have been shown to reduce household food waste and improve residents' waste-management self-efficacy, suggesting that municipalities can be effective partners in household-focused policy design (Campbell et al. 2025).

Despite the relevance of our findings and their policy implications, we acknowledge several limitations that may constrain causal inference. Specifically, we lacked detailed data on how households allocate their time to food-related activities, as well as information on the number and ages of children, which limits our ability to assess how child demographics influence food waste creation (e.g., Tonini et al. 2023), indicating a valuable direction for future research. We also lacked continuous income measures, and the categorical nature of our dataset restricts numerical granularity. While one could approximate these missing details by matching with external surveys from the Spanish Statistical Institute, this approach would require strong assumptions about average household characteristics (e.g., income and main shopper's age). Further research into lifestyle and family composition could therefore provide valuable insights for refining sociodemographic targeting in waste reduction policies.

Bearing these limitations in mind, future research should link household panels with time-use surveys or administrative registries to unpack behavioural mechanisms. It could also explore product heterogeneity in more depth by having access to databases with a higher level of product disaggregation or employing scenario analysis to examine how the adoption of different diets reshape waste distributions and food outcomes, and how this impacts household welfare and food access. By aligning distributional insights with specific interventions, policymakers can accelerate progress toward national and international waste reduction goals while strengthening household welfare and fostering sustainable food systems.

Author contribution

H.F. and P.G. equally contributed to conceptualization, methodology, formal analysis, investigation, data curation, writing-original draft, and writing-review and editing. H.F. is responsible for funding acquisition from MCIN/AEI. Both authors reviewed the manuscript.

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Data availability

The data that support the findings of this study are available from Kantar World Panel upon request. The data are not publicly available due to licensing and privacy restrictions.

Declarations

Competing interests
The authors declare no competing interests.

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