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Do consumer cognition and dependence on food date labels contribute to reducing food waste? Evidence from urban China

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ABSTRACT

Global food waste remains a major challenge to the sustainability of agri-food systems. Although substantial research has quantified food waste, identified its drivers, and evaluated its environmental consequences, few studies have explored the role of consumer cognition and dependence on food date labeling (FDL), particularly in the context of transition economies. Based on 2282 online survey samples from China, this study applies a three-stage modeling approach to investigate how FDL cognition influences food waste behavior and to uncover the underlying mechanisms through the lens of FDL dependence. Our findings indicate that 26.42% of consumers are confused about the meaning of FDL, and this confusion is associated with an annual per capita food waste of approximately CNY 190, resulting from the premature disposal of food. This relationship also demonstrates significant heterogeneity across regions, education levels, and age groups. Further analysis reveals that 82.68% of consumers exhibit strong dependence on FDL, which acts as a suppressor variable that intensifies the relationship between cognition and food waste. These findings provide new mechanistic insights into food waste generation from the FDL perspective and contribute to the broader discourse on sustainable consumption. They also carry practical implications for consumers, food producers, and policymakers, supporting progress toward United Nations Sustainable Development Goal 12.3 “halving global food waste by 2030.”

1. Introduction

Global food waste has escalated dramatically in recent decades, threatening economic stability, social equity, and environmental sustainability [1–3]. The Food and Agriculture Organization of the United Nations [4] estimates that roughly one-third of food produced worldwide is lost or wasted annually. Notably, the consumption stage accounts for the largest share of waste within the food supply chain [5]. In advanced economies, households generate up to 50% of total food waste [6], with American households discarding approximately 28% of purchased food [7].

Food labels play a vital role in communicating essential food information to consumers [8,9]. Among these, food date labeling (FDL) is one of the most influential, particularly for fresh food [10–12], as it directly shapes purchasing behavior, consumption habits, and even health outcomes. Initially implemented to aid producers, retailers, and consumers

in managing food distribution and inventory, most FDLs indicate quality or freshness rather than safety [13]. However, widespread misunderstanding persists due to information asymmetry in the market [14,15]. Many consumers erroneously interpret FDLs as safety indicators [13,16,17], leading to the premature disposal of edible food that remains safe for consumption but has exceeded its labeled date to avoid foodborne illness [18,19].

Brucks [20] categorizes consumer cognition into three types: objective, subjective, and experiential. Objective cognition pertains to verifiable knowledge assessed through standardized measures, where higher scores reflect greater factual understanding. Subjective cognition, in contrast, refers to consumers' self-perceived knowledge, which may not align with their actual understanding [21]. Experiential cognition arises from personal experience and accumulated exposure. While prior research has extensively explored how objective knowledge of FDL affects food waste behavior [15,19,22], a critical gap remains: consumers

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often lack clarity about whether they truly comprehend FDL meanings. This oversight is significant because subjective cognition - more than objective knowledge - has proven a stronger predictor of individual behavior [23,24]. This study therefore investigates how consumers' subjective cognition (self-assessed understanding of FDL) influences food waste behavior, offering crucial insights for its reduction.

Do consumers rely on sensory cues - such as a food's appearance (e.g., color) or smell - to determine its edibility? Research indicates that many individuals use sensory evaluation as a primary determinant of food safety [15]. This tendency raises an important but underexplored question: To what extent does FDL ultimately influence discarding decisions when sensory cues are available? In this study, we conceptualize this behavior as FDL dependence - the propensity for consumers to combine sensory judgments with FDL information when judging the edibility of food and explore its role in the relationship between subjective FDL cognition and food waste behavior to make up for the neglect of this issue in existing research.

China's gradual adoption of food labeling policies in the post-reform era [25] has been accompanied by relatively slower progress in food safety and public health regulation, making it an instructive case for examining food industry development in transitional economies - a context underexplored in the existing literature, which predominantly focuses on advanced economies [26]. Leveraging this setting, our study employs subjective cognition - a demonstrated stronger predictor of individual behavior than objective knowledge - to quantitatively assess its relationship with food waste attributable to food expiration, and investigate the role of FDL dependence in this dynamic. Our study provides a novel contribution to the existing literature, and may help identify more efficient and effective strategies to mitigate food waste.

2. Literature review

2.1. Consumer attention and cognition of FDL

Extensive research has examined consumer engagement with food labels, highlighting the influence of design elements such as label size [27], color contrast [28], placement [29], and individual differences [30,31]. While these factors are shown to significantly influence attention, studies also highlight a paradox: label viewing tends to become habitual [15,32,33], yet deeper cognitive processing remains limited. Eye-tracking evidence further indicates that consumers often notice labels without fully comprehending their meaning [34,35], underscoring the critical distinction between attention and understanding in effective communication [36].

Empirical studies reveal considerable gaps in consumers' ability to accurately interpret the FDL [18,37,38]. Only 6.46% of urban Chinese consumers correctly understood the most common type of FDL [16], and merely 18% of U.S. consumers could accurately define "Use By" labels [22]. However, existing research has predominantly focused on objective cognition of FDL through standardized testing, largely overlooking the role of subjective cognition - consumers' self-assessed understanding of FDL, which may better predict individual actual behavior. A qualitative study by Patra et al. [17] found that 75% of food industry stakeholders experienced confusion about date labels, suggesting that subjective cognition warrants systematic investigation. The absence of quantitative research on consumers' self-perceived FDL understanding represents a significant knowledge gap.

2.2. Consumer dependence on FDL

The concept of dependence serves as a crucial bridge linking cognitive psychology and behavioral decision theory in the field of food waste. It reveals that consumers are not simply individuals who know or not, but rather complex actors who engage in intricate interactions among knowledge, self-assessment, and preferences for decision-making rules. The concept of consumer dependence on FDL remains

understudied and lacks conceptual consensus. Some studies documented when consumers feel uncertain about whether the food products are safe or not, they seldom trust their sensory judgment [39–42]. However, Katiyo et al. [41] documented that sensory characteristics are as important as date labels for consumers in assessing food quality. Kavanaugh and Quinlan [15] observed that 82.3% of consumers integrate sensory checks with FDL information when assessing food edibility. These contradictions may stem from methodological limitations in prior research, particularly the reliance on binary classifications of dependence, which oversimplify a complex behavioral construct. Furthermore, there is insufficient attention to the issue of dependence in existing research, as most studies only briefly mention very limited information and lack substantial data support.

To strengthen the theoretical underpinning, this section integrates the dual-process theory of risk perception [43] into the analytical framework. These perspectives help explain the continuum of FDL dependence, positing that its level is dynamically shaped by factors like perceived risk of foodborne illness, and trust in label accuracy [44]. Moving beyond the binary paradigm, this study conceptualizes FDL dependence as a multi-dimensional, continuous variable. This refined framework aims to provide a more nuanced analysis of how consumers navigate the interplay between institutional cues (FDL) and personal assessment (sensory evaluation) in food edibility decisions, thereby offering a meaningful theoretical contribution to the field.

2.3. Research gaps and our marginal contributions

Building directly upon the foundational work of key studies in this field, this study addresses specific gaps to advance the literature on FDL and food waste. (a) From geographic context to theoretical mechanism: existing research, including the pivotal work by Kavanaugh and Quinlan [15], is predominantly situated in advanced economies. This study shifts the context to China, a major transitional economy, to test the generalizability of existing frameworks. More importantly, we move beyond replicating findings to probe the mechanism - specifically, the role of FDL dependence - through which cognition influences waste in this distinct setting. (b) From objective to subjective cognition: prior studies have effectively measured objective FDL knowledge. Our contribution lies in directly addressing the oversight noted in the introduction regarding subjective cognition. We quantitatively examine how consumers' self-assessed understanding (subjective cognition), a stronger predictor of behavior than objective knowledge, influences discarding decisions, thereby offering a more accurate lens on real-world consumer behavior. (c) From isolated concepts to an integrated framework: a key limitation in the current literature is the treatment of FDL cognition and reliance on sensory cues as separate domains. Inspired by the interplay suggested in prior work, we conceptualize and measure FDL dependence - the propensity to integrate FDL with sensory judgment. We then explicitly model its role as a mediating and moderating variable in the relationship between subjective cognition and food waste, thereby answering the call for a more nuanced understanding of how these factors jointly shape outcomes. (d) Methodological synthesis: while valuable insights have been generated through statistical and qualitative approaches, we apply econometric methods to the study of FDL cognition and dependence. This allows for robust quantitative tests of the proposed relationships, adding a layer of analytical rigor to the theoretical propositions found in the literature.

In summary, our marginal contributions are: (a) providing quantitative evidence on subjective FDL cognition in a transitional economy; (b) introducing and validating a novel measure of FDL dependence that bridges cognitive and sensory evaluation; and (c) establishing and testing an integrated mechanism that links subjective cognition, FDL dependence, and final waste behavior. This positions our study not as a reiteration, but as a direct theoretical and empirical extension built upon the gaps identified in key referenced works.

3. Materials and methods

3.1. Data collection and sampling strategy

We sourced our data from Questionnaire Star, a leading professional online survey platform in China. It boasts over 6.2 million registered users, including more than three million active monthly respondents. This large and diverse platform user base enables effective random sampling across all 31 provincial-level administrative divisions in mainland China (excluding Hong Kong, Macao, and Taiwan), ensuring representation of participants with varied socioeconomic and demographic characteristics. To guarantee data quality, the platform employs a rigorous integrity scoring system to screen participants (all platform users), and its professional survey distribution and collection services have been validated in prior research [45]. The questionnaire was designed to capture consumers' basic demographic characteristics, FDL cognition and dependence, and household food waste behavior. We obtained our data by purchasing sample services from the survey company, which was responsible for participant recruitment and controlling the representativeness and quality of the samples while ensuring the principle of random sampling at our request.

Given that existing research on food waste primarily examines perishable foods, especially dairy products [46], we acquired the last five-year per capita milk consumption statistics from the *China Statistical Yearbook*, which contains data for provinces, cities, and autonomous regions (hereafter referred to as provinces). By ranking the data numerically and following the principle of keeping the number of provinces in each group as equal as possible, we divided the provinces into three groups (high, medium, and low). Further, to ensure geographical and economic diversity, we selected six provincial capitals as survey sites, covering China's eastern, central, and western regions: (a) high milk consumption: Beijing and Xining; (b) medium milk consumption: Chengdu and Hefei; (c) low milk consumption: Guangzhou and Changchun.

Here we need to make some explanations regarding the representativeness of selected provincial capital cities: *Urban Focus*. Since our survey targeted prepackaged foods, we thought that compared with rural residents, urban residents, who purchased such products more frequently, may be more concerned about the use of food date labels. Therefore, we focused our survey on urban residents to ensure data validity. *National Representation*. Considering that the regulations of FDL are consistent nationally, we expected to cover a larger survey scope in China. However, considering the cost and operability of the survey, we finally took the province as the unit and selected the provincial capital city that best represents the province as the sample areas. This consideration was quite in line with the current food consumption research, which often selected sample areas with very national characteristics, such as the capital Beijing and Guangzhou [47,48]. *Nearly equal sample sizes across the six cities*. We overcame the higher cost and longer time required to collect nearly the same amount of samples among cities with relatively low population density for two purposes: (a) Ensuring inter-group comparability and statistical power. Equal sample sizes ensure comparable statistical power for each city subsample, avoiding unbalanced testing power due to disproportionately large samples in bigger cities and small samples in smaller cities. This allows for a fairer and more reliable detection and comparison of differences across cities. (b) Preventing dominance by larger cities: if samples were proportional to population size, the largest city would contribute the majority of observations. In analysis, overall results or models could be dominated or diluted by characteristics of the largest city, making it difficult to clearly identify and interpret unique patterns or issues in medium and small cities. Equal sample sizes ensure each city carries equal weight in the overall analysis, which is crucial for revealing potential heterogeneity.

Participants were required to be at least 18 years old, with each individual permitted only one submission to avoid duplicate responses. To

mitigate seasonal biases, participants were instructed to base their answers on their average experiences over the time frame of the past year. To ensure data quality in the online survey, we incorporated multiple attention-check measures, such as basic arithmetic questions and repeated items, to verify participants' response validity. Responses that failed attention-check questions were deemed invalid. Following data cleaning, we acquired 2282 valid survey samples with balanced

Table 1
Variables and descriptive statistics.

Variables	Definition	Description	Mean	S.D.
Dependent variable				
Food waste value	Per capita value of food waste due to expiration.	CNY/year	190.20	224.80
Independent variable				
FDL cognition	Cognitive evaluation of the meaning of FDL.	1 = very clear; 2 = clear; 3 = somewhat clear; 4 = neutral; 5 = somewhat confused; 6 = confused; 7 = very confused	3.51	1.47
Mediator variable				
FDL dependence	Judging whether a food is edible or not relies on the FDL.	1 = strongly disagree; 2 = disagree; 3 = somewhat disagree; 4 = neutral; 5 = somewhat agree; 6 = agree; 7 = strongly agree	5.60	1.18
Control variables				
Gender	Participant's gender	0 = Female 1 = Male	1365 (59.82%) 917 (40.18%)	
Age	Participant's age	Years old	30.59	6.89
Education	Participant's education level	1 = less than bachelor's degree; 2 = bachelor's degree; 3 = master or doctoral degree	1.88	0.56
Risk attitude	Participant's risk attitude	-1 = risk aversion; 0 = risk neutral; 1 = risk preference	-0.48	0.85
Household size	The number of members living in the household.	Person	3.06	1.31
Income	Per capita disposable income	CNY/month	4083	3465
Household health status	Whether all the family members living together are healthy	0 = No 1 = Yes	609 (26.69%) 1673 (73.31%)	
Freshness requirement	The freshness requirements when purchasing food.	Continuous integer variable (0,1,2,3). 0 = no requirement; 3 = the highest requirement.	1.95	1.04
Purchasing frequency	The frequency of households purchasing food	The range is 1-11, increasing in frequency as the number increases.	8.73	2.09
Region variables				
Eastern China	Including Beijing city and Guangzhou city		790 (34.62%)	
Central China	Including Hefei city and Changchun city		748 (32.78%)	
Western China	Including Chengdu city and Xining city		744 (32.60%)	
Number of observations			2282	

Notes: CNY is the monetary unit of China, and one CNY was equal to 0.1408 US dollars in March 2023.

representation across all survey locations.

Variable definitions and descriptive statistics are presented in Table 1. Male participants constitute 40% of the survey sample. Although the proportion of male respondents is slightly lower than the 51.20% male demographic among Chinese internet users [49], this discrepancy can be reasonably explained by existing research indicating that women tend to show greater concern regarding food-related issues [50]. The average age of participants is 30.59, which is consistent with the largest age group among Chinese internet users (30-39 years old). The majority (77.65%) hold a bachelor's degree, a proportion higher than the national average (9.30%) for Chinese internet users [51]. However, this discrepancy aligns with expectations due to the inherent biases of online survey methodologies, as evidenced by prior China-based studies employing similar approaches [52,53]. Additionally, the sample reflects urban demographics, with a per capita monthly disposable income of approximately 4083 yuan, mirroring the financial profile of urban netizens (approximately 4107 yuan) [54]. In summary, the dataset skews toward younger, more educated, and predominantly female participants, maintaining strong representativeness among China's urban population.

3.2. Conceptual definition

3.2.1. Definition of food waste behavior

This study adopts the definition of food waste from FAO [4], which refers to the discarding of edible food (excluding inedible parts). In the context of China's FDL system, where all labels uniformly indicate a "best before" date, we classify the discarding of food nearing its labeled expiration date as food waste behavior in this study. To quantify this behavior, survey participants are asked to report the monetary value of expired food they discarded on a monthly basis. Given that most FDL periods span 3-6 months or longer, assessing food waste over shorter intervals, such as in the past week, might have a significant impact on the result. Thus, participants are instructed to estimate their average monthly food discards over the past year to ensure data reliability. A methodological consideration arises from the challenge consumers face in converting discarded food into standardized units of measurement (e.g., weight), particularly for heterogeneous items such as liquids (e.g., milk) and solids (e.g., cookies). Our focus encompasses all expired food waste (including solid and liquid foods) regardless of form, relying on weight-based metrics would introduce substantial measurement error. Consequently, we chose monetary value as a consistent and practical proxy for assessing the scale of food waste. Consistent with the common approach of measuring food waste behavior using monetary value [55], we adopted a self-reporting method to obtain this measurement from consumers. In the questionnaire, this item was phrased as: "In the past year, approximately how many RMB on average, did your household discard due to expired food (per person per month)?" (originally in Chinese). This precise and clear wording ensured both terminological accuracy and consistency in statistical measurement.

3.2.2. Definitions of FDL cognition

As stated in the introduction, subjective cognition may serve as a stronger predictor of consumer behavior than objective measures [24]. While prior research has predominantly examined objective FDL cognition [15,19], this study shifts focus to subjective FDL cognition - a potentially more influential yet understudied factor in food waste behavior. Drawing on Brucks' [20] conceptualization of subjective knowledge, we operationalize subjective FDL cognition through self-reported assessments. Specifically, participants are asked: "Are you confused about the meaning of different date labels on pre-packaged food?", and we measure this key variable through a 7-point Likert scale (1 = very clear, 7 = very confused, the specific assignments are shown in Table 1 for details). In this study, higher reported confusion (i.e., higher Likert scores) corresponds to lower subjective FDL cognition, which means the variable inversely reflects participants' understanding

of date labels: greater confusion indicates weaker cognition.

3.2.3. Definitions of FDL dependence

Referring to the measurement of FDL dependence in the study of Van Boxtael et al. [56], we employ a 7-point Likert scale to assess participants' dependence on FDL. The questionnaire includes the statement: "I am often unsure whether pre-packaged food is still edible and mainly rely on the food date labels." And the corresponding options range from 1 (strongly disagree) to 7 (strongly agree), with detailed scale assignments provided in Table 1. A higher agreement score indicates stronger FDL dependence, suggesting that participants predominantly use date labels to determine food edibility. Conversely, drawing upon Kavanaugh & Quinlan's [15] research finding that most respondents (82.3%) combined sensory evaluations (smell and sight) with date labels when assessing food edibility, we based on the results of our questionnaire item - "I will judge whether milk/cookies are still edible through my senses (sight, smell or taste)" - and found that only 38.78% of consumers expressed their approval. We thus infer that lower agreement scores here may imply that individuals rely more on personal judgment, such as sensory evaluation or past experience to guide their food waste decisions.

3.3. Model specification and analytical methods

Given that Ordinary Least Squares (OLS) regression yields unbiased estimates under relatively weak assumptions, requiring only a linear conditional expectation rather than strict normality of residuals, which provides reliable and interpretable baseline results that remain valid across a wide range of conditions, we first employ an OLS framework to analyze the benchmark relationship between consumers' FDL cognition and food waste behavior. The regression model is specified as shown in formula (1):

$$Waste_i = \delta + c \text{Cognition}_i + \sum_k \delta_k X_{ki} + \varepsilon_i \quad (1)$$

Waste denotes the monetary value of participant's food waste due to expiration, *cognition* represents the subjective cognition of the FDL, *i* represents individual, *X* encompasses control variables, including participant and household characteristics, and food consumption habits, and detailed variable definitions and descriptive statistics are presented in Table 1. *k* represents the number of control variables, and ε represents random error term.

To ensure the reliability of our benchmark OLS results, we conduct three robustness tests using alternative model specifications and estimation techniques. (a) Modifying the model. Considering that the food waste values represent truncated data with a cluster of zero observations, we replace the original OLS model with the Tobit model to account for censoring at zero. (b) Winsorization treatment. Following Zhao et al. [57], we winsorize extreme monetary values of food waste by recoding observations below the 5th percentile and above the 95th percentile to their respective threshold values. (c) Propensity Score Matching (PSM). PSM is a suitable method for reducing bias and controlling the effect of observable variables, thereby producing a quasi-random trial effect [58]. After dichotomizing FDL cognition (1 = confused [>4 Likert points]; 0 = not confused [≤ 4]), we perform kernel matching using all Table 1 covariates. In addition, considering the prevalent research context where online survey methods often lead to a participant pool with relatively high education levels, we also employ PSM method to perform nearest neighbor matching and kernel matching between sub-bachelor's and bachelor's (or above) demographic groups within the existing sample to mitigate potential robustness issues in research findings.

We conduct additional analyses to examine how the FDL cognition-food waste relationship varies across population subgroups and try to reveal several patterns. First, we examine regional disparities by

dividing China into eastern, central, and western regions. Second, considering that participants with different educational levels may vary in their ability to acquire and process information, which may lead to different cognition and food waste behavior, we explore differences in educational levels. Finally, we split the sample into two groups based on the median age of the population to investigate potential heterogeneity driven by the age. To investigate the mediating role of FDL dependence in the relationship between FDL cognition and food waste behavior, we construct a three-stage econometric model following the approach developed by Wen and Ye [59] and was widely applied in current studies [60,61]. Combined with formula (1), the other two formulas used are as follows:

$$Dep_i = \beta + a \text{ cognition}_i + \sum_k \beta_k X_{ki} + \mu_i \quad (2)$$

$$\text{Waste}_i = \gamma + c' \text{ Cognition}_i + b \text{ Dep}_i + \sum_k \gamma_k X_{ki} + \theta_i \quad (3)$$

Dep denotes the participant's dependence on FDL, μ , θ represent random error terms. The three steps analysis are as follows: In the first step, we examine the influence of cognition on dependence and the impact of cognition and dependence on food waste behavior, which means examining the significance of coefficients a and b . If both are statistically significant, the indirect effect of FDL dependence between FDL cognition and food waste behavior is significant. If either coefficient is non-significant, we examine the second step - whether the 95% confidence interval for the product term ab contains 0. If it does not include 0, then continue the third step; if it includes 0, then there is no mediating effect, and the test ends. In the third step, we test coefficient c' . If c' is non-significant, it indicates that the FDL dependence completely mediates FDL cognition and food waste behavior. If the coefficient of c' is significant, the direct effect is significant, and we proceed to step 4. In the fourth step, we compare the signs of ab and c' . Consistent signs indicate partial mediation, while opposite signs suggest a suppression effect [59,62]. To ensure the robustness of the research findings, we conduct the test on the empirical regression results here using the same method winsorization treatment and PSM as the robustness tests mentioned above.

4. Results

4.1. Relationship between FDL subjective cognition and food waste behavior

4.1.1. Benchmark regression results

Participants report discarding expired food worth CNY 190 per capita annually. Considering that 24 participants (1.05% of the sample) indicate they have not discarded any expired food in the past year. Extrapolating this to China's approximate population of 1.4 billion

people with 66.16% are the urban population [63], the estimated annual food waste due to expiration amounts to CNY 174 billion in urban China. The mean score of FDL cognition is 3.51 (below the scale midpoint of 4), and 26.42% of consumers express confusion about FDL meanings (defined as selecting a score >4 on the 7-point Likert scale), which means that consumers' subjective cognitive level regarding FDL is relatively high. The OLS regression results (Table 2, column 1) reveal a statistically significant positive relationship between consumers' subjective cognition of FDL and food waste behavior. Specifically, greater confusion about FDL (indicating lower cognitive levels) is associated with increased food waste. Quantitatively, a one-unit increase in consumer confusion level corresponds to an additional 11.32 yuan in annual per capita food waste expenditure.

4.1.2. Robustness tests

The regression results are robust. (a) *Modifying the model*. As shown in column (2) of Table 2, the significant relationship between FDL cognition and food waste persists, confirming that zero observations do not bias our core findings. (b) *Winsorization treatment*. The re-estimated results (Table 2, column 3) remain statistically significant, demonstrating that our findings are not driven by outlier effects. (c) *Propensity Score Matching (PSM)*. The excellent common support domain is shown in Fig. 1 (a). The label "Treated: Off support" in (a) refers to those observations in the treatment group that fall outside the common support region of the propensity score distribution, which means no sufficiently comparable counterparts could be found in the control group for these treated units. These samples will be excluded from subsequent analysis. In our study, this proportion is small, indicating a good common support condition. The matching results of observable variables are shown in Fig. 1 (b), and the bias of each variable is closer to zero, indicating the matching is effective and we can conduct further tests for robustness [64]. The PSM-adjusted estimates (Table 2, column 4) reconfirm our benchmark results, providing robust evidence that FDL confusion systematically increases food waste. The corresponding results obtained through the educational level matching approach are presented in columns (5-6) of Table 2. As shown in Fig. 2 (a, c) for the common support domain and Fig. 2 (b, d) for the matching results of observable variables correspond to nearest neighbor matching and kernel matching respectively, all findings confirm that the robustness of the benchmark regression results remains unaffected by sample bias.

4.1.3. Heterogeneity analysis

(a) *Regional heterogeneity*. Table 3 (columns 1-3) presents regional breakdowns showing significant effects in eastern and western regions, but not in central China. This unexpected pattern persists despite nationwide FDL standardization, suggesting the need for targeted mitigation measures. (b) *Education-level heterogeneity*. The cognition-waste relationship proves significant only for consumers with bachelor's degrees or less (Table 3, columns 4-6), which also underscores the

Table 2
The relationship between FDL cognition and food waste behavior.

Variables	(1)	(2)	(3)	(4)	(5)	(6)
Cognition	11.316*** (3.260)	6.903*** (1.854)	8.301*** (2.334)	28.012*** (9.052)	10.932*** (3.449)	11.114*** (3.313)
Control variables	Yes	Yes	Yes	Yes	Yes	Yes
Constant	-34.714 (50.848)	-42.889 (53.523)	17.046 (38.879)	-7.027 (49.102)	14.798 (57.485)	14.180 (52.319)
R-squared	0.091	/	0.099	0.089	0.085	0.087
Pseudo R2	/	0.0069	/	/	/	/
ATT	/	/	/	2.86	2.69	3.31
Observations	2282	2282	2282	2280	2094	2219

Notes: Robust standard errors in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. We conduct a multicollinearity test for the benchmark regression model to avoid multicollinearity. The mean VIF (variance inflation factor) is 1.16, and the maximum VIF value is 1.33, indicating no severe multicollinearity in the variable selection. The coefficients of the Tobit regression model in column (2) have been transformed (dy/dx for factor levels is the discrete change from the base level). The control variables are consistent with those shown in Table 1.

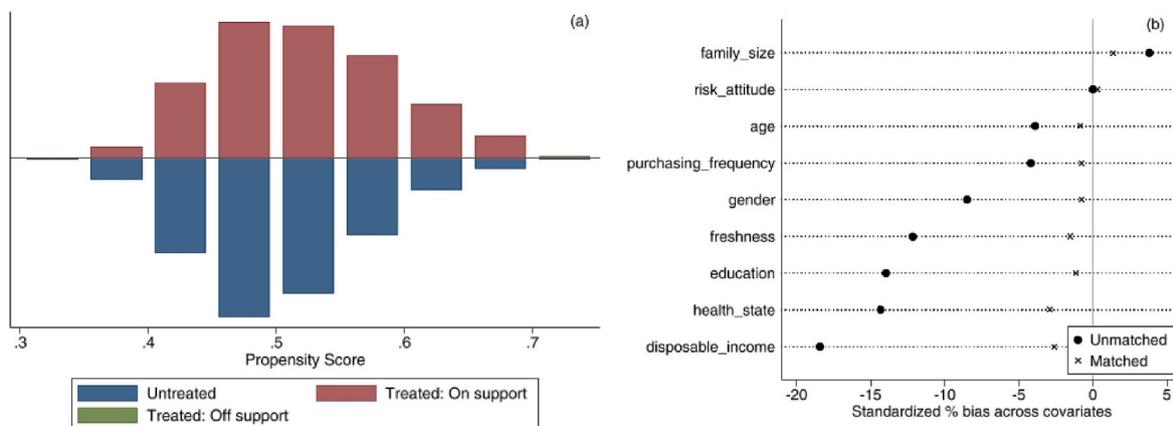


Fig. 1. Common support domains (a) and kernel matching results (b). The y-axis in (a) represents density, and that in (b) represents covariates.

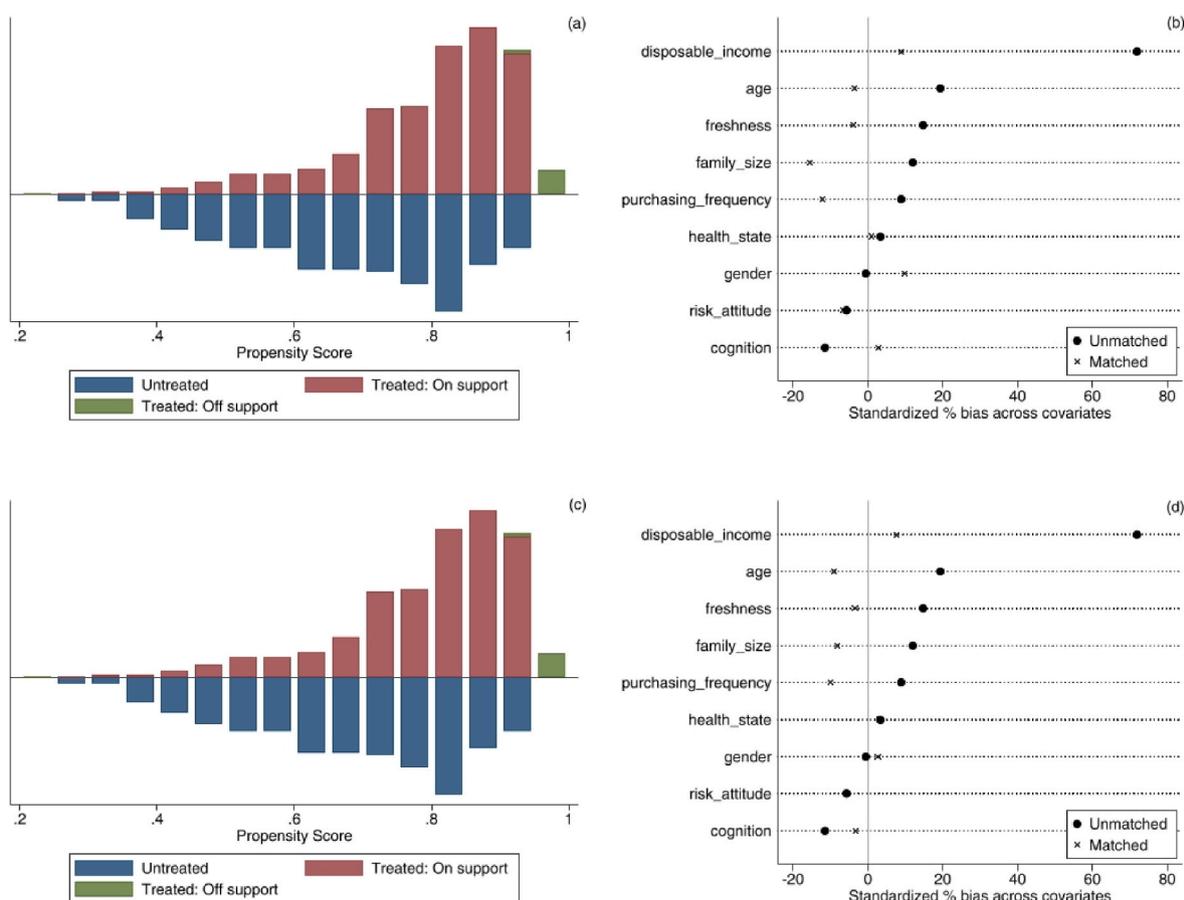


Fig. 2. Common support domains (a, c) and matching results (b, d) correspond to nearest neighbor matching and kernel matching respectively. The y-axis in (a, c) represents density, and that in (b, d) represents covariates.

importance of targeted educational outreach for these populations to reduce their confusion about the meaning of FDL and food waste. (c) Age heterogeneity. The results are shown in columns (7-8) in Table 3. The regression coefficients of both age groups pass the significance test, which means this relationship is a common issue, and the situation does not improve with age.

4.2. Further mechanism analysis

4.2.1. Benchmark regression results

To elucidate the underlying mechanisms through which consumers'

FDL cognition affects food waste behavior, we employ a three-stage model to examine the role of FDL dependence (see Table 4). The first-stage regression results are consistent with the regression in section 4.1.1, which also shown in column (1) of Table 4. The second stage regression results are shown in column (2) of Table 4, and we identify a significant negative relationship between FDL cognition and dependence. This indicates that consumers with greater confusion about FDL meanings demonstrate lower dependence on FDL, consistent with our theoretical expectations. What needs to be clarified here is that the mean score of FDL dependence is 5.6 (well above the midpoint of 4), with 82.69% of participants indicating they are dependent on FDL for food

Table 3
Heterogeneity regression results.

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Eastern	Central	Western	Edu ₁	Edu ₂	Edu ₃	Age ₁	Age ₂
Cognition	12.626** (5.537)	5.169 (5.726)	16.153*** (5.508)	14.795** (6.641)	12.221*** (3.934)	5.026 (11.345)	8.261* (4.783)	14.463*** (4.460)
Area control	/	/	/	Yes	Yes	Yes	Yes	Yes
Education control	Yes	Yes	Yes	/	/	/	Yes	Yes
Age control	Yes	Yes	Yes	Yes	Yes	Yes	/	/
Other variables	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Constant	115.214 (91.120)	2.297 (80.720)	-135.627 (83.415)	189.578** (87.886)	-0.627 (71.696)	-266.032 (194.544)	-91.284 (75.304)	-164.345** (74.974)
R-squared	0.064	0.129	0.115	0.102	0.088	0.103	0.084	0.095
Observations	790	748	744	510	1526	246	1104	1178

Notes: Robust standard errors in parentheses. ***p < 0.01, **p < 0.05, *p < 0.1. According to the criteria set by the National Bureau of Statistics of China, the eastern region includes 11 provinces: Beijing, Tianjin, Hebei, Liaoning, Shanghai, Jiangsu, Zhejiang, Fujian, Shandong, Guangdong, and Hainan; the central region includes eight provinces: Heilongjiang, Jilin, Henan, Shanxi, Anhui, Jiangxi, Hubei, and Hunan, and the remaining provinces are classified as the western region. Edu₁₋₃ represent the level of education from low to high, and Age₁₋₂ represent the age below and above the median, respectively. The control variables are consistent with those shown in Table 1.

Table 4
Mechanism analysis and the robustness test results.

Variables	Benchmark regression		Winsorize regression			PSM regression			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	FW	Dep.	FW	FW	Dep.	FW	FW	FW	FW
Cognition	11.316*** (3.260)	-0.045** (0.018)	11.646*** (3.253)	8.301*** (2.334)	-0.045** (0.018)	8.547*** (2.335)			
Dependence			7.396** (3.703)			5.544** (2.746)		7.007* (3.892)	7.047* (3.741)
Dependence*							21.144* (11.361)		
Control variables	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Constant	-34.714 (50.848)	4.970*** (0.303)	-71.474 (53.910)	17.046 (38.879)	4.970*** (0.303)	-10.509 (41.211)	23.714 (47.078)	23.910 (57.097)	30.829 (51.594)
R-squared	0.091	0.014	0.092	0.099	0.014	0.101	0.087	0.082	0.081
ATT	/	/	/	/	/	/	1.73	1.89	3.23
Observations	2282			2282			2282	2121	2241

Notes: ***p < 0.01, **p < 0.05, *p < 0.1. The control variables are consistent with those shown in Table 1.

edibility judgments (defined as selecting a score >4 on the 7-point Likert scale) in our sample, which means that FDL plays a significant role in consumers' judgment of the edibility of food, and a large proportion of consumers rely on FDL to assess the edibility of food. Further, we simultaneously introduce the FDL cognition, dependence, and food waste behavior in the third-stage model, and the results show that FDL cognition and dependence significantly affect food waste behavior (Table 4, column 3). Based on the results of the above three stages, we analyze and conclude that the sign of *ab* is opposite to the sign of *c'*, which indicates a classic suppression pattern that FDL dependence plays

a suppression effect in the influence path of cognition to food waste [59, 62]. Since the absolute value of *c'* is greater than *c*, this suppression effect enhances the relationship between FDL cognition and food waste [65].

4.2.2. Robustness tests

To ensure the robustness of our regression results, we implement two validation approaches similar to that in section 3.3 Model settings. (a) Winsorization treatment. We conduct robustness test for the three-stage analysis, with corresponding results presented in columns (4-6) of

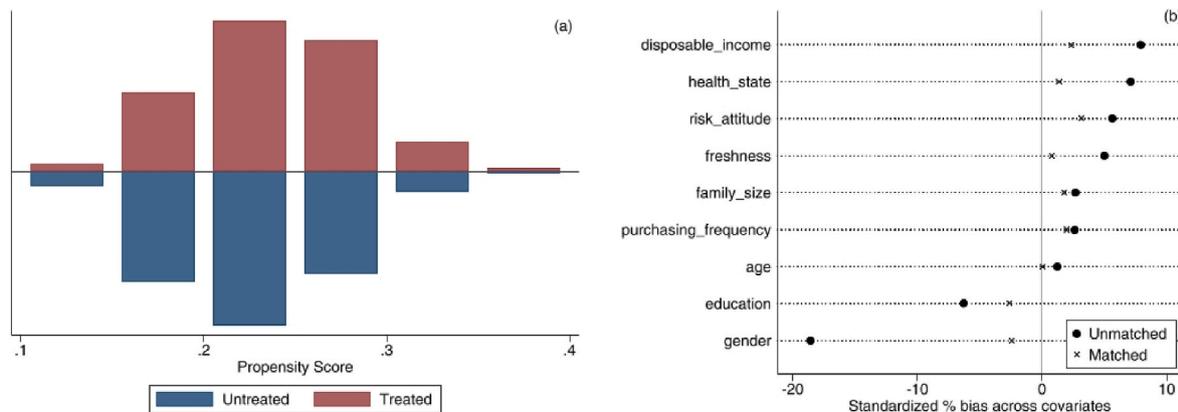


Fig. 3. Common support domains (a) and kernel matching results (b). The y-axis in (a) represents density, and that in (b) represents covariates.

Table 4. (b) PSM. We address potential endogeneity through PSM analysis again through transforming the suppression variable dependence into a 0-1 dummy variable (naming less than and equal to “6” as “0” and naming equal to “7” as “1”, which means whether consumers rely entirely on the FDL or not) and demonstrate its relationship with food waste. The common support domain is shown in Fig. 3 (a), and the matching observable variables included as shown in Fig. 3 (b), the bias of each variable is closer to zero, indicating that the match is effective [64]. Post-matching regression analyses yield consistent results (Table 4, column 7), confirming the robustness of our primary findings. The corresponding results obtained through the educational level matching approach are presented in columns (8-9) of Table 4. As shown in Fig. 4 (a, c) for the common support domain and Fig. 4 (b, d) for the matching results of observable variables correspond to the nearest neighbor matching and kernel matching respectively, all findings also confirm that the robustness of the benchmark regression.

5. Discussion

5.1. Theoretical contributions and implications

Through empirical analysis, this study reveals the complex relationships among consumers' subjective cognition regarding FDL, their dependence on these labels, and their food waste behavior. The main findings not only confirm theoretical expectations but also advance the existing literature in the following key aspects. First, this study provides the first global quantitative evidence for the mechanism that label subjective cognition could lead to food waste. We found a statistically significant positive relationship between consumers' subjective cognition and food waste behavior. This finding aligns with the consensus in

research from developed economies, which suggests that consumers tend to adopt a risk-averse strategy - often discarding food - when uncertain about its edibility [13]. However, prior literature has primarily focused on qualitative descriptions or case studies within specific contexts, lacking generalizable quantitative tests of the link between individual-level cognition and behavior. Our study confirms the existence and strength of this association, thereby elevating this theoretical proposition from a contextual finding to a generalizable empirical rule. This significantly enhances the understanding of upstream drivers of food waste.

Second, this study uncovers the crucial dual role of FDL dependence, constructing and validating a previously overlooked mediating pathway. A counterintuitive yet vital finding is that FDL confusion reduces consumers' dependence on the labels, while a higher level of dependence, in turn, strengthens the positive impact of confusion on food waste. This indicates that dependence acts as an exacerbating mediator in this relationship, and existing research overlooks its potential negative effects when consumer comprehension is insufficient. Our quantitative framework places cognition, dependence, and waste behavior within a single analytical model, empirically demonstrating that: in the current context of widespread consumer confusion, blindly promoting reliance on FDL to guide consumption decisions may inadvertently increase waste by substituting consumers' own sensory judgments. This finding significantly supplements theoretical models of label effectiveness. Promoting label dependence can become an effective strategy for reducing food waste only when auxiliary measures (e.g., public education) successfully lower consumer confusion. Another point to be discussed is our results show that the mean score of FDL cognition is 3.51 and 26.42% of consumers express confusion about FDL meanings. This proportion is significantly lower than the 75% confusion rate

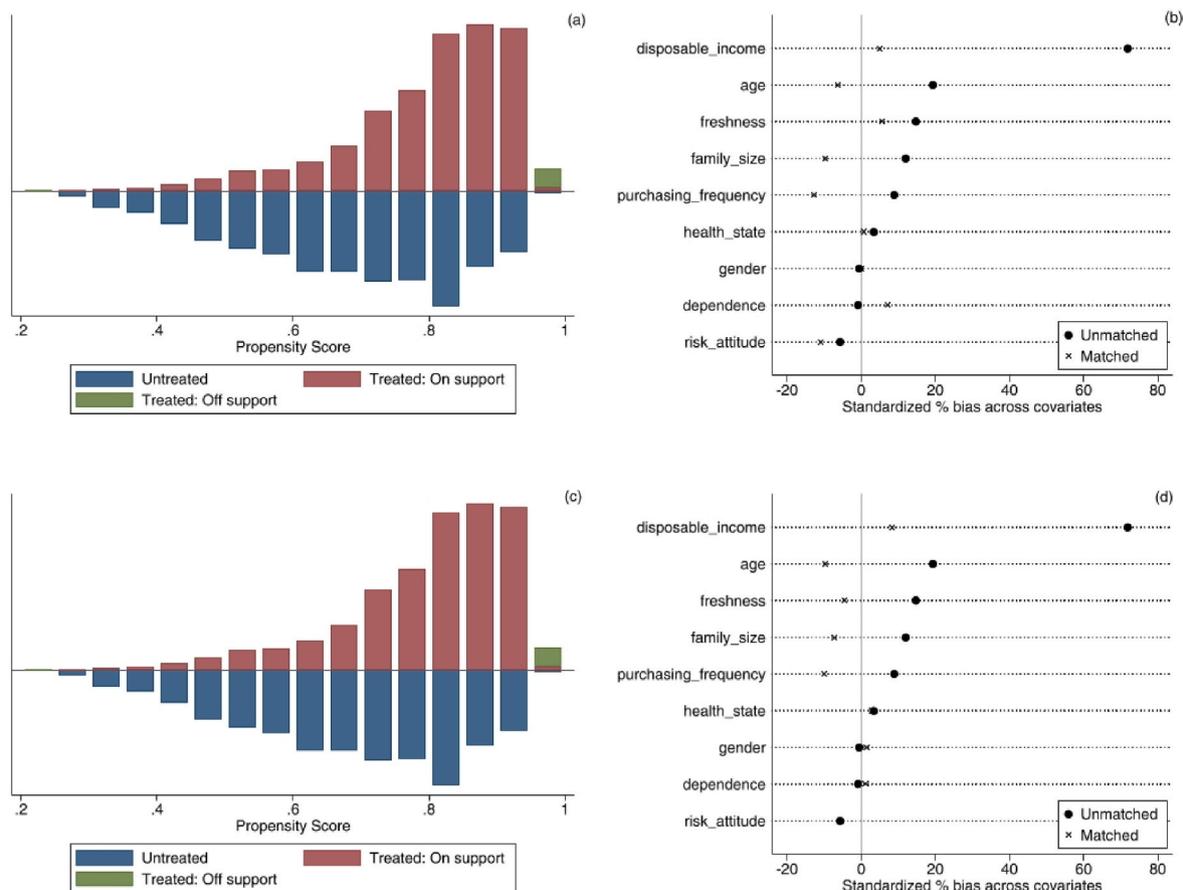


Fig. 4. Common support domains (a, c) and matching results (b, d) correspond to nearest neighbor matching and kernel matching respectively. The y-axis in (a, c) represents density, and that in (b, d) represents covariates.

reported in a U.S. sample [17], a discrepancy potentially attributable to differences in stakeholder representation. While the U.S. study includes stakeholders across the food supply chain, our study focuses solely on consumers.

Finally, through detailed heterogeneity analysis, this study deepens the understanding of the boundary conditions for the aforementioned mechanisms and points the way for theoretical development. The research finds that the core relationships vary significantly across regions and age groups. Regarding regional heterogeneity, the effect of confusion on waste is most pronounced in the western region. This contradicts our initial expectation based on economic development levels - the effect is not significant in the eastern region, which has the highest level of confusion. A potential theoretical explanation is that consumers in the eastern region, despite being more confused, may have access to richer alternative information channels (e.g., social media, dietitian consultations), thereby weakening the direct behavioral consequences of FDL confusion. Conversely, consumers in the western region may rely more heavily on standardized label information, making the behavioral impact of confusion more direct and intense. This contrast suggests that future theoretical models need to incorporate factors like information environment richness as moderating variables. Regarding age heterogeneity, we found that the impact of confusion on waste is pervasive across different age groups. This appears to create a tension with findings by Leib et al. [66] and Stancu et al. [6] that older adults waste less per capita. This highlights the multiplicity of causes for food waste. Our study focuses specifically on information cognition as a particular antecedent, whereas the effect of age on waste likely operates more through non-cognitive pathways such as habit formation and meal planning. This difference underscores the necessity of building integrative theoretical frameworks that distinguish and integrate different antecedent pathways and their interactions.

5.2. Limitations and future research

The limitations of this study are as follows. First, the most significant limitation concerns potential endogeneity due to the bidirectional relationship between consumer cognition and food waste. Although our model is grounded in established theory and empirical consensus [15, 18], we acknowledge that reverse causality may exist. For example, individuals with prior experiences of high food waste may become more sensitive to FDL, altering their subsequent cognitive responses. Despite extensive efforts to mitigate this issue - including careful research design and rigorous testing of potential instrumental variables (IVs) - no robust IV was identified within the constraints of our cross-sectional data. For example, candidate instruments such as participants' primary sources of FDL information, failed to meet the exclusion restriction. Thus, the estimated relationship may more reflect correlation. Another point that needs to be raised is that the pervasive consumer misunderstanding surrounding date labels may attenuate the severity of this issue. This cognitive disconnect suggests that consumers often discard food believing it to be unsafe, not wasteful, thereby reducing the likelihood of a systematic behavioral feedback loop based on perceived waste. Future studies could adopt longitudinal or experimental designs to clarify temporal precedence, and further exploration of IVs or use of panel data with fixed-effects models would also help establish causality. Transparency regarding this limitation contextualizes our findings and highlights meaningful directions for future research. Second, although using monetary value to measure food waste is a common practice [67] when actual weight data are less available especially for online survey methods, we acknowledge that this approach brings a limitation. This is because a higher monetary value does not necessarily indicate more food being discarded (in terms of weight), which may be more prevalent in higher-income households. Therefore, future studies could adopt on-site measurement methods to make up for the difficulty of obtaining weight data and conduct comparative empirical analysis. Third, this research mainly focuses on urban consumers who are convenient for

conducting online surveys, without conducting surveys on consumers in rural areas. Given the dietary and habitual differences between urban and rural residents, conducting comparative experiments focusing on rural populations to examine cognition and behavioral disparities represents a promising avenue for future research. Fourth, the reliance on Likert-scale measurements, while providing standardized comparison, may obscure nuanced thresholds in FDL cognition and dependence. Future studies could combine psychometric scales with behavioral experiments to establish more valid measurement frameworks. Finally, like all online survey data collection methods, online surveys inherently introduce a certain degree of sample bias. Our online urban sample exhibits a higher education level than the general netizens in China and automatically excludes populations without mobile devices and those uninterested in the topic. Although we have acknowledged in the manuscript that this is a common issue in online surveys and the official internet general netizens statistics do not align with our survey cities, it would be beneficial to conduct further research.

5.3. Practical implications and policy recommendations

The findings carry clear practical and policy implications. First, the results demonstrate that strengthening public understanding of FDL meanings can mitigate label confusion and subsequent food waste. Targeted educational initiatives should prioritize consumers in eastern and western regions, as well as those with lower education levels. Second, considering the suppression effect of FDL dependence, it is necessary to popularize the meaning of FDL to consumers first in the program, followed by calling on them to make better use of FDL to finally reduce their food waste effectively. Third, results call for the simplification and standardization of the FDL system itself. A labeling system that is intuitive and accurately understood by consumers is the most effective means to fundamentally disrupt the negative chain of "confusion-dependence-waste." Food manufacturers and policymakers should collaborate to design intuitive, consumer-friendly FDL expressions. For instance, they can propose more understandable and easy-to-understand expressions of FDL to jointly reduce consumers' confusion about FDL from both practical operation and policy levels. Ensuring scientific rigor in label standards while enhancing consumers' flexible use of labels may further curb food waste.

6. Conclusions

This study quantitatively examines the impact of consumers' FDL cognition on household food waste, with a further exploration of the role of FDL dependence in this process. The key findings are as follows: Consumers' subjective cognition of FDL exhibits a significant positive correlation with household food waste, with notable regional and educational-level heterogeneity. Considering the current consumers' generally high dependence on FDL, consumers may give up more food to avoid the risk of foodborne illness, which would significantly enhance the relationship mentioned before and further exacerbate food waste. The results offer valuable insights for consumers, food manufacturers, and policymakers, thereby accelerating progress toward United Nations Sustainable Development Goal 12.3 "Halve food waste" by 2030.

CRedit authorship contribution statement

Shujun Cheng: Writing – review & editing, Writing – original draft, Investigation, Formal analysis, Conceptualization. **Liang Cheng:** Writing – review & editing, Writing – original draft, Methodology, Formal analysis. **Yanjuan Ren:** Writing – review & editing, Methodology, Conceptualization. **Minjuan Zhao:** Writing – review & editing, Supervision, Project administration, Funding acquisition.

Consent to participate

The study was anonymous. Informed consent was obtained from all individual participants included in the study.

Ethics approval

Approval was obtained from the ethics committee of Northwest A&F University. The procedures used in this study adhere to the tenets of the Declaration of Helsinki.

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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.

Data availability

Data will be made available on request.

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