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Alternative water resources for a more sustainable agriculture: European consumers' perceptions of the use of reclaimed and desalinated water in food production

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Abstract
Water scarcity is increasing worldwide, but its effects are particularly severe in Southern Europe, where limited water resources are further strained by climate change and the rise of water-intensive agriculture. In response, EU countries are developing innovative water strategies, expanding the use of reclaimed (treated wastewater) and desalinated water to secure irrigation. However, consumer response to foods produced with these non-conventional waters remains underexplored. This study analyses European consumers' perceptions of the use of non-conventional water irrigation sources in almond production, along with the EU origin and organic production labels. To this end, discrete choice experiments are used in a sample of 1,371 consumers across three European countries (Spain, Germany, and Sweden). The results show consistent premiums for EU origin and organic production in all countries, while proposed irrigation water sources attract less consumer attention. Despite expectations, reclaimed water does not face greater rejection among consumers than desalinated water. However, notable cross-country differences emerge: Spanish consumers tend to reject almonds irrigated with desalinated or reclaimed water, whereas German and Swedish consumers show neutral or mixed responses. Latent class segmentation within these countries reveals substantial heterogeneity, identifying traditionalist segments, but also groups with a positive willingness to pay for almonds produced employing the proposed water sources. Overall, these alternative water sources appear to be market-compatible, as consumers reveal no strongly negative attitudes. Nevertheless, the continuing importance of traditional attributes such as origin and production system supports the strategy of combining established quality labels with information about the source of water used.

Keywords Choice experiment, Consumers' attitudes, Consumers' willingness to pay, Cross-country comparison, Almonds

Introduction

Water scarcity is becoming a cause for concern throughout Europe, particularly in the Mediterranean, which is recognised as climate-change "hotspot", where amplified warming, more frequent and intense droughts and seasonal deficits point to structural imbalances in water supply and demand (EEA 2024; EU Parliament Council 2020). Across countries, water scarcity may be caused by increased industrial demand, population growth, climate change and the continued shift toward irrigated farming, with pressures especially acute across the Mediterranean (Romero-Trigueros et al. 2020). This situation calls for more efficient and sustainable water use, especially in agriculture, where pressures on water bodies and ecosystems are greatest (EEA 2024). Agriculture accounts for around 70% of freshwater withdrawals, underscoring the sector's central role in water-security strategies (FAO 2017).

In response to growing water scarcity (particularly in vulnerable regions) and in line with the Circular Economy Action Plan and the EU Strategy on Adaptation to Climate Change, the European Commission is promoting an integrated approach to water management that coordinates all available resources, both conventional and non-conventional (EC 2020; Tocados-Franco et al. 2024). Recent technological advances in wastewater treatment and desalination, together with programmes promoted by the European Green Deal and the new Circular Economy Action Plan, have driven growth in the production and use of non-conventional water (Ricart et al. 2021).

In this context, reclaimed water (defined as urban wastewater treated in accordance with Directive 91/271/EEC and then subjected to additional processing in a reclamation facility) and desalinated water (produced by removing dissolved salts from saline sources such as seawater and brackish groundwater), are increasingly positioned as reliable complements to conventional supplies (Council Directive 1991; EU Parliament Council 2020; Karimidastenaei et al. 2022). At European level, the reuse of treated wastewater for agricultural irrigation is regulated by Regulation (EU) 2020/741, which establishes harmonised minimum quality requirements, monitoring obligations and risk management plans to ensure the protection of human health and the environment (EU Parliament Council 2020). This regulatory framework has been implemented through Commission Delegated Regulation (EU) 2024/1765 (EC 2024). The use of reclaimed water is already increasing in several European countries and is expected to expand substantially in the coming years as policy support and treatment technologies mature (EC 2018; Pistocchi et al. 2017). Because adoption is largely a response to scarcity, the largest capacities and reuse volumes are concentrated in arid regions; in the Mediterranean context, Spain is particularly notable, ranking among global leaders in both desalination output and wastewater recycling (Jodar-Abellan et al. 2024).

Non-conventional water sources can enhance water security and stabilise agricultural yields. Reclaimed water can raise crop productivity and support soil conditions, while desalinated water provides a reliable, climate-independent supply; taken together, both sources expand agricultural water availability and help stabilise yields and farm incomes, bolstering water security (Abou Jaoude et al. 2025; Martínez-Alvarez et al. 2023; Palatnik et al. 2025). In addition, using reclaimed and desalinated water instead of fresh water protects rivers and aquifers from over-extraction, which reduces ecological pressures and potential conflicts between competitors (Martínez-Granados and Calatrava 2014; Mizyed 2025). However, these supplies need treatment and analysis to ensure irrigation safety standards, as they may contain high levels of salinity or nitrogen, and residual contaminants, such us heavy metals and pathogens (Chen et al. 2013; Singh 2021). Furthermore, desalinated water is energy-intensive and therefore relatively costly, so its large-scale use can be an economic and environmental burden where energy is expensive or ecosystems are sensitive (Eke et al. 2020; Elsaid et al. 2020). These limitations can be mitigated by powering with renewable energy, particularly solar, for desalination, and careful planning and management to minimise environmental impacts (Elsaid et al. 2020; Panagopoulos and Haralambous 2020). Field studies shows that both reclaimed and desalinated water are agronomically suitable for irrigation when managed to regulatory specifications (Chen et al. 2013; Martinez-Alvarez et al. 2020; Truchado et al. 2021) in line with the minimum quality classes, control frequencies and risk management plans prescribed by legislation.

Given these considerations, the present study focuses on almonds as a suitable case study for examining consumer responses to irrigation water. The almond tree, rather than the edible nut, is directly exposed to irrigation water, which may increase consumer acceptance (Ellis et al. 2022). Moreover, almond consumption has grown in Europe, with Spain and Germany ranking as the highest per-capita consumers, and Spain being the main producer in the EU (CBI 2019; FAO 2017). In Spain specifically, persistent scarcity and recurrent drought already necessitate the continuous optimisation of irrigation management (Egea et al. 2010; Moldero et al. 2022). Moreover, almond *(Prunus dulcis* (Mill.) D.A. Webb) is a major European tree-nut and can be considered irrigation-dependent to maintain economic viability, particularly in regions with low rainfall and high evapotranspiration rates (Egea et al. 2010).

Despite the growing momentum for the use of non-conventional water sources in agriculture, there is a notable gap in understanding consumers' views on their adoption in the sector. According to Dolnicar and Schäfer (2009), consumers' knowledge about the use of desalinated and recycled water has been historically low. This is highly important, as consumer knowledge is crucial to ensure consumer acceptance of circular and more sustainable production practices (Ornelas Herrera et al. 2025; Siegrist 2008). In this regard, various studies have explored how consumers perceive desalinated and reclaimed water. For example, Dolnicar and Schäfer (2009) found that consumers tend to associate recycled water with health risks and desalinated water with environmental disadvantage. In assessing the determinants of acceptance, Savchenko et al. (2019) and Verhoest et al. (2022), found that disgust, food neophobia and safety concerns are the principal factors underlying rejection of foods produced with reclaimed water, reflecting that limitations are similar to those reported for other novel food technologies (Siegrist and Hartmann 2020). In addition, perceptions of quality and benefits linked to desalinated and reclaimed water also influence acceptance or rejection (Gómez-Ramos et al. 2024; Villacorta-Ranera et al. 2025).

Sociodemographic characteristics have also been found to determine the acceptance of desalinated and reclaimed water. Studies indicate that the influence of these variables is heterogeneous and context-dependent (Fielding et al. 2019; Garcia-Cuerva et al. 2016). Evidence indicates that older consumers seem more likely to accept the use of desalinated and recycled water, while gender and education are not determining factors (Dolnicar et al. 2011; Dolnicar and Schäfer 2009). Additionally, higher levels of education generally correlate with greater acceptance of reclaimed water (Garcia-Cuerva et al. 2016).

Based on these water supply alternatives, non-conventional water sources (reclaimed and desalinated) offer a way to maintain agricultural production in situations of scarcity while promoting sustainable and circular economy goals. Understanding how consumers perceive foods produced with non-conventional water sources is essential to guide both innovation and policy. In this regard, the present study examines European consumers' attitudes towards desalinated and reclaimed water to secure irrigation for almond production. Based on preferences and willingness to pay in Spain, Germany and Sweden, the study aims to contribute to the design of sustainable and socially accepted irrigation and labelling practices in European agriculture.

Methods

Database

We examined consumer preferences for almonds using an online survey conducted in Spain, Germany and Sweden. Respondents who participated in this study had to be aged 18 years or over, be responsible for more than half of the food purchases in their household and buy almonds at least once a month. In January 2025, a total of 1,371 surveys were collected in Spain (460 consumers), Germany (459 consumers) and Sweden (452 consumers). We selected Sweden (North), Germany (Centre) and Spain (South) to capture Europe's structural gradient in water conditions and non-conventional water use: water scarcity and drought risks are most acute in Southern Europe, moderate in central regions and lower in the north (EEA 2024). Moreover, almond is widely consumed in these countries, with Spain and Germany being among the highest per-capita consumers and Spain the EU's leading producer (CBI 2019; FAO 2017). According to Eurostat (2024), almonds are the most important nut crop in the European Union in terms of cultivated area, with Spain accounting for around 85% of the EU's almond tree production area and around 300 thousand tonnes of almond production, illustrating the importance of this crop within the European agricultural sector. Participant recruitment and survey administration were carried out by Qualtrics LLC (Provo, US). Respondents were randomly selected using sampling quotas based on gender and age. All participants provided informed consent, and our study was approved by the institutional ethics committee.

We implemented two procedures to ensure data quality. First, before presenting the set of choice tasks, respondents were asked if they had "given [their] full attention to the study so far" and whether, in their honest opinion, we should use their responses. This "attention check" question was placed just before key questions (choice tasks) and is based on evidence that such questions motivate respondents to pay more attention rather than detecting unreliable responses (Meade and Craig 2012). Second, we only retained respondents whose completion time exceeded one-third of the average survey length for the sample.

Based on this literature and the context of our case, we proposed the following hypotheses to be tested using the discrete choice experiment: (i) Compared to conventional irrigation, consumers show a lower willingness to pay (WTP) for almonds irrigated with reclaimed and desalinated water; (ii) WTP differs between countries (Spain, Germany and Sweden), with higher penalties expected in Southern Europe and weaker or neutral effects in Northern and Central Europe; (iii) Determinants such as prior knowledge about reclaimed water, openness to sustainable technologies and water conservation behaviour are positively associated with WTP for almonds irrigated with reclaimed water; (iv) Within each country, consumers segments differ in their WTP for irrigation water types, ranging from traditional-oriented groups to undecided and innovation-oriented groups.

Choice experiment design

In the discrete choice experiment (DCE) design, almonds were presented using four attributes and their respective levels: origin, irrigation water, production system and price (Table 1). Regarding attributes and levels evaluated, two levels of origin were stablished: European Union origin and Non-European Union origin. Second, we included irrigation water production, since the main goal of the study was to examine consumers' WTP for almonds produced using different types of irrigation water. Therefore, the three levels of this attribute were (i) irrigated with conventional water; (ii) irrigated with desalinated water; and (iii) irrigated with reclaimed water. Third, we included production system as an attribute, referring to the agricultural production system used for almond production. Thus, two levels of this attribute were established: no information and organic production. Finally, price included three levels considering the current market prices for packaged almonds in supermarkets in Spain (2.00€/200 g; 3.50€/200 g; 5.00€/200 g) and the equivalent for Germany (2.00€/200 g; 3.50€/200 g; 5.00€/200 g) and Sweden (25.00kr/200 g; 40.00kr/200 g; 55.00kr/200 g).

Following the choice tasks, we included questions in the survey designed to test our hypotheses on attitudinal factors. Specifically, we asked respondents questions about (i) whether they had heard of the term "reclaimed water" prior to the study (i.e. HEARING); (ii) whether they had a positive attitude towards openness to new sustainable food technologies (OT_{food}) (Berthold et al. 2022); and (iii) whether they had a positive attitude towards water conservation behaviour (WCB) (Verhoest et al. 2022).

Each choice scenario included two hypothetical almond alternatives and an opt-out option (no choice option) using a D-optimal and efficient design defined by Ngene 1.2. software (Rose and Bliemer 2009). The 16 choice sets were divided into two blocks of eight. Each respondent completed eight randomly ordered choice tasks to avoid ordering effects. Figure 1 shows an example of a choice set presented to respondents in Spain (translated into English). The shelled almond pack image is AI-generated to simulate a

Table 1 Attributes and levels used in the conjoint designs

Attributes		Levels	
Origin		EU origin	
		Non-EU origin	
Irrigation water		Irrigated with conventional water	
		Irrigated with desalinated water	
		Irrigated with reclaimed water	
Production system		No information	
		Organic production	
Price	**Spain**	**Germany**	**Sweden**
	2.00€/200 g	2.00€/200 g	25.00kr/200 g
	3.50€/200 g	3.50€/200 g	40.00kr/200 g
	5.00€/200 g	5.00€/200 g	55.00kr/200 g

Note: 1kr = 0.09€

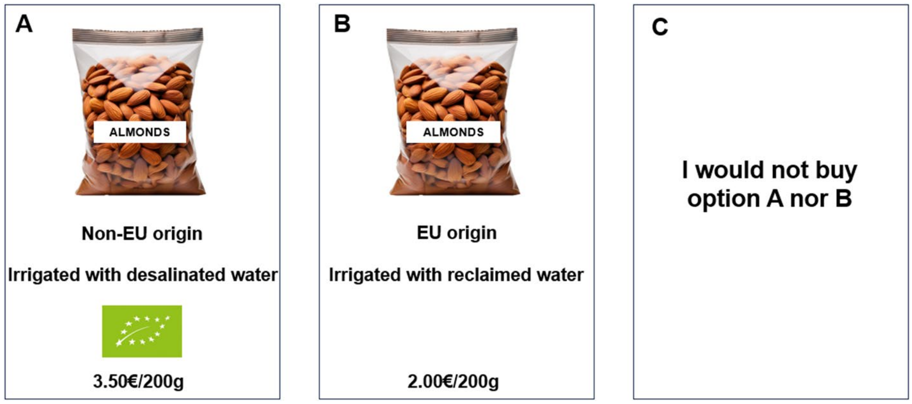

Fig. 1 An example of a decision-making situation

realistic product (OpenAI 2025). Before the choice tasks, we provided a description of the different attributes and levels together with a cheap talk script to eliminate the hypothetical bias (Lusk 2003). After the choice task, respondents completed a questionnaire covering socioeconomic characteristics (including gender, age and level of education) and their attitudes, including consumers' attitudes towards openness to new sustainable food technologies (OT_{food}) (Berthold et al. 2022), and attitudes towards water conservation behaviour (WCB) (Verhoest et al. 2022).

Econometric analysis

Data from the choice experiment were analysed using the discrete choice model (DCM) (Train 2009). In line with Lancaster's theory (Lancaster 1966), DCM assumes that the overall utility that consumers derive from a product can be separated into the marginal utilities derived from the product's design attributes. The approach is based on random utility theory (McFadden 1974), according to which the utility for an individual *n* who selects alternative *j* in a given choice situation *t* can be represented as follows:

$$U_{njt} = \beta' X_{njt} + \epsilon_{njt} \tag{1}$$

In this model, X_{njt} is a vector of observed variables associated with individual *n*'s choice of alternative *j* in choice situation *t*; *β'* denotes a vector of structural taste parameters that describe the choices; and ϵ_{njt} is an unobserved error term assumed to be independent of both *β* and *x*.

The data were analysed in three steps. First, we examined consumer's marginal WTP (mWTP) for almonds considering only the main effects of the design attributes and using the Random Parameters Mixed Logit (RP-MXL) model in preference space. Accordingly, the utility function (*U*) in our study can be specified as follows:

$$\begin{aligned} U_{njt} = {} & ASC + \beta_{1n} ORIGIN_{njt} + \beta_{2n} DESALINATED_{njt} \\ & + \beta_{3n} RECLAIMED_{njt} + \beta_{4n} ORGANIC_{njt} + \beta_{5n} PRICE_{njt} + \varepsilon_{njt} \end{aligned} \tag{2}$$

In this model, *n* refers to the "individual", *j* refers to each of the three choices available in the choice set and *t* represents the number of choice occasions. The alternative specific constant (ASC) represents the choice of the opt-out (no purchase) option. ORIGIN_{njt} is a dummy variable representing the origin of almonds, taking the value of 0 if almonds are not produced in the European Union and 1 if they are produced in the European

Union. $\mathrm{DESALINATED}_{njt}$ is a dummy variable for almonds irrigated with desalinated water. $\mathrm{RECLAIMED}_{njt}$ is a dummy variable for almonds irrigated with reclaimed water. $\mathrm{ORGANIC}_{njt}$ is a dummy variable representing the production system of almonds, taking the value of 0 if no information is included in the packaging of almonds and 1 if almonds are grown under organic systems, including the EU organic logo on the packaging. PRICE_{njt} is experimentally defined and is represented by three different levels. The term $\in_{njt}$ represents the unobserved error term. The parameters of the four non-price attributes are characterised as random variables following a normal distribution, while the exclusion parameters are treated as fixed parameters. Following random utility theory, marginal WTP (mWTP) for each attribute was obtained from the preference space estimates as the ratio of the attribute and price coefficients.

In the second step, we estimated consumers' mWTP for almonds by incorporating both the main effects of the design attributes and interactions between the RECLAIMED attribute and individual characteristics, to test whether these characteristics influence consumers' mWTP for almonds and employing the RP-MXL model in preference space. Accordingly, the utility function (U) in our study is specified as follows:

$$\begin{aligned}
&U_{njt} = ASC + \beta_{1n}ORIGIN_{njt} + \beta_{2n}DESALINATED_{njt} \\
&+ \beta_{3n}RECLAIMED_{njt} + \beta_{4n}ORGANIC_{njt} + \beta_{5n}PRICE_{njt} \\
&+ \beta_{6n}(RECLAIMED \times GENDER)_{njt} + \beta_{7n}(RECLAIMED \times AGE)_{njt} \\
&+ \beta_{8n}(RECLAIMED \times EDUCATION)_{njt} + \beta_{9n}(RECLAIMED \times HEARING)_{njt} \\
&+ \beta_{10n}(RECLAIMED \times OTFOOD)_{njt} + \beta_{11n}(RECLAIMED \times WCB)_{njt} + +\varepsilon_{njt}
\end{aligned} \tag{3}$$

GENDER is a dummy variable and indicates the consumer's gender, where 0 corresponds to males and 1 to females. AGE represents a continuous variable that represents the consumer's age in years. EDUCATION indicates a dummy variable that represents the consumer's education level, where 0 corresponds to those not having completed higher education (no university) and 1 to those having completed higher education (university). HEARING represents a dummy variable and indicates whether the consumer had heard of the concept "reclaimed water" prior to the study, with 1 for the consumer having heard of the term and 0 for not. $\mathrm{OT}_{\mathrm{food}}$ is a variable representing a positive attitude towards openness to new sustainable food technologies. WCB is a variable representing a positive attitude towards water conservation behaviour. The other variables are specified in the same way as in Eq. (2). In this model, the parameters of the four non-price attributes were modelled as random parameters with normal distribution, whereas the exclusion parameters and the interactions of the RECLAIMED with consumer characteristics (such as GENDER, AGE, EDUCATION, HEARING, $\mathrm{OT}_{\mathrm{food}}$, WCB) were treated as fixed parameters.

We estimated the RP-MXL model using Stata's *mixlogit* module to obtain the regression coefficients, and the module *wtp* to obtain the corresponding mWTP in currency terms (i.e. €) (Hole 2007). We also computed mWTP via the delta method using nonlinear combinations of parameters (*nlcom).* We examined several RP-MXL models with different numbers of draws, considering both correlated and uncorrelated variables. Models using five hundred Halton draws with correlated variables were found to perform best according to the logL, AIC and BIC parameters. The marginal WTP (mWTP) for each attribute was obtained from the preference space estimates as the ratio of the attribute and price coefficients.

In the third step, we identified consumer clusters using a Latent Class Mixed Logit (LC-MXL) model (Greene and Hensher 2003), which assumes that the population can be divided into two or more clusters, each with constant model parameters. This approach captures consumer heterogeneity through a mixed distribution. The probability of individual *n* belonging to a class *s* is inferred from their observed choices among alternatives *j* at time *t* and depends on the vector of observable attributes *x'*.

$$Prob_{jnt|s} = \frac{\exp\left(x'_{ntj}\beta_{\ s}\right)}{\sum_{\ j=1}^{Jn}\exp\left(x'_{ntj}\beta_{\ s}\right)} \quad (4)$$

where *s* = *1,…, s* denotes the number of classes, β_s is the vector of fixed parameters (constants) associated with class *s*, and x_{njt} is a vector of product attributes. Choice probabilities are obtained by multiplying them by the set of choices made by all individuals, to determine probability.

To assess potential endogeneity of attitudinal variables, we applied a control-function approach following Mariel and Arata (2022), estimating auxiliary regressions and including the corresponding residuals in the class allocation function. In the first stage, attitudinal variables (OT_{food} and WCB) were regressed on sociodemographic characteristics (gender, age and education) and contextual variables available in the survey, which were used as instruments. The results of the auxiliary regressions indicate that the instruments are statistically significant and provide sufficient explanatory power. The residual terms are generally not statistically significant, suggesting that endogeneity is not a major concern in our data. The detailed results of these auxiliary regressions and the corresponding control-function specifications are reported in the supplementary materials.

We estimated the LC-MXL model using the expectation-maximisation (EM) algorithm, which provides a strong numerical stability and efficient runtime (Bhat 1997; Pacifico and Yoo 2013; Train 2008). In Stata, we employed the *lclogit2*, *lclogitml2* and *lclogitwtp2* modules (Yoo 2020).

All the models were estimated in Stata 18.0 (Stata-Corp LP, College Station, USA).

Results

WTP estimates: main effects

Table 2 shows the results in monetary terms by reporting the mWTP of the main effects, after estimating the RP-MXL models using Eq. (2) for Spain, Germany and Sweden, reporting average regression coefficients with the main effects (see Table C1 in Appendix D of the Additional File 1). Specifically, it shows the mWTP for origin, irrigation (desalinated water and reclaimed water, each compared to conventional water), production (organic compared to no information), price and opt-out, together with the corresponding standard errors (SE) and significance of the attributes (p-values). Across all three countries, the opt-out value option is negative and significant in both tables, indicating that consumers tend to choose one of the two product alternatives in the choice set rather than the opt-out option.

Across the three countries, consumers are willing to pay more for almonds of EU origin in every market, with a moderate premium in Spain (mWTP: 1.21 €/200 g, p-value: <0.001) and Germany (mWTP: 1.06 €/200 g, p-value: <0.001) and a smaller premium in Sweden (mWTP: 8.83 kr/200 g, p-value: <0.001). Regarding the irrigation source,

Table 2 Estimated mWTP with variables for main effects by country

Attribute	Spain (N = 460)		Germany (N = 459)		Sweden (N = 452)	
	mWTP (€/200 g) (SE)	p-value	mWTP (€/200 g) (SE)	p-value	mWTP (kr/200 g) (SE)	p-value
EU origin	1.21 (0.12)	< 0.001	1.06 (0.10)	< 0.001	8.83 (0.84)	< 0.001
Irrigated with desalinated water	−0.66 (0.18)	< 0.001	−0.17 (0.13)	0.195	−1.01 (1.25)	0.418
Irrigated with reclaimed water	−0.69 (0.19)	< 0.001	−0.01 (0.13)	0.920	2.36 (1.17)	0.044
Organic production	1.21 (0.12)	< 0.001	1.29 (0.11)	< 0.001	9.57 (0.91)	< 0.001
Opt-out	−6.60 (0.41)	< 0.001	−5.13 (0.28)	< 0.001	−56.83 (2.76)	< 0.001

Note: 1kr = 0.09€

mWTP = marginal willingness to pay

SE = standard error

Spanish consumers show negative WTP for almonds irrigated with desalinated water (mWTP: –0.66 €/200 g, p-value: <0.001) and reclaimed water (mWTP: –0.69 €/200 g, p-value: <0.001), indicating a clear penalty when these practices are applied. By contrast, German consumers' WTP for reclaimed and desalinated water is not significant. However, although small, Swedish consumers' WTP for reclaimed water is positive and statistically significant (mWTP: 2.36 kr/200 g, p-value: <0.001). This may be consistent with the conflicting opinions and the lower importance of the irrigation attribute compared to others. For the almond production system, consumers are consistently open to paying a premium for organic almonds, with positive valuations in all three countries: a moderate premium in Spain (mWTP: 1.21 €/200 g, p-value: <0.001) and Germany (mWTP: 1.29 €/200 g, p-value: <0.001) and a smaller premium in Sweden (mWTP: 9.57 kr/200 g, p-value: <0.001). Premiums for EU origin and organic production indicates that these credence attributes, associated with EU standards, increase consumers' willingness to pay for almonds across all evaluated markets.

WTP estimates: main effects and interactions of reclaimed water with consumer characteristics

Table 3 shows these results in monetary terms by reporting the mWTP of the main effects and interactions with consumer characteristics, after estimating the RP-MXL models using Eq. (3) for Spain, Germany, and Sweden, reporting average regression coefficients with the main effects and interactions (see Table C6 in Appendix D of the Additional File 1). Specifically, it includes the mWTP for socioeconomic variables (gender, age and education), hearing (if the consumer had heard of the concept "reclaimed water"), attitudes towards openness to new sustainable food technologies (OT_{food}), and attitude towards water conservation behaviour (WCB). In our study, we present the main effect estimates, as well as the interactions of consumer characteristics with the reclaimed water and the opt-out parameters. We also include the corresponding standard errors (SE) and the significance of the attributes (p-values).

The results presented in Table 5 show that consumers in all three countries are willing to pay for almonds produced within the EU and using organic production systems

Table 3 Estimated mWTP with main effects and interactions with consumer characteristics by country

Attribute	Spain (N = 460)		Germany (N = 459)		Sweden (N = 452)	
	mWTP (€/200 g) (SE)	*p*-value	mWTP (€/200 g) (SE)	*p*-value	mWTP (kr/200 g) (SE)	*p*-value
EU origin	1.21 (0.12)	< 0.001	1.10 (0.10)	< 0.001	8.75 (0.83)	< 0.001
Irrigated with desalinated water	−0.72 (0.17)	< 0.001	−0.22 (0.14)	0.112	−1.02 (1.21)	0.398
Irrigated with reclaimed water	0.26 (0.78)	0.736	−0.77 (0.58)	0.185	−4.56 (4.63)	0.326
Organic production	1.27 (0.14)	< 0.001	1.33 (0.11)	< 0.001	9.67 (0.92)	< 0.001
Opt-out	−6.83 (0.41)	< 0.001	−5.29 (0.30)	< 0.001	−57.31 (2.74)	< 0.001
Reclaimed x Gender	−0.28 (0.21)	0.194	0.25 (0.17)	0.153	1.76 (1.72)	0.305
Reclaimed x Age	0.00 (0.01)	0.692	0.00 (0.01)	0.426	−0.02 (0.06)	0.768
Reclaimed x Education	0.03 (0.21)	0.873	−0.12 (0.18)	0.508	−3.76 (1.69)	0.026
Reclaimed x Hearing	0.40 (0.22)	0.066	0.23 (0.18)	0.202	−1.35 (1.82)	0.459
Reclaimed x OT_{food}	0.04 (0.03)	0.146	0.03 (0.02)	0.234	0.22 (0.20)	0.278
Reclaimed x WCB	−0.03 (0.02)	0.040	0.00 (0.01)	0.809	0.14 (0.10)	0.164

Note: 1kr = 0.09€

mWTP = marginal willingness to pay

SE = standard error

(p-values: <0.001) in the same order as in the previous table, with the price value being negative and significant (p-values: <0.001). The interactions between RECLAIMED and consumer characteristics have a limited influence on WTP for almonds. Among Spanish consumers, the only significant interaction is with water conservation behaviour (WCB): higher WCB is associated with a lower WTP for almonds irrigated with reclaimed water (mWTP: –0.03 €/200 g, p-value: 0.040). In Germany, no interaction is significant, indicating that WTP for reclaimed irrigation is not moderated by the characteristics considered. For Sweden, education shows a negative association with WTP for reclaimed irrigation (mWTP: –3.76 kr/200 g, p-value: 0.026), whereas the remaining interactions are not significant (p-values ≥ 0.164). Overall, these results suggest that favourable attitudes towards water conservation in Spain may be associated with a lower willingness to pay for almonds irrigated with reclaimed water, while the interactions do not significantly moderate preferences in Germany and only a slight negative association with education is observed in Sweden.

WTP estimates: latent class mixed logit (LC-MXL) model

Table 4 presents the results of the LC-MXL model with the three-cluster solution for Spain, including the mWTP for origin, irrigation (desalinated water and reclaimed water), production (no information vs. organic production), price, and opt-out parameters. Group 1 ("Undecided": 279 consumers, 60.6% of the sample) is the largest group and includes consumers that show no strong significant preference for any of the attributes studied. Group 2 ("European water traditionalist": 91 consumers, 19.8% of the

Table 4 Estimated mWTPs from the LC-MXL model for Spain

Attribute	Group 1 Undecided *(N=279)*		Group 2 European water traditionalist *(N=91)*		Group 3 European strong water traditionalist *(N=90)*	
	mWTP (€/200 g) (SE)	*p*-value	mWTP (€/200 g) (SE)	*p*-value	mWTP (€/200 g) (SE)	*p*-value
EU origin	−2.96 (22.92)	0.897	1.26 (0.12)	< 0.001	1.24 (0.21)	< 0.001
Irrigated with desalinated water	−8.12 (41.34)	0.844	−0.61 (0.17)	< 0.001	−1.49 (0.24)	< 0.001
Irrigated with reclaimed water	15.34 (78.04)	0.844	−0.37 (0.18)	0.041	−2.21 (0.31)	< 0.001
Organic production	−105.15 (524.75)	0.844	0.40 (0.13)	0.002	0.59 (0.20)	0.003
Opt-out	22.54 (131.21)	0.864	−10.84 (0.72)	< 0.001	−3.14 (0.26)	< 0.001
logL	-2688.05					
df	20					
AIC	5416.09					
BIC	5416.71					

mWTP = marginal willingness to pay

SE = standard error

BIC = Bayesian information criterion

sample) shows a slight negative attitude towards almonds irrigated with desalinated water (– 0.61 €/200 g, p-value: <0.001) and for almonds irrigated with reclaimed water (– 0.37 €/200 g, p-value: 0.041), with consumers in this group being willing to pay a small premium price for almonds of EU origin and organic production. Group 3 ("European strong water traditionalist": 90 consumers, 19.6% of the sample) shows a moderate and negative attitude towards almonds irrigated with desalinated water (– 1.49 €/200 g, p-value: <0.001) and for almonds irrigated with reclaimed water (– 2.21 €/200 g, p-value: <0.001), with these consumers being willing to pay a small premium price for almonds of EU origin and organic production. These results show that the negative willingness to pay for desalinated and reclaimed water in Spain is concentrated within two consumer segments that together account for 39.4% of the sample, whereas the majority of Spanish consumers show no significant aversion to alternative water sources.

Table 5 shows the results of the LC-MXL model for Germany with the three-cluster solution. Group 1 ("Undecided": 228 consumers 49,7% of the sample) includes the highest percentage of consumers and includes those with no particular preference for any of the attributes studied. Group 2 ("European water traditionalist": 106 consumers, 23.1% of the sample) shows the highest willingness to pay for EU almonds (1.26 €/200 g, p-value: <0.001) and a moderate and positive preference for organic almonds (0.46 €/200 g, p-value: <0.001). Moreover, this group shows moderate and negative attitudes towards almonds irrigated with desalinated water (– 0.51 €/200 g, p-value: 0.004), but not towards reclaimed water. Consumers in Group 3 ("Organic European": 125 consumers, 27.2% of the sample) are willing to pay the highest premium price for EU origin (0.95 €/200 g, p-value: <0.001) and organic almonds (0.86 €/200 g, p-value: <0.001), but show no significant preferences for the water sources proposed.

Table 5 Estimated mWTPs from the LC-MXL model for Germany

Attribute	Group 1 Undecided *(N = 228)*		Group 2 European water traditionalist *(N = 106)*		Group 3 Organic European *(N = 125)*	
	mWTP (€/200 g) (SE)	*p*-value	mWTP (€/200 g) (SE)	*p*-value	mWTP (€/200 g) (SE)	*p*-value
EU origin	5.21 (14.85)	0.725	1.26 (0.11)	< 0.001	0.95 (0.15)	< 0.001
Irrigated with desalinated water	0.22 (9.38)	0.982	−0.51 (0.18)	0.004	−0.15 (0.19)	0.445
Irrigated with reclaimed water	−8.86 (26.33)	0.736	−0.11 (0.18)	0.553	−0.34 (0.21)	0.102
Organic production	73.58 (211.88)	0.728	0.46 (0.13)	< 0.001	0.86 (0.14)	< 0.001
Opt-out	−41.26 (108.39)	0.703	−9.02 (0.64)	< 0.001	−2.25 (0.24)	< 0.001
logL	-2691.70					
df	20					
AIC	5423.41					
BIC	5505.99					

mWTP = marginal willingness to pay

SE = standard error

BIC = Bayesian information criterion

Table 6 Estimated mWTPs from the LC-MXL model for Sweden

Attribute	Group 1 Undecided *(N = 116)*		Group 2 Organic European *(N = 239)*		Group 3 Eco-water European *(N = 97)*	
	mWTP (kr/200 g) (SE)	*p*-value	mWTP (kr/200 g) (SE)	*p*-value	mWTP (kr/200 g) (SE)	*p*-value
EU origin	0.263 (2.15)	0.770	32.60 (6.25)	< 0.001	7.83 (1.24)	< 0.001
Irrigated with desalinated water	-3.24 (3.74)	0.386	−0.37 (4.31)	0.931	0.26 (1.71)	0.875
Irrigated with reclaimed water	1.74 (2.75)	0.527	−7.67 (5.19)	0.139	5.31 (1.60)	0.001
Organic production	4.33 (1.77)	0.015	38.76 (7.17)	< 0.001	5.99 (1.25)	< 0.001
Opt-out	−66.63 (9.17)	< 0.001	−132.72 (19.88)	< 0.001	−25.69 (1.70)	< 0.001
logL	-2568.68					
df	20					
AIC	5177.36					
BIC	5259.63					

Note: 1kr = 0.09€

mWTP = marginal willingness to pay

SE = standard error

BIC = Bayesian information criterion

Table 6 presents the results of the LC-MXL model for Sweden with the three-cluster solution. Group 1 ("Undecided": 116 consumers, 25.7% of the sample), unlike the segment in Spain and Germany, includes an average percentage of consumers that show a small preference for organic almonds (4.33 kr/200 g, p-value: 0.015), although they show no particular preference for any of the other attributes. Group 2 ("Organic European":

239 consumers, 52.8% of the sample) includes the highest WTP for both organic almonds (38.76 kr/200 g, p-value: <0.001) and almonds of EU origin (32.60 kr/200 g, p-value: <0.001) with no preference for any of the proposed water sources. Consumers in Group 3 ("Eco-water European": 97 consumers, 21.5% of the sample) are willing to pay a premium price for almonds irrigated with reclaimed water (5.31 kr/200 g, p-value: 0.001) and also for almonds with EU origin (7.83 kr/200 g, p-value: <0.001) and organic almonds (5.99 kr/200 g, p-value: <0.001). This is the only segment across the countries evaluated in which consumers may show positive attitudes towards one of proposed alternative water sources.

Discussion

This study evaluated and compared consumer attitudes in three European countries toward non-conventional water irrigation sources, together with the EU origin and organic production labels in almond production. The results show different attitudes towards the parameters evaluated in these countries. Our multi-country experiment reveals a consistent premium for EU origin in the three countries. These results align with the credence-attribute literature, which documents that origin information strongly shapes food choices in Europe (Lagerkvist et al. 2014; Thøgersen 2023). Furthermore, reliable EU frameworks reinforce the credibility associated with origin as an indicator of quality and sustainability (Grunert and Aachmann 2016). The results of previous European studies corroborate a premium for EU origin across food categories. For olive oil, Roselli et al. (2020) find positive valuation for Italy/EU and a significant penalty for non-EU origin. For beef, Lagerkvist et al. (2014) confirm the importance of EU vs. non-EU origin information as a determinant factor of choice. Beyond regulatory credibility, part of the EU origin premium is also consistent with consumer ethnocentrism and local support motives, whereby consumers pay more attention to origin and prefer local or regional options (Fernández-Ferrín et al. 2019; Thøgersen 2023; Van Loo et al. 2019).

Regarding organic production, consumers from all three countries show a willingness to pay a premium for the organic label. A meta-analysis of 80 studies identifies organic as one of the strongest sustainability attributes of WTP, with high premiums in Europe (on par with Asia and higher than in North America) (Li and Kallas 2021). In our study, consumers show a significant WTP for organic almonds, which may be driven by health considerations, environmental values, perceived quality and trust in certification, as discussed in the study by Katt and Meixner (2020). These results are in line with specific evidence for almonds: in a non-hypothetical choice experiment in Spain, de Magistris and Gracia (2016) reported clear premiums for organic almonds.

However, consumer attitudes towards irrigation water source in agriculture are heterogeneous. In Spain, consumers show a negative WTP for almonds irrigated with desalinated and reclaimed water. This preference for conventional water over reclaimed or desalinated water has also been reported in the study by Ellis et al. (2022), which also reported a preference for conventional water over recycled or desalinated water. The low preference of consumers for desalinated water could be explained by the perception of it being expensive due to its high energy demand or its associated environmental burdens (Eke et al. 2020; Elsaid et al. 2020). More generally, it may also reflect a perception of inferior quality for these water sources (Gómez-Ramos et al. 2024), which could also affect the quality of food produced using it. The negative attitude towards reclaimed water found among Spanish consumers may be consistent with the study conducted by Savchenko et al. (2018) in the U.S., which reported a lower WTP for fresh foods produced with recycled water. In terms of plausible determinants, disgust, neophobia and safety concerns are likely the factors underlying rejection of foods produced with reclaimed water, due to the importance of its origin and/or concern about the possible health risks (Savchenko et al. 2019; Verhoest et al. 2022). It has also been proved that emphasising the risks associated with the source of irrigation reduces WTP for products irrigated with non-conventional water and provokes aversion and neophobia responses (Savchenko et al. 2019). In contrast, our results indicate that in Germany and Sweden, the average mWTP for desalinated and reclaimed water does not significantly differ from zero, except for reclaimed water in Sweden, where consumers are willing to pay more for it. This finding can be interpreted as a mixture of ambiguous preferences and attitudes: some respondents value this type of sustainable practice while others remain cautious. Although Ellis et al. (2022) suggest a preference for irrigation with desalinated water over recycled water, our study shows no clear preference for desalinated or reclaimed water. Other studies document mixed attitudes on the use of desalinated and reclaimed water for irrigation (Aznar-Sánchez et al. 2021; Villacorta-Ranera et al. 2025), which is consistent with the heterogeneity of our results. However, by presenting the first cross-country study on the acceptance of these water sources, our research confirms the existence of heterogeneity across countries.

This study found a significant interaction between WTP for almonds irrigated with reclaimed water and the attributes of water conservation behaviour (WCB) and education level. In Spain, the strongest WCB is negatively associated with WTP for almonds irrigated with reclaimed water. This is compatible with evidence that, when reuse risks are known, WTP falls and disgust/neophobia dominate responses (Savchenko et al. 2018, 2019). At the same time, WCB tracks conservation intentions but does not guarantee acceptance of reuse in the absence of clear safety/risk-management cues, as consumer acceptance studies show (Garcia-Cuerva et al. 2016; Verhoest et al. 2022). In Sweden, a higher level of education is negatively associated with WTP for almonds irrigated with reclaimed water. This results runs counter to other studies, where higher education level is positively associated with the acceptance of reclaimed water (Garcia-Cuerva et al. 2016). However, Savchenko et al. (2019) suggest that among U.S. consumers a higher level of education does not increase the acceptance of reclaimed irrigation water sources. This reported finding may result from higher education levels and greater knowledge leading consumers to be more risk-averse, thereby reducing their acceptance of reclaimed water use.

Meanwhile, a latent-class structure identifies three notable segments: (i) In all three countries, there is an undecided majority that attaches weak importance to attributes; (ii) European water traditionalist groups emerge in Spain and Germany. These segments highly value EU origin and organic production, while penalising non-conventional irrigation; (iii) Specifically in Sweden, an eco-water European segment that values reclaimed water alongside EU origin and ecological attributes appears. This structure may be explained by referring to the cultural divisions that exist in European consumers: the northern context emphasises industrial efficiency and innovation, while southern contexts prioritise territorial social and cultural integration (Parrott et al. 2002). Moreover, several studies have reported that Northern European countries are more pro-environmental (Gómez-Román et al. 2021) and circular (Nieto-Villegas et al. 2025) than Southern European countries. The largest undecided and the two traditionalist Spanish segments fit this southern profile, while the Swedish segment that values positively reclaimed water is an example of the innovation-oriented food culture of Northern Europe.

This pattern may also align with differences between countries in terms of food technology neophobia, which tends to be lower in Nordic countries and higher in Southern Europe (Rabadán and Bernabéu 2021; Wendt and Weinrich 2023), as Nordic consumers consider innovation and environmental technologies to be a key driver for a green economy (Khan et al. 2021). Moreover, consumers with lower food technology neophobia, greater knowledge about food and greater concern for sustainability are more likely to adopt new sustainable technologies (Siegrist and Hartmann 2020). This may help explain why the reported more pro-sustainability segment in Sweden positively values irrigation with reclaimed water accompanied by EU/organic trust signals. In this regard, the integration of novel water sources into almond production in the EU is viable if accompanied by reliable credibility signals (EU origin, organic label). This is consistent with Aminravan et al. (2025), who conclude that consumers' willingness to pay for eco-labelled food is largely due to trust and positive attitudes towards existing certification systems.

Conclusions

This study demonstrates that European consumers respond heterogeneously to the use of novel water sources for irrigation. A notable cross-country conclusion is that Spain, despite being the EU country with the highest use of non-conventional water in agriculture, is the country where consumers show the greatest aversion. The source of irrigation water is rarely disclosed, and so the average consumer is unaware of this attribute. Consequently, attitudes towards non-conventional waters are primarily formed based on credibility signals and the communicative framework, rather than direct verification of the attribute. In contrast, acceptance is relatively higher in the northern countries in our study (Germany and Sweden), in line with more environmentally-friendly attitudes and more openness to the use of technologies. In other words, acceptance seems to depend less on basic "knowledge" of "familiarity" and more on the interaction between culture and environmental concerns.

Conversely, value credibility attributes, such as EU origin and organic certification, generate a positive WTP across markets, while reactions to irrigation water sources are heterogeneous and dependent on the context of each country. This heterogeneity further reveals the coexistence of certain segments: tradition-oriented consumers who rely on familiar signals (EU origin and organic production) and tend to dismiss food produced with non-conventional irrigation water; a sizable undecided group with no clear preference but who do not refuse the preference of food produced with desalinated and reclaimed irrigation water; and innovation-oriented consumers who evaluate reclaimed water more favourably in food production when combined with EU origin and organic production.

Taken together, these findings support the market-compatible integration of non-conventional waters into EU agricultural production, even within certified organic production. The findings suggest that, first, non-conventional irrigation water should be accompanied by credibility attributes already valued (EU origin and organic production certification) to buffer ambiguity, leverage existing trust and capture willingness to pay. Secondly, communication should be segmented: emphasising water sustainability and circularity for innovation-open segments, while highlighting compliance, control and oversight for more traditionalist consumers. Under these conditions, desalinated and reclaimed water can be used in food production with organic standards and create added value within the EU, reinforcing water resilience without penalising consumer acceptance.

Nevertheless, this study has limitations that condition the scope of its conclusions and point to priorities for future work. The empirical data come from a limited set of countries and a single product category, which limits external validity in other countries, regions with different water stress profiles and other foods, where the importance of the quality of the water used for irrigation may vary. Future research should expand geographical coverage within and beyond Europe and compare products (fresh versus processed). Consumer acceptance is fundamental to market acceptance and policy viability. However, it must be balanced with up-to-date data on human health, environmental results, agronomic performance, energy consumption and costs. The widespread use of non-conventional water in EU agriculture must be based on non-hypothetical evidence and an interdisciplinary synthesis that integrates toxicological and microbiological risk assessment, life cycle and water, energy and nutrient balance, as well as economic models linked to consumer demand.

Supplementary Information

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Supplementary Material 1

Author contributions

RNV: Conceptualization, Methodology, Investigation, Data Curation, Formal Analysis, Writing—Original Draft, Writing—Review & Editing. MB: Investigation, Formal analysis, Conceptualization, Writing—Review and Editing. LMC: Investigation, Formal analysis, Conceptualization, Writing—Review and Editing. APC: Investigation, Formal analysis, Conceptualization, Writing—Review and Editing. RB: Project administration, Investigation, Formal analysis, Resources, Writing—Review and Editing & Supervision. AR: Funding acquisition, Conceptualization, Methodology, Investigation, Resources, Formal Analysis, Writing—Original Draft, Supervision, Writing—Review and Editing.

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Data availability

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate

The Research Ethics Committee of the University of Castilla-La Mancha granted full approval of this study under reference number CEIS-2024-86313. The participants provided informed consent to participate in the research after reading important information in the introduction section, including details about privacy protection, their rights, and what they could do in the stress situation, during the survey. The research was conducted in accordance with the Declaration of Helsinki.

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

During the preparation of this work the authors used GPT-5 mini model in order to spell check and grammar check the manuscript. After using this tool/service, the authors reviewed and edited the content as needed and take full responsibility for the content of the published article.

Competing interests

The authors declare no competing interests.

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