

Water Resources Research®

RESEARCH ARTICLE

10.1029/2022WR033031

Key Points:

- Consumers' willingness to pay for foods irrigated with different types of recycled water is explored in framed field experiments
- Consumers prefer foods irrigated by recycled gray water to recycled produced (industrial) water and both are preferred to recycled black water
- Scientific information about the benefits and risks of using recycled irrigation water did not change people's behavior

Supporting Information:

Supporting Information may be found in the online version of this article.

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Citation:

Ellis, S. F., Ganguly, D., Kecinski, M., & Messer, K. D. (2023). Back to the source: Consumers response to produce irrigated with different sources of recycled water. *Water Resources Research*, 59, e2022WR033031. <https://doi.org/10.1029/2022WR033031>

Received 14 JUN 2022
Accepted 1 JUN 2023

Back to the Source: Consumers Response to Produce Irrigated With Different Sources of Recycled Water

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Abstract Using recycled water to irrigate agricultural products can be an effective solution to water scarcity and security. However, a better understanding of how society values different sources of recycled water provides insights into potential demand-side barriers to adoption of these solutions. This paper implements a framed field experiment conducted in the Southwest and Mid-Atlantic regions of the United States that evaluates consumers' willingness-to-pay (WTP) for three sources of recycled irrigation water: “gray,” “black,” and “produced.” Our analysis indicates that people consider certain sources of recycled water more acceptable for irrigating produce than others. Recycled gray water is preferred to recycled produced water, and both are preferred to recycled black water. We also explore how people respond to scientific information about the benefits and risks of using recycled irrigation water and found no evidence to support that this information changes people's behaviors.

Plain Language Summary We evaluate consumers' willingness to pay for produce irrigated with recycled water. We differentiate recycled water into “gray,” “black,” and “produced” categories following EPA guidelines. EPA defines gray water as household wastewater from washing, laundering, bathing and showering. Black water includes waste water that comes from toilets and urinals. Produced water comes from oil and gas drilling. We find that consumers are willing to pay more for produce irrigated with recycled gray water, followed by recycled produced water and that they prefer recycled black water the least.

1. Introduction

In light of the pressing nature of current and future water scarcity and security issues, this study focuses on providing a better understanding of how consumers respond to agricultural products irrigated with recycled water. A potential solution to drought is the use of recycled water in irrigation. Conventional irrigation water comes from a variety of sources, including surface water (i.e., rivers, lakes, ponds, and reservoirs) and ground-water supplies (Centers for Disease Control and Prevention, 2009). Recycled irrigation water typically refers to recycled wastewater (WateReuse, 2019), which comes from a variety of sources, such as gray, black, and produced water. Gray water is household wastewater from washing, laundering, bathing, and showering (Environmental Protection Agency (EPA) 2021) while black water includes wastewater that comes from toilets and urinals (EPA, 2021). Produced water comes from oil and gas drilling and is a mixture of water naturally stored in oil and gas pockets and water injected into wells to extract oil (Igunnu & Chen, 2014). Produced water is not the same as the mixture of water and chemicals used in hydraulic fracturing. Hydraulic fracturing is the process of injecting water, sand, and chemicals into a well to free up oil and gas reserves. Recycled produced water is a by-product generated during oil and gas recovery operations. This water can be treated to be a source of fresh water. Any treated water source other than groundwater and treated surface water is considered recycled, including recycled “gray,” recycled “black,” and recycled “produced” water, the three sources we specifically examine.

Widespread adoption of recycled irrigation water in the United States and across the world depends, among other things, on consumer acceptance of it. Other technologies in food production, such as genetically modified foods, irradiation, and use of growth hormones and antibiotics have faced consumer backlash because of perceived risks (Eckley & McEowen, 2012; Messer et al., 2017). Consumers attach a stigma toward recycled water and prior studies have portrayed recycled water as a homogenous commodity, describing it with catch-all terms such as recycled, reclaimed, and reused (Bakopoulou et al., 2008; Hui & Cain, 2017; Menegaki et al., 2007). However, little is known about consumers' perception of different types of recycled water and how providing this information influences their perceptions. Knowing if consumers' perception varies with different types of recycled water

would provide better tools for policymakers to respond to environmental challenges related to surface water and groundwater scarcity. The types of water that are least stigmatized should be prioritized when used to irrigate food for direct human consumption.

Using an economic framed field experiment conducted in the Southwest and Mid-Atlantic regions of the United States that involved 458 adult subjects, we seek to enhance the relatively sparse literature investigating whether consumers' preferences vary by recycled water source. Since information and messaging have been shown to influence consumers' food purchasing behavior (Dillaway et al., 2011; Hayes et al., 2002; Marette et al., 2010; Wu et al., 2015), we also examine the effect of presenting scientific information about recycled water's benefits and risks.

According to the Intergovernmental Panel on Climate Change (IPCC)'s Sixth Assessment Report, strains on freshwater supplies will only increase pressure on renewable surface water and groundwater resources as climate change continues to unfold, increasing the disparity between wet and dry regions (IPCC, 2021). Addressing these water shortages is particularly pressing for farmers in the western United States, which encompasses 74% of the country's irrigated acres (U.S. Geologic Survey, 2016). Agriculture is a major user of "blue" water (groundwater and surface water) with irrigation accounting for 42% of withdrawals. The 2017 U.S. Census of Agriculture states that farms employing some form of irrigation accounted for 54% of total crop sales (Economic Research Service (ERS), U.S. Department of Agriculture 2017). The U.S. food system, including agricultural production and supply chain stages, constitutes one-third of the country's freshwater use (USDA ERS, 2021). On average in the first quarter of 2022, approximately 57% of the continental United States was experiencing some degree of drought with 38% suffering from severe drought (USDA, 2022).

Consumers' refusal to purchase and ingest produce irrigated with recycled water has been widely documented (Menegaki et al., 2007; Rozin et al., 2015; Savchenko et al., 2018). A primary reason for the rejection may be explained by stigma—consumers reject recycled water because they perceive the water as posing health risks or inducing feelings of disgust (Dingfelder, 2004; Fischhoff, 2001; Rozin & Nemeroff, 2002; Rozin et al., 2015; Walker, 2001). Previous research has found evidence to support this hypothesis in the context of produce irrigated with recycled water (Ellis et al., 2019; Ellis, Kecinski, et al., 2021; Ellis, Savchenko, & Messer, 2021; Li et al., 2018; Savchenko et al., 2018; Savchenko, Kecinski, et al., 2019; Savchenko, Li, et al., 2019; Whiting et al., 2019). However, there is also evidence from these studies and more that stigma can be partially mitigated through message framing and additional physical purification treatments (Kecinski & Messer, 2018; Rozin et al., 2015). Furthermore, Savchenko, Li, et al. (2019) and Ellis, Savchenko, and Messer (2021) show that simple processing (e.g., drying or liquefying) of produce and explicitly disclosing the trophic levels of agricultural products, mitigates consumers' stigma attached to produce irrigated with recycled water (a trophic level is an organism's place in the food chain; for example, plants are trophic level 1 as they do not consume other living organisms, whereas herbivores, such as cattle, consume plants and are trophic level 2). An increase in the need for recycled water due to serious drought and severe water restrictions in Australia, has also been shown to increase acceptance (Dolnicar & Schäfer, 2009), as has informing consumers that recycled water has been used extensively without incident (Hui & Cain, 2017). Even simply rebranding recycled water with a name that evokes its fresh, clean, and pure status has been shown to increase acceptance (Ellis et al., 2019).

On the other hand, information could increase consumers' repulsion. For example, exposing consumers to information about potential health risks from recycled water has been found to reduce willingness to pay (WTP) for vegetables irrigated with it (Savchenko et al., 2018). A plan to incorporate recycled water into the municipal drinking supply in Toowoomba, Australia in 2006, was rejected by the public when scientists could not guarantee that there would never be any issues associated with it (Morgan & Grant-Smith, 2015). In the United States, plans to use recycled potable water in Tampa, Florida, and Brownwood, Texas, were delayed indefinitely and then canceled due to public concerns (Hummer & Eden, 2016; Wester et al., 2016). Ellis, Kecinski, et al. (2021) and Savchenko et al. (2018) found that consumers are less willing to pay for produce irrigated by recycled water. Interventions with framed messages showed that messages regarding the environmental benefits of this recycled water did not alleviate these concerns. Furthermore, in other experimental contexts unrelated to recycled water, studies have found that it is not just the information provided that is important but also the source providing it, the perspective of the source, and the receivers' beliefs (B. R. McFadden & Lusk, 2015; J. R. McFadden & Huffman, 2017; Whiting et al., 2019). A key contribution to this literature is the fact that this study analyzes three sources of recycled water rather than describing it with a generic term such as recycled, reused, or reclaimed. In

doing so, we address two key concerns about recycled water, and comment on a third. First, we explore whether consumers' WTP for agricultural produce irrigated with recycled water varies in response to the source of recycled water used (gray, black, and produced). This additional layer of information can identify the kinds of projects most likely to be accepted by the public.

Second, this study assesses the effects of exposing participants to three types of scientific information about recycled water—its environmental benefits, its risks, and both its benefits and risks—on consumer WTP for produce irrigated with each source of water. Finally, this study explores the effect of prior knowledge about sources of recycled water on consumer WTP for produce irrigated with it.

2. Materials and Methods

To assess consumer WTP for produce irrigated with different sources of recycled water, we conducted a framed field experiment in two regions of the climate diverse United States—the Southwest (this region of the United States generally includes Arizona, New Mexico, parts of California, Colorado, Nevada, Oklahoma, Texas and Utah), which is prone to drought, and the Mid-Atlantic (this region of the United States typically includes Delaware, the District of Columbia, Maryland, New Jersey, New York, Pennsylvania, Virginia and West Virginia), which is a historically water-abundant area. To ensure incentive compatibility of this revealed preference study, we used a single-bounded, dichotomous-choice mechanism to solicit consumer decisions. Multiple studies have shown that dichotomous-choice mechanisms are more robust and less biased than other formats such as auctions because they are more representative of the type of decisions consumers typically make (Arrow et al., 1993; Frykblom & Shogren, 2000; Loomis et al., 1997; Wu et al., 2021). When considering an item, consumers either purchase it at the posted price or pass on buying it. Formally in this case, participant i is offered purchase opportunity j at listed price P and chooses to accept it (purchase) ($D = 1$) or reject it (passes) ($D = 0$):

$$D_{ij} = \{1 \text{ if } P_{ij} \leq EU_{ij} \text{ } 0 \text{ if } P_{ij} > EU_{ij}\} \quad (1)$$

If the price of P_{ij} is less than or equal to a participant's expected utility, EU_{ij} , the participant accepts it; otherwise, the participant rejects it. In the experiment, all purchase opportunities were presented on a single page so participants could go back and change previous decisions after making the final one to avoid bias associated with the discovered preference hypothesis (Plott, 1996).

The experiment successfully collected data from 458 adult consumers: 199 in the Southwest and 259 in the Mid-Atlantic, resulting in 6,870 observations. Data from the framed field experiment in the Southwest was collected at a festival in Arizona. In the Mid-Atlantic, the data were collected from 125 participants at a regional transportation hub in Delaware and 135 participants at a farmer's market in Washington, D.C. These field locations were chosen to obtain samples that were more representative of adult consumers than could be recruited at a traditional university experimental economics laboratory (it is important to note that recruitment at these locations is likely not perfectly representative of the general population).

At the start of the experiment, all participants were endowed with \$10 as payment for their participation (this is a feature of the experiment that could have induced the house money effect (Thaler & Johnson, 1990), potentially impacting participants valuation of the produce). In the instructions (see Appendix A in Supporting Information S1), they were told to think of the money as a bank account from which they could withdraw funds to purchase various items. All participants were also informed that only one of their decisions would be randomly chosen and implemented, encouraging them to carefully consider each decision independently of the others. The following definitions from the EPA (U.S. EPA, 2021) for each source of irrigation water were provided to the participants at the beginning of the experiment and were displayed on the purchase opportunities page:

Conventional Water: Traditional sources of irrigation water, such as surface water (rivers, lakes, ponds, and reservoirs) and well water.

Recycled Black Water: Treated wastewater from toilets and urinals.

Recycled Gray Water: Treated wastewater from washing, laundering, bathing, and showering.

Recycled Produced Water: Treated wastewater from oil and gas drilling operations.

The experiment was completed on tablet computers using a Willow-based software program (Weel & McCabe, 2009) that both administered the experiment and collected the data. The products offered to participants were “debranded” by removing all identifying labels and were displayed in one area so participants could

Table 1
Experimental Design: 2 × 2 Between Subject Treatments

		Risk information	
		No	Yes
Benefit information	No	Control	T1
	Yes	T2	T3

Note. This table describes the between subject design of the framed field experiment implemented in the Mid-Atlantic and Southwest locations. The control group saw no information about recycled water before making purchase decisions. T1 participants saw only the risk information about recycled water, T2 participants saw benefit information about recycled water and T3 participants saw both benefit and risk information about recycled water.

examine them. Since this design followed the general prohibition on deception in experimental economics (Rousu et al., 2015), the types of produce used in each region varied based on what was available at the time and that we could identify as having been grown with the various water sources.

Participants were presented with 15 purchase opportunities as a within-subject treatment—five versions of three types of produce. Purchase opportunities were grouped by produce type (e.g., all the clementine purchase opportunities appeared together) and presented in a random order. Within each produce type, the first version all participants saw did not specify the source of irrigation water used on the produce and served as a control by replicating how produce is currently commonly labeled in the United States. The other four versions were treatments that specified the irrigation water as conventional, recycled gray, recycled black, or recycled produced and were presented in a randomized order across participants to avoid order effects. The produce offered in the Mid-Atlantic experiment consisted of baby carrots, almonds,

and grapes; in the Southwest experiment, participants were offered baby carrots, almonds, and clementines. None of these purchase opportunities were hypothetical and the research team spent considerable time identifying these items and their available locations. Finally, all decisions were equally likely to be binding with the binding decision determined randomly after the participant had made all their decisions.

Prices were randomly generated and drawn from normal distributions that were unique for each type of produce (baby carrots, almonds, grapes, clementines). Each distribution ranged from \$0 to \$10, had a mean that was a 2015 food inflation adjustment of the 2013 national mean price, and a standard deviation that was half of the mean price. For the Mid-Atlantic region, the mean price of baby carrots was \$1.54 (SD \$ 0.76), the mean price of almonds \$3.12 (SD \$ 1.58), the mean price of grapes \$2.48 (SD \$ 1.30). For the Southwest region, the mean price of baby carrots was \$1.52 (SD \$ 0.75), the mean price of almonds was \$3.16 (SD \$1.56), the mean price of clementines was \$2.93 (SD \$1.44).

The experiment also employed a 2 × 2 between-subject design to test the effects of scientific information about recycled water. We used a no-information control group and three information treatment groups that presented recycled irrigation water's (a) benefits, (b) risks, and (c) both benefits and risks, presented in a randomized order. The treatment table is represented in Table 1. Each participant was randomly assigned to one of the four groups and, if in a treatment, given the information at the beginning of the experiment. The text for the risk information treatment (T1) displayed to participants was as follows:

According to, croplife.org. “There have been a number of risk factors identified for using recycled waters for purposes such as agricultural irrigation. Some risk factors are short term and vary in severity depending on the potential for human, animal, or environmental contact (e.g., microbial pathogens), while others have longer term impacts which increase with continued use of recycled water (e.g., [effects of salt and heavy metals] on soil).”

The text benefit information treatment (T2) displayed to participants was as follows:

“According to the United States Environmental Protection Agency (EPA), “In addition to providing a dependable, locally controlled water supply, water recycling provides tremendous environmental benefits. By providing an additional source of water, water recycling can help us find ways to decrease the diversion of water from sensitive ecosystems.” Other benefits include “decreasing wastewater discharges and reducing and preventing pollution... Recycled water can also be used to create or enhance wetlands and [riverside] habitats.”

Each information treatment was designed to affect how a participant calculated their expected utility for a product by changing how they weight the attribute of recycled water. The information treatments highlighted some dimension of recycled water, either its relative risk to humans or relative benefits to the environment. After reviewing the information, the participants responded to the 15 purchase opportunities, selecting yes or no to purchase the product, and then completed a survey that collected information on their previous knowledge of different sources of recycled water and demographic characteristics (see Appendix B in Supporting Information S1).

Table 2
General Overview of the Between and Within Subject Design

Between Subject Design	Produce Type	Within Subject Design				
		Water Type				
		Unspecified	Conventional	Recycled Gray	Recycled Black	Recycled Produced
Control	All participants were offered baby carrots, almonds, clementines (Southwest only), and grapes (Mid-Atlantic only)	This irrigation water type always appeared first	These irrigation water types appeared in a random order for each participant			
Benefits						
Risks						
Benefits and Risk						

Note. This table summarizes our framed field experiment, which included both between and within subject variation. For the between subject variation, participants were randomly assigned to either control or one of the three treatment groups (benefits, risks, benefits and risks). Each participant then made purchasing decisions for three types of produce (i.e., baby carrots, almonds, clementines (Southwest only), and grapes (Mid-Atlantic)) irrigated with five different types of water (unspecified, conventional, recycled gray, recycled produced, and recycled black) for a total of 15 purchasing options. The order in which they saw each type of produce was randomized.

At the end of the experiment, a digital die was “rolled” to select the purchase opportunity to be implemented. Participants who selected yes for the implemented option received the produce and the balance of the \$10 endowments after deducting the purchase price. For example, if the purchase price for the binding option was \$2, they received the produce and \$8. Participants who selected no for the implemented option received the entire \$10 participation fee and no produce. A general overview of the experiment, combining both within and between subject variation can be found in Table 2.

Because of the binary nature of the data (yes/no decisions), we used a linear probability model to isolate the effect of each treatment, source of irrigation water, field site, and previous knowledge of different sources of recycled water on the likelihood of purchasing produce. Given the within-subject design (15 observations per participant), we implemented a random effects specification and estimated the coefficients using clustered standard errors:

$$D_{ij} = \alpha + \beta_1' P_{ij} + \beta_2' W_{ij} + \beta_3' T_i + \beta_4' S_i + \beta_5' K_i + \beta_6' X_i + \mu_i + \varepsilon_{ij} \quad (2)$$

where $\mu_i \sim N(0, \sigma_\mu^2)$ and $\varepsilon_{ij} \sim N(0, \sigma^2)$, W_{ij} is a matrix of dummy variables for irrigation water source, T_i is a matrix of dummy variables for the scientific information treatment received by participant i , S_i is a matrix of dummy variables identifying the field site, K_i is a matrix of dummy variables for participant i 's knowledge of different sources of recycled water prior to participating in the experiment, and X_i is a matrix of control variables for produce type, if the participant grows their own food, if the type of recycled water their food is irrigated with is important to them and key demographic variables including annual household income and highest educational attainment. As a robustness check, we re-estimated Equation 2 using logit and probit specifications (see Appendix C in Supporting Information S2). All results are consistent with those of the linear probability model.

Since our analysis involves multiple comparisons, which increases the likelihood of rejecting a true null hypothesis, we used a Bonferroni correction of the Wald Test probability values to account for the family-wise error rate and guard against Type I errors. The Bonferroni-Holm method corrects for multiple comparisons by dividing the overall alpha level by the number of hypotheses being tested in a family of hypotheses. The Bonferroni-Holm correction used in our analysis is $\rho/31$. The regression results for the linear probability model are presented first. Then we present the Wald test results that are based on regression results of the linear probability model.

To explore whether knowing about a particular source of recycled water increases participants' WTP for produce irrigated with it, we estimated an expanded version of Equation 2 that collapses the nonrecycled water variables (conventional and unspecified) into a single term. We included an interaction term between each recycled irrigation water source and prior knowledge about each water source. We collapse the nonrecycled water variables into a single term because the scientific information treatments focused on recycled water and not on any of the other water types.

3. Results

Table 3 presents summary statistics of the demographic characteristics of participants at each field site. Though the overall sample is representative nationally and regionally based on gender, it is skewed toward non-Hispanic

Table 3

Summary Statistics of Study Population Indicating Mean Percentages of Key Demographic Characteristics of Participants

		2018 American Community survey			Sample	
		Arizona	Delaware	U.S.	Mid-Atlantic	Southwest
	Total Participants				260	199
Gender	Female	50%	52%	51%	59%	54%
Educational Attainment	High School or Less	37%	42%	40%	15%	21%
	Some College	25%	19%	21%	22%	26%
	Associate Degree	9%	7.8%	8%	10%	14%
	Bachelor's Degree	18%	18.3%	19%	29%	24%
	Graduate Degree	11%	13.1%	12%	23%	16%
Ethnicity	Non-Hispanic White	54%	63%	61%	84%	75%
	Black	4%	22%	12%	7%	2%
	Hispanic	32%	9%	18%	6%	12%
	Asian	3%	4%	5%	2%	1%
	Other	7%	3%	3%	2%	10%
Income	\$49,999 or less	45%	38%	40%	25%	44%
	\$50,000 to \$99,999	31%	32%	30%	38%	41%
	\$100,000 to \$149,999	14%	15.9%	15%	21%	10%
	\$150,000 or more	11%	14%	15%	16%	5%
Age	18–34	27%	26%	27%	35%	22%
	35–54	25%	25%	26%	30%	12%
	55 and older	29%	31%	29%	35%	66%

Note. Summary statistics of the demographic characteristics of participants at each field site is presented. Data in Columns 3–5 comes from the U.S Census Bureau 2018 American Community Survey (<https://www.census.gov/programs-surveys/acs>). Column 6–7 reflect the mean percentages of each respective variable.

white consumers aged 55 and older who earned \$50,000 to \$99,000 annually. It also oversamples consumers whose highest educational attainment is a bachelor's degree and under samples those whose highest educational attainment is a high school diploma or less. We acknowledge that this sample is not representative. There is recent evidence however, that the representative nature of the sample may not always be a big issue in predicting consumer's purchase decisions. For instance, in a paper related to consumers response to products produced with recycled water, Ellis et al. (2022) find no significant differences in the key behaviors of interest between a non-representative in-person convenience sample and one from a representative online counterpart. Furthermore, Ellis, Savchenko, and Messer (2021) find consistent estimates from convenience and national samples from their study on mitigating stigma of recycled water. Other stated preference papers (Bass et al., 2022) also find that consumers have an implicit bias against recycled water which is similar to what we find in this revealed preference setting.

3.1. Effect of Irrigation Water Source on Consumer Likelihood to Purchase Produce

The estimates from Equation 2 are reported in Table 4. We find that price, as expected, has a statistically significant ($p = 0.000$) and negative effect on participants' likelihood of purchasing produce. Whereas, prior knowledge of recycled gray water, some college or higher (relative to a high school diploma or less), and annual household income, have statistically significant ($p \leq 0.027$) and positive effects on participants' likelihood of purchasing produce. We ran an additional regression that controlled for the gender of the participant and if they were a primary shopper of their household and find that these variables don't significantly impact consumers' purchase decisions. Results from this regression are reported in Appendix C (Table C.2.3 in Supporting Information S2). Even though we conducted these experiments in two distinctly climate diverse regions, one with relative water abundance (Mid-Atlantic) and one with frequent water scarcity (the Southwest), we find that the region does not significantly impact consumers' revealed preference for produce irrigated with different water types. This could

Table 4
Regression-Estimated Effects of Irrigation Water Source and Scientific Information Treatments on Consumer Likelihood to Purchase Produce

		Linear probability model			Linear probability model with treatment interaction terms		
		Coef.	S.E.	p-value	Coef.	S.E.	p-value
Treatment	Price	−0.094	0.005	0.000	−0.094	0.005	0.000
	Benefits	0.013	0.029	0.662	0.023	0.042	0.585
	Risks	−0.007	0.028	0.803	0.079	0.045	0.083
Produce	Benefits and Risks	−0.012	0.028	0.675	0.001	0.044	0.977
	Clementines	0.112	0.015	0.000	0.112	0.015	0.000
	Almonds	0.105	0.013	0.000	0.106	0.013	0.000
Water source	Grapes	0.079	0.014	0.000	0.079	0.014	0.000
	Unspecified	−0.005	0.018	0.763			
	Recycled Gray	−0.209	0.021	0.000	−0.167	0.038	0.000
Prior Knowledge	Recycled Black	−0.380	0.021	0.000	−0.323	0.039	0.000
	Recycled Produced	−0.268	0.022	0.000	−0.227	0.039	0.000
	Recycled Gray	0.057	0.026	0.027	0.057	0.026	0.027
Interactions	Recycled Black	−0.012	0.025	0.637	−0.012	0.025	0.637
	Recycled Produced	−0.025	0.021	0.234	−0.025	0.021	0.234
	Recycled Gray × Benefits				−0.014	0.050	0.777
	Recycled Gray × Risks				−0.158	0.056	0.005
	Recycled Gray × Benefits and Risks				0.009	0.053	0.860
	Recycled Black × Benefits				−0.058	0.052	0.264
	Recycled Black × Risks				−0.122	0.056	0.030
	Recycled Black × Benefits and Risks				−0.042	0.053	0.431
	Recycled Produced × Benefits				0.020	0.052	0.706
	Recycled Produced × Risks				−0.150	0.056	0.008
	Recycled Produced × Benefits and Risks				−0.033	0.054	0.542
Field Site	Mid-Atlantic	−0.014	0.023	0.534	−0.014	0.023	0.534
Demographics	Annual Household Income	0.011	0.004	0.005	0.011	0.004	0.005
	Grow Their Own Food	0.055	0.020	0.007	0.055	0.020	0.007
	Importance of Irrigation Water	−0.024	0.009	0.005	−0.024	0.009	0.005
Educational Attainment	Some College	0.063	0.033	0.054	0.063	0.033	0.055
	Associate Degree	0.052	0.040	0.195	0.052	0.040	0.195
	Bachelor's degree	0.084	0.032	0.008	0.084	0.032	0.008
	Graduate degree	0.156	0.033	0.000	0.156	0.033	0.000
Constant		0.584	0.058	0.000	0.555	0.061	0.000
Total <i>N</i>		6,870			6,870		
Individual participants		458			458		

Note. This table reports the regression coefficients of two linear probability models. The predictor variable in each regression is the consumer's purchase decision for different types of produce irrigated by different types of recycled water. Standard errors have been clustered by participants. Model 1 does not include interaction terms between the types of recycled water and the information treatments, Model 2 includes these interaction terms.

be due to several reasons. For instance, while water scarcity may be a key concern for farmers in the Southwest, it may be significantly less important to consumers when they are making their food choices. Furthermore, the recruitment of the participants may not have captured a perfectly representative sample of the regions' broader population. Finally, more observations could have powered the research to sufficiently detect a smaller, but statistically significant difference between the two regions.

Table 5
Wald Tests of Effects of Water Source on Consumer Likelihood to Purchase Produce

Wald test	χ^2	Probability	BCP
Conventional = Unspecified	0.09	0.763	1.000
Conventional = Recycled Gray	95.58	0.000	0.000
Conventional = Recycled Black	325.78	0.000	0.000
Conventional = Recycled Produced	152.05	0.000	0.000
Unspecified = Recycled Gray	105.83	0.000	0.000
Unspecified = Recycled Black	346.96	0.000	0.000
Unspecified = Recycled Produced	166.77	0.000	0.000
Recycled Gray = Recycled Black	100.37	0.000	0.000
Recycled Gray = Recycled Produced	10.55	0.001	0.032
Recycled Black = Recycled Produced	39.58	0.000	0.000

Note. BCP, Bonferroni-corrected probability values. This table corrects for multiple hypotheses testing by conducting the Bonferroni correction on Wald Test probability values. We test for the consumer's likelihood to purchase produce given that it is irrigated with different types of recycled water.

The results of the Wald tests examining participant preferences for each source of water using the regression results shown in Table 4 are presented in Table 5. We find that participants did not differentiate ($p = 0.763$, BCP = 1.000) between produce irrigated with conventional and unspecified irrigation water. These results are in line with findings by Savchenko et al. (2018) and Ellis, Kecinski, et al. (2021). However, it does diverge from the findings of Savchenko, Li, et al. (2019) which found that consumers marginally significantly preferred food produced with unspecified irrigation water over food produced with conventional irrigation water. Li et al. (2018) found mixed evidence.

Participants in our study, however, were more likely ($p \leq 0.000$, BCP ≤ 0.000) to purchase foods irrigated with either conventional or unspecified irrigation water than produce irrigated with any source of recycled water. Decreased demand for produce irrigated with recycled water is widely believed to result from psychological reactions of disgust because of the salience of its sources for consumers, concerns about potential health risks, and/or fear of trying new and/or possibly risky foods (i.e., neophobia) (Menegaki et al., 2007; Rozin et al., 2015; Savchenko, Kecinski, et al., 2019). While we believe, given the strong evidence found in the literature, that disgust is likely driving the decrease in demand for produce irrigated with recycled water, it should be noted that this experiment was not designed to test if it is disgust and not something else that is driving this decrease in demand.

The results of the Wald tests (see Table 5) also show that participants differentiate between sources of recycled water. Produce irrigated with recycled gray water was preferred ($p \leq 0.001$, BCP ≤ 0.032) over produce irrigated with recycled black and recycled produced water and produce irrigated with recycled produced water was preferred ($p \leq 0.000$, BCP = 0.000) over produce irrigated with recycled black water.

To quantify these preferences, we estimated participants' mean WTP for all three products produced with the five descriptions of irrigation water (see Table 6). Participants mean WTP for produce is highest for conventional irrigation water (\$7.86), followed by unspecified (\$7.81), recycled gray (\$5.65), recycled produced (\$5.02), and recycled black (\$3.83). Figure 1 displays the decrease in WTP for produce irrigated with each of the recycled water types relative to conventional water. WTP dropped 28% for recycled gray water, 36% for recycled produced water, and 51% for recycled black water.

Recycled gray water likely prompts less disgust than recycled black water and probably provokes less perceived risk than recycled produced water. Such stereotypes were also documented in a different context, where the researchers found that using recycled water for car washing was seen more favorably than recycled water for potable use (Hou et al., 2021). What is less clear is why participants preferred recycled produced water over recycled black water. A potential explanation is that fecal matter evokes "pathogen disgust," a cognitive response

humans developed to avoid disease (Sparks et al., 2018). The present analysis does not capture any dimensions of disgust in our experiment. However, this would be a good direction to extend this research. Produced water likely evokes concern about health risks associated with ingesting water that was once in contact with fossil fuels, chemicals that are harmful if consumed. Such concerns have been documented in earlier studies, although the distinction between sources of recycled water has not been made (Chen et al., 2013; Wester et al., 2016).

3.2. Effect of Scientific Information on Recycled Irrigation Water Preferences

The regression results for the linear probability model in Table 4 show that the between-subjects scientific information treatments did not have any overall significant ($p \geq 0.662$) effects on consumer willingness-to-purchase produce.

Table 6
Consumer Mean Willingness to Pay (WTP) for All Three Types of Produce Irrigated by Different Types of Water

Water source	Mean WTP	95% Conf. Interval	Prob.
Conventional	\$7.86	[\$7.37, \$8.35]	0.000
Unspecified	\$7.81	[\$7.32, \$8.29]	0.000
Recycled Gray	\$5.65	[\$5.35, \$5.95]	0.000
Recycled Black	\$3.83	[\$3.62, \$4.04]	0.000
Recycled Produced	\$5.02	[\$4.74, \$5.30]	0.000

Note. The 95% confidence intervals were generated using a bootstrap method. The p-value is derived from a Wald test with a null hypothesis that the WTP estimate is less than or equal to zero.

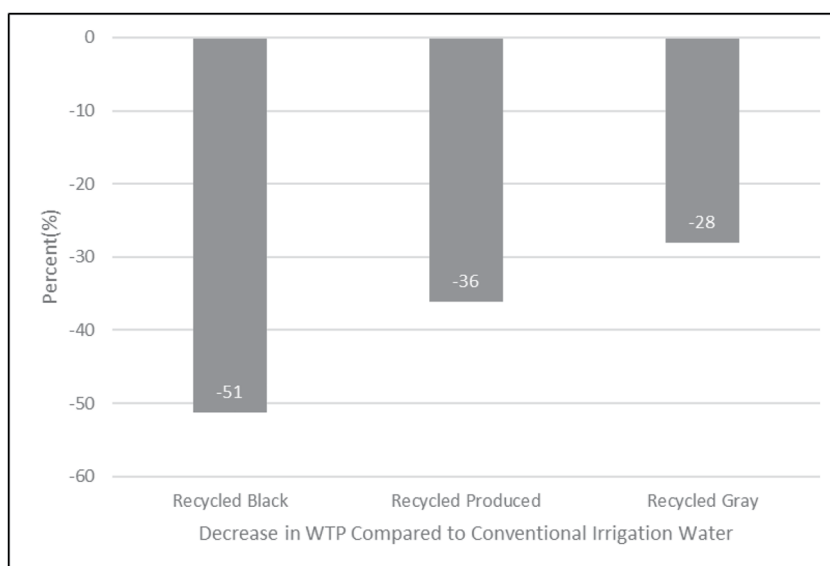


Figure 1. Histograms indicating consumers' bias against recycled irrigation water. The bias is indicated by the decrease in mean willingness to pay for produce irrigated by different types of recycled water compared to conventional irrigation water.

To see if the scientific information treatments had any effect on consumer preferences for the different types of recycled irrigation water, we estimated an iteration of Equation 2 that collapses the nonrecycled water variables (conventional and unspecified) into a single term and incorporates interaction terms between water types and the scientific information treatments. The regression results presented in Table 4 and Wald Test results shown in Table 7 provide marginally significant ($p \leq 0.069$) evidence that, exposure to scientific information about the health risks associated with recycled water decreased consumer willingness to purchase produce irrigated with recycled gray water (relative to the control and the other two treatments) and recycled produced water (relative to information about the environmental benefits of recycled water). There was also marginal evidence ($p = 0.089$) that exposure to the benefits and risks of recycled water decreased consumer willingness to purchase produce irrigated with recycled produced water relative to being shown only information about recycled water's benefits. However, after correcting for multiple-hypothesis testing, these results do not hold ($BCP \geq 0.279$). These results are consistent with, but far weaker and more limited than the findings by Savchenko et al. (2018), in which providing risk information decreased consumer demand for produce irrigated with recycled water by 50%. The sources used in the treatment information, cropsscience.org and U.S. EPA, could affect different consumers in different ways. Whiting et al. (2019) examine the role of messengers and their impact on produce irrigated by recycled and conventional irrigation and find that consumer response changes with the messenger of the information (the message is perceived least favorable when scientists are messengers and most favorably when a newspaper is the messenger). The difference in the sources of information in the treatments is not accounted for and is therefore a limitation.

3.3. Exploratory Analysis of the Effect of Prior Knowledge of Recycled Water on Recycled Water Preferences

The results, reported in Table 8, and the Wald test results, displayed in Table 9, suggest that prior knowledge about recycled gray water has a significant ($p = 0.000$, $BCP = 0.000$) and positive effect on consumer willingness to purchase produce irrigated with it relative to no prior knowledge about it. There is also evidence ($p = 0.044$) that prior knowledge about recycled produced water increases consumer willingness to purchase produce irrigated with it, however, this result does not hold after correcting for multiple hypothesis testing ($BCP = 1.000$). We find no evidence that prior knowledge about recycled black water has any effect on consumer willingness to purchase produce irrigated with it.

Different types of recycled irrigation water are novel and viable alternatives to conventional irrigation water. With fast approaching global water scarcity and increasing demand for fresh water, how consumers are

Table 7
Wald Tests of Effects of Scientific Information on Consumer Preferences for Sources of Recycled Irrigation Water

Water source	Wald test	χ^2	Probability	BCP
Recycled Gray	No Information = Benefits	0.043	0.836	1.000
Recycled Gray	No Information = Risks	3.309	0.069	1.000
Recycled Gray	No Information = Benefits and Risks	0.057	0.811	1.000
Recycled Gray	Benefits = Risks	4.123	0.042	1.000
Recycled Gray	Benefits = Benefits and Risks	0.001	0.972	1.000
Recycled Gray	Risks = Benefits and Risks	4.163	0.041	1.000
Recycled Black	No Information = Benefits	0.909	0.340	1.000
Recycled Black	No Information = Risks	1.378	0.240	1.000
Recycled Black	No Information = Benefits and Risks	1.443	0.230	1.000
Recycled Black	Benefits = Risks	0.058	0.810	1.000
Recycled Black	Benefits = Benefits and Risks	0.031	0.860	1.000
Recycled Black	Risks = Benefits and Risks	0.007	0.932	1.000
Recycled Produced	No Information = Benefits	0.863	0.353	1.000
Recycled Produced	No Information = Risks	2.657	0.103	1.000
Recycled Produced	No Information = Benefits and Risks	0.528	0.467	1.000
Recycled Produced	Benefits = Risks	6.820	0.009	0.279
Recycled Produced	Benefits = Benefits and Risks	3.049	0.081	1.000
Recycled Produced	Risks = Benefits and Risks	0.982	0.322	1.000

Note. BCP, Bonferroni-corrected probability values. This table corrects for multiple hypotheses testing by conducting the Bonferroni correction on Wald Test probability values. We test for the consumer's preferences for different sources of recycled water given different information treatments.

exposed to the unavoidable future of widespread alternative water use is an important policy consideration (see Appendix D in Supporting Information S3 for examples of how irrigation was is starting to be presented to consumers). Solutions to water scarcity must be incorporated into policymaking and public marketing efforts need to be developed to increase public acceptance of these sources of water, as long as they continue to be found to be safe. Increased public awareness and understanding of water scarcity and alternative water technology will likely encourage government officials and regulators to adopt alternative water sources when possible.

4. Conclusions

Recycled irrigation water is a technologically feasible and safe solution for addressing the growing need for water by the agricultural sector in the United States. Traditional irrigation water from surface and underground sources is already being augmented with recycled water in many regions of the U.S. and other parts of the world. However, the ultimate success of large-scale adoption will in part depend on consumers' acceptance of the produce irrigated with alternative sources of water, such as gray, black and produced water. Moreover, in addition to learning about the acceptability of such practices, it is important to understand the potential demand side implications, and, specifically, whether adopters of gray, black and produced irrigation water can expect to see a decline in the consumption of their products compared to those not irrigated with them if/when consumers become aware of the use of this water to produce these products. This consumer response will likely impact producers' decisions to adopt and use these various types of recycled water and therefore have direct implications for policies that address agricultural production, water use and availability, climate policies, and food prices in the future. Hence, examining demand for food products irrigated with different sources of recycled water is one critical component of sustainable water management. The incentive compatible framed field experiment used in this research provides non-hypothetical insights about the effect of differentiating the sources of recycled water on U.S. consumers' WTP for recycled gray, recycled black, and recycled produced water.

Table 8
Regression-Estimated Effects of Prior Knowledge About Recycled Water on Consumer Preferences for Sources of Recycled Irrigation Water

		Coef.	S.E.	p-value
Treatment	Price	−0.094	0.005	0.000
	Benefits	0.013	0.029	0.662
	Risks	−0.007	0.028	0.803
	Benefits and Risks	−0.012	0.028	0.676
Produce	Clementines	0.111	0.015	0.000
	Almonds	0.105	0.013	0.000
	Grapes	0.079	0.014	0.000
Water Source	Recycled Gray	−0.318	0.030	0.000
	Recycled Black	−0.400	0.030	0.000
	Recycled Produced	−0.288	0.032	0.000
Prior Knowledge	Recycled Gray	0.011	0.040	0.782
	Recycled Black	0.042	0.040	0.295
	Recycled Produced	−0.085	0.034	0.013
Interactions	Prior Knowledge Recycled Gray × Recycled Gray	0.208	0.049	0.000
	Prior Knowledge Recycled Gray × Recycled Black	0.001	0.052	0.986
	Prior Knowledge Recycled Gray × Recycled Produced	0.022	0.052	0.665
	Prior Knowledge Recycled Black × Recycled Gray	−0.105	0.053	0.046
	Prior Knowledge Recycled Black × Recycled Black	−0.017	0.054	0.753
	Prior Knowledge Recycled Black × Recycled Produced	−0.146	0.053	0.006
	Prior Knowledge Recycled Produced × Recycled Gray	0.083	0.042	0.048
	Prior Knowledge Recycled Produced × Recycled Black	0.062	0.044	0.154
	Prior Knowledge Recycled Produced × Recycled Produced	0.153	0.043	0.000
Field Site	Mid-Atlantic	−0.014	0.023	0.534
Demographics	Annual Household Income	0.011	0.004	0.005
	Grows Their Own Food	0.055	0.020	0.007
	Importance of Irrigation Water	−0.024	0.009	0.005
Educational	Some College	0.063	0.033	0.055
Attainment	Associate Degree	0.052	0.040	0.195
	Bachelor's Degree	0.084	0.032	0.008
	Graduate Degree	0.156	0.033	0.000
Constant		0.612	0.060	0.000
Total <i>N</i>		6,870		
Individual participants		458		

Note. This table reports the regression coefficients of a linear probability model. The predictor variable in each regression is the consumer's purchase decision for different types of produce irrigated by different types of recycled water. Standard errors have been clustered by participants.

Despite the safety of irrigating produce with recycled gray, recycled black, and recycled produced water, we find that once adult consumers in our experiments became aware of the use of this water their willingness-to-pay for different types of produce declined. This was consistent among consumers from the Southwest and Mid-Atlantic regions of the US. The analysis also indicates that consumers consider certain sources of recycled irrigation water more acceptable than others. Recycled gray water is preferred over recycled produced water, and both are preferred over recycled black water. These differences in valuation persist even after we correct for multiple-hypothesis testing. According to our findings, irrigation with recycled gray water rather than recycled black water and recycled produced water should be prioritized by policymakers and industry stakeholders when advancing and developing programs to supplement food crop irrigation. That said, all

Table 9

Wald Tests of Effects of Prior Knowledge About Recycled Water on Consumer Preferences for Recycled Irrigation Water

Water source	Wald test	χ^2	Prob.	BCP
Recycled gray	No Prior Knowledge = Previously Heard of Recycled Gray Water	26.06	0.000	0.000
Recycled black	No Prior Knowledge = Previously Heard of Recycled Black Water	0.48	0.487	1.000
Recycled produced	No Prior Knowledge = Previously Heard of Recycled Produced Water	4.05	0.044	1.000

Note. BCP, Bonferroni-corrected probability value. This table corrects for multiple hypotheses testing by conducting the Bonferroni correction on Wald Test probability values. We test for the consumer's preferences for different sources of recycled water given they have prior knowledge about them.

types of recycled water will likely require efforts to mitigate negative public perception. These mitigation efforts may include public marketing campaigns, which could include framing of the issue or invoking positive emotions related to improving water security. Approaches that should be the subject of further research efforts and inquiry.

Future research should focus on how increased consumer familiarity with different sources of recycled water might also mitigate their concerns about its safety and reduce or offset the initial decline in demand suggested by the results found in this paper. Israel, arguably the world leader in water reuse, has been supplementing agricultural irrigation with recycled water for 30 years. They have also complemented the use of these technologies with extensive media campaigns to mitigate public concerns. Whether such methods to change perception can be successful in the U.S. is an important next step for research. Exploratory analyses of the data used in this study show that having prior knowledge of recycled gray water increased consumers' WTP for produce irrigated with it. Determining what kind of information about each source of recycled water would result in positive welfare implications and reduce existing stigmas may be a suitable starting point. This research should also explore how these various factors (whether information, nudges, or other behavior targeting treatments) interact with different source of recycled water used in agriculture to promote large-scale adoption of recycled water by the agricultural industry. Ensuring food production now and in the future for a growing world population will depend on supplementing irrigation with recycled water. Doing so most effectively without invoking a negative consumer response is imperative and policy makers should be aware of these issues ex-ante to avoid negative public overreactions.

Data Availability Statement

All analyses were estimated using Stata/BE 17 and the data code for this paper can be retrieved from the anonymized link: https://osf.io/hg9dx/?view_only=e40ee271f84d47b693d791df0a252bb1.

Acknowledgments

This study received ethics approval from the Institutional Review Board at the University of Delaware (874969-5). Funding support for this research was provided by the USDA National Institute for Food and Agriculture (Grant 20166800725064), which established CONSERVE, a Center of Excellence at the Nexus of Sustainable Water Reuse, Food, and Health, and CBEAR, the Center for Behavioral and Experimental Agri-Environmental Research. The authors acknowledge Natalie Brassill and Maddi Valinski for their assistance in administering this field experiment. A special thanks to the editor, Dr Shafiqul Islam, and three anonymous referees for constructive comments.

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