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RESEARCH ARTICLE

Consumer Preferences for Per- and Polyfluoroalkyl Substances Versus Bio-Based Treatments of Disposable Dinnerware: A Discrete Choice Experiment

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Abstract
Alternative disposable dinnerware treatments to per- and polyfluoroalkyl substances (PFAS) are under development. A discrete choice experiment of 1,304 U.S. consumers addressed the market's response to bio-based alternatives. Information nudges were used to assess the impact of health and environmental information on behavior. Data were analyzed using mixed logit models. Bio-based treated plates generated premiums compared to the PFAS-treated plates. Participants exposed to either environmental or health information were willing to pay a price premium of $2.0-$2.12 for bio-based treatments. Both information nudges generated premiums for the USDA Certified Bio-based products relative to the control.

Keywords: Agricultural fibers; choice experiment; information nudging; molded dinnerware; tree pulp; willingness-to-pay

JEL classifications: D81; D91; M31; Q1

1. Introduction

Per- and polyfluoroalkyl substances (PFAS) are human-made chemicals that have been used for over 80 years on cookware and food packaging and in food processing to increase product durability through their nonstick properties and grease, oil, and water resistance (USDA – FDA, 2022). There are currently 1400 different PFAS used in over 200 products (Glüge et al., 2020). However, there are concerns that PFAS do not easily break down (leading to the term "forever chemicals") and can accumulate in the environment (soil, water, air), and subsequently plants, animals, and humans. PFAS are commonly detected in different sources like municipal and industrial wastewater, leachates from landfills, agricultural runoff, and stormwater. Their widespread presence, primarily as anionic species, is attributed to their extensive utilization and inherent solubility. This has led to concerns about potential negative effects on the environment and human health if PFAS continue to be produced and used in food handling and preparation (USDA - FDA, 2022). Therefore, attention to PFAS and alternatives is increasing in and outside the scientific community. For example, food packaging companies are starting to adopt "PFAS free" labels on their products to reassure consumers about their safety. The results from Google Trends (2024) research show increasing interest in PFAS over time via online Google searches,

where the search data from last two decades (from January 2004 to the present year) show exponential growth.

This research focuses on the disposable dinnerware industry and their use of PFAS or bio-based treatments to improve product durability. The disposable dinnerware was selected as the focal product category because of its direct food contact (and heightened migration exposure to PFAS (Lerch et al., 2022)) and recent regulatory changes resulting in the phasing out of PFAS in the industry (Perkins Coie LLC, 2023). Studying consumer preferences in this context provides timely insights into the market of PFAS-free products. Within the disposable dinnerware category, we focus on molded dinnerware. Molded dinnerware includes plates, cups, and bowls made from plant fibers as an alternative to disposable dinnerware constructed from petroleum-based (e.g., plastic) materials (Semple et al., 2022). Molded dinnerware is of interest given that global demand for molded dinnerware has increased (Global Market Insights, 2023). Specifically, in 2022, the molded dinnerware industry was valued at $3.4 billion and is forecasted to grow with an 8.2% compound annual growth rate (CAGR) between 2023 and 2038 (Global Market Insights, 2023). In 2018, the U.S. production of foodware, including molded dinnerware containers, exceeded 1.4Mt (Environmental Protection Agency, 2019). Molded dinnerware is inexpensive and renewable but sometimes lacks the functional properties of petroleum-based packaging (e.g., oil and water resistance, durability) which consumers have come to expect. Additionally, molded dinnerware (or any dinnerware) comes in direct contact with food, meaning that unintentional migration of PFAS may occur to the food and subsequently be consumed by consumers (Lerch et al., 2022). Straková et al. (2021) demonstrated that across different food packaging and disposable dinnerware items, PFAS concentrations were highest on molded dinnerware. Regardless of the amount of PFAS chemicals that migrate into foods, the problem remains that the PFAS chemicals or their byproducts will persist long after the useful life of the packaging material. Further, when municipalities began banning plastic foam take-out containers, the molded pulp fibers seemed to be one of the best alternatives. Due to many of the aforementioned PFAS concerns, in 2016, the FDA established regulations revoking the use of long-chain PFAS on products that come in contact with food (Perkins Coie LLC, 2023). Given these challenges, firms are actively pursuing safe, environmentally-sound alternatives to PFAS treatments including bio-based treatments (Glenn et al., 2021).

Several studies have addressed consumer perceptions of bio-based products as alternatives to plastics. A small study of Dutch consumers used focus groups to address perceived benefits and concerns related to bio-based technologies (Lynch et al., 2017). They identified high costs, food shortages, and deforestation as their top concerns. However, they also indicated an overall favorable opinion toward bio-based technologies related to economic growth and sustainability. Other studies identify consumer confusion about what bio-based means (Lusk, 2022) and some negative perceptions related to bio-based production methods (Lynch et al., 2017). Very few studies address consumers' awareness, liking, or purchasing behavior for bio-based products (see review by Ruf et al., 2022). To date, no studies exist that compare consumer preferences and valuation for bio-based treatments over PFAS treatments on molded dinnerware. Moreover, consumer awareness of PFAS remains limited, and prior studies have not investigated whether information treatments framed around personal or environmental health alter preferences of sustainable dinnerware attributes. Here we address that knowledge gap by investigating the following research objectives:

1. Assess consumers' awareness and knowledge of PFAS and alternative treatments that may break down easier in the environment;
2. Estimate consumers' willingness to pay (WTP) for molded dinnerware with bio-based treatments, USDA certifications, and different fiber sources; and
3. Identify whether personal health or environmental information nudges improve value of alternative molded dinnerware treatments (i.e., bio-based treatment) relative to general PFAS information (i.e., the control).

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The contributions of this study include practical applications for the disposable dinnerware industry in terms of consumer preferences, acceptance, and valuation of non-PFAS alternatives. The attributes included in the choice experiment were identified through industry consultation and are either already available in the marketplace or are currently under development. Comparing results across the information treatments aids in better understanding the framing potential of marketing messages (personal health, environmental) to encourage more sustainable purchasing behavior among U.S. consumers. Furthermore, the findings of this study can contribute to the limited consumer behavior literature on PFAS treatments, bio-based treatments, and molded dinnerware preferences.

2. Literatue review – consumer behavior studies

Consumers are becoming increasingly conscientious about how their purchases impact the environment and their own health (Li et al., 2021; Morone et al., 2021; Muhammad et al., 2022). Demand has increased for products that are perceived as more environmentally friendly, including disposable dinnerware options (see review by Ruf et al., 2022). Gill et al. (2020) identified important eco-friendly attributes of disposable dinnerware among Tennessee consumers. Key attributes included being recyclable and containing no plastics. Crop byproduct fiber sources or dedicated crops (i.e., agricultural crops) were also perceived as important. Interestingly, organic cellulose was perceived as important to 54% of the participants, and USDA Certified Bio-based was important to 53% of the participants. They also found that males, urban or suburban residency, age, children, and household income positively impacted the importance of eco-friendly disposable dinnerware.

Many studies that incorporate "bio-based" elements focus on bio-based plastic alternatives rather than disposable dinnerware treatment options. For instance, a study by Notaro et al. (2022) addressed Italian consumers' preferences for bio-plastic products and found that participants were willing to pay premiums for bio-plastic cups and jackets relative to plastic products. Another study addressed attitudes toward bio-plastic bottles and found that British consumers exhibit a more positive attitude toward bio-plastic bottles relative to plastic bottles (Zwicker et al., 2023). Rumm (2016) determined that bio-based shopping bags and disposable cups were preferred by German consumers relative to conventional alternatives due to less dependency on fossil fuels and reduced carbon emissions; however, some concern was expressed related to reduced land availability for food production, increased monoculture agriculture, and use of genetically modified crops to produce bio-based products. Lusk (2022) used a choice experiment and found that U.S. consumers needed discounts for foods in take-out containers that were made from bio-based or bio-plastic materials. Conversely, they were willing to pay premiums for food in compostable, plant-based, or recyclable take-out containers. This implies there are perceptual differences based on the materials and terms used when considering plastic alternatives.

A 2022 industry report assessed U.S. consumer confusion related to the terms "bio-based, biodegradable, bioeconomy, bioplastics, biopolymer, circular economy, compostable, organic, plant-based, and recyclable" (Lusk, 2022). In general, responses indicated low consumer awareness, subjective knowledge, and objective knowledge, while there was high confusion about the definition of the terms. Often, the term bio-based was defined similarly to biodegradable, compostable, and organic. Perceived quality was different across the terms with organic generating the highest quality ratings while recyclable obtained the lowest quality ratings. Participants supported labeling products as bio-based, but not to the degree that they support policies indicating the product was compostable, recyclable or biodegradable.

Related literature demonstrates that fiber source influences consumer valuation of bio-based products. Gill et al. (2019) determined that Tennessee consumers are willing to pay a $1.33

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premium for a disposable bowls (25-count) made from wheat straw relative to conventional disposable bowls. Italian consumers valued bio-plastic cups and jackets made from 100% wood-based plastics relative to fossil-based plastic products (Notaro et al., 2022). Paper-based bioplastics generated a premium over plastic bottles among British consumers (Zwicker et al., 2023). These studies provide evidence of the potential premium for products produced using alternative fiber sources, which may overcome additional production expenses.

Wensing et al. (2020) addressed how green information nudges impacted bio-based plastic packaging preferences among German consumers. They determined that alignment between the information type (nature picture, reflections, information, normative information) with the consumers' cognitive style amplified WTP for the bio-based packaging. Nature photos only increased value for consumers who based their choices on emotions and intuition, while information treatments increased value for those who preferred cognitive discussion. This suggests there is potential to use information nudges to assess the market's response to bio-based (and PFAS) targeted information, which could provide insights for future marketing efforts. To date, this has not been done.

Consumer behavior literature suggests strong consumer support for disposable dinnerware constructed from bio-based plastic alternatives (Gill et al., 2020; Lusk, 2022; Notaro et al, 2022; Zwicker et al., 2023); however, none of the literature addresses bio-based treatments on disposable dinnerware or take-out containers to improve durability. Additionally, consumers may be confused about terms related to these alternatives, including bio-based treatments (Lusk, 2022). The present study aims to dive further into PFAS versus bio-based treatment alternatives to identify consumer preferences and WTP for molded dinnerware with these attributes. Consumer preferences for additional molded dinnerware attributes were also assessed, including price, USDA Biobased Certified, fiber source, microwavable, and compostable. Further, we investigate how information nudges (i.e., personal health, environmental) influence behavior to identify the potential impact of framing on consumer behavior for these items. In turn, this information can be used to develop marketing and promotional strategies to encourage sustainable purchasing behavior.

3. Methodology

The overall research objective is to assess how participants respond (i.e., WTP estimates) to information nudges about the impact of PFAS on (1) personal health and (2) the environment. To address the research objective, an online survey of 1,304 U.S. consumers was conducted during December 2022 through the online survey panel provider Qualtrics (Provo, UT). The survey consisted of a consent form, screening questions, purchase behavior questions, a choice experiment, perceived risk, and socio-demographic questions. The screening questions were used to target individuals who purchased disposable dinnerware (molded, paper, plastic, or Styrofoam) within the past 12 months, were 18 years old or older, and were the primary household grocery shopper or had shared responsibility for grocery shopping. The purchasing behavior questions addressed current and past purchases related to disposable dinnerware, including products purchased in the past year, awareness and knowledge of forever chemicals and bio-based products, concerns related to personal and environmental health, retailers used, frequency of purchase, amount spent, and reasons for purchase. Prior to the choice experiment, participants received a cheap talk script reminding them of their household budgets and to accurately select the product they would purchase. Cheap talk scripts have been shown to decrease hypothetical bias by reminding participants of real-world constraints (Cummings & Taylor, 1999; Tonsor and Shupp, 2011). After the cheap talk script, participants were randomly assigned to an informational treatment (personal health, environmental health) or the control. They then completed the choice experiment, risk perceptions questions, and demographic questions. All experimental processes and protocols were approved by the institutional review board

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(IRB-22-07051-XM). Prior to the formal launch, the survey was soft launched with 50 participants. After reviewing their responses to identify any experimental issues prior to launch, the formal survey was launched two weeks later.

3.1. Choice experiment design

We used a discrete choice experiment (DCE) to address the research objective. DCEs are based on Lancaster's (1966) consumer demand theory stating that consumers gain utility from attributes of the product rather than the product itself. DCEs are widely used in behavioral research due to the benefits of simulating real situations where participants make decisions by evaluating the potential benefits received from product attributes and the ability to have a larger number of observations from smaller samples relative to other methods (e.g., contingent valuation; Louviere et al., 2000). Examples from previous research using DCEs with information treatments include addressing the impact of message source and local food preferences (Liu, Kassas, and Lai, 2024), sugar labeling (Ma et al., 2024), and natural food coatings to reduce food waste (Dsouza et al., 2023).

The DCE scenarios were developed using JMP Pro 16 software in SAS. The D-efficiency was used to identify the optimal number of scenarios and could range from 0 to 100% with 100% indicating a balanced, orthogonal design (Vanniyasingam et al., 2016). The choice experiment consisted of 12 scenarios with a D-efficiency of 92.319%. While the design orthogonalized attribute combinations, we excluded choice scenarios where a weak dominance may occur (e.g., choice A was a better choice at a lower price than choice B). Each scenario had three answer options, including option A, option B, or neither (Figure 1). The options each had six attributes listed (Table 1). Each attribute and level were reviewed by researchers and industry professionals to ensure accuracy. The attributes included the treatment (bio-based or PFAS) and a corresponding picture where the bio-based treated product was tan while the PFAS was light gray. Other attributes included microwavable (yes, no), compostable (yes, no), USDA Certified Biobased (yes, no), fiber source (trees, agricultural plants), and price per 25 plates ($3.99, $4.99, $5.99, $6.99). Each attribute was defined prior to the DCE (Table 1). Participants were also instructed that although some of the attributes may appear similar, each is distinctly different. The USDA Certified Biobased attribute definition provided a broad definition of "the plates are made from renewable resources composed wholly or significantly of biological ingredients (e.g., renewable agricultural or forestry materials)." No other information was provided about specific thresholds (percent composition) given the lack of this information in typical retail environments and due to the focus of the study being PFAS treatments. Price levels were determined based on a retail pricing survey of molded dinnerware products conducted across several types of stores (e.g., big-box, convenience, online, grocery stores, etc.) The observed price range was subsequently validated with industry stakeholders. Participants received definitions of the attributes prior to the choice scenarios (Table 1). For analysis, the attribute variables were coded as binary (1 = present, 0 = absent), and price was left as the monetary value. Figure 1 shows an example of how the choice scenarios appeared to participants.

3.2. Information treatments

Two information treatments (personal health, environmental health) and a control were used. All three treatments were based on USDA PFAS information (USDA - FDA, 2022). The personal health treatment emphasized the potential impact of PFAS on personal health. The environmental treatment focused on the potential impact of PFAS on the environment. The control treatment defined PFAS but did not disclose any human or environmental health information. Figure 2 presents the three sets of information shown to participants. Based on consumers' low awareness of PFAS (Lusk, 2022), we hypothesize that the personal health (H_{a1}) and environmental health (H_{a2}) treatments will increase participants' WTP for PFAS-free dinnerware treatments (i.e., bio-based treatments) relative to the control treatment:

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Table 1. Attributes and attribute levels used in a choice experiment investigating U.S. consumer preferences for molded fiber dinnerware

Attribute	Attribute levels[1]	Definitions
Treatment	Bio-based (1)	Plant-based materials were used to treat the plates for grease, water and heat resistance
	PFAS (0)*	PFAS were used to treat the plates for grease, water and heat resistance
Microwavable	Yes (1)	Plates are microwavable
	No (0)*	
Compostable	Yes (1)	Plates are compostable
	No (0)*	
USDA certified biobased[2]	Yes (1)	The plates are made from renewable resources composed wholly or significantly of biological ingredients (e.g., renewable agricultural or forestry materials)
	No (0)*	
Fiber source	Trees (1)	Plates are made from tree pulp
	Agriculture products (0)*	Plates are made from agriculture byproduct pulp (e.g., wheat or rice straws) where the main crop was harvested for a different use or from crops specifically grown for pulp production (e.g., Miscanthus, sorghum, switchgrass)
Price	$3.99	Price per 25 plates
	$4.99	
	$5.99	
	$6.99	

[1]Coded values are provided in parentheses where applicable.
[2]*Source:* USDA (2022).
PFAS = per- and polyfluoroalkyl substances.
*Indicates the attribute level used in the analysis as the base for comparison.

$$\mathbf{H_{01}}: \mathbf{WTP_{bio\text{-}based}}^{\mathbf{Personal\ health\ treatment}} \leq \mathbf{WTP_{bio\text{-}based}}^{\mathbf{Control}},$$

$$\mathbf{H_{a1}}: \mathbf{WTP_{bio\text{-}based}}^{\mathbf{Personal\ health\ treatment}} > \mathbf{WTP_{bio\text{-}based}}^{\mathbf{Control}},$$

$$\mathbf{H_{02}}: \mathbf{WTP_{bio\text{-}based}}^{\mathbf{Environmental\ treatment}} \leq \mathbf{WTP_{bio\text{-}based}}^{\mathbf{Control}},$$

$$\mathbf{H_{a2}}: \mathbf{WTP_{bio\text{-}based}}^{\mathbf{Environmental\ treatment}} > \mathbf{WTP_{bio\text{-}based}}^{\mathbf{Control}}.$$

3.3. Econometric analysis

DCEs are based on random utility theory where individuals strive to obtain the greatest utility (i.e., benefits, value) from the product selected. Thus, they weigh the available products and attributes and select the option that provides the best utility. Following Train (2003), the utility U that participant n gains from j alternative for a choice task t can be expressed as:

$$U_{njt} = \beta_n^{'} x_{njt} + \varepsilon_{njt} \tag{1}$$

where observed variables x_{nj} represent the alternatives and decision makers, β_n represents the vector of the variable coefficients for participant n and reflects his/her preferences, and ε_{nj} is the error term that is iid extreme value. Across members of the population, the coefficients vary with density $f(\beta)$ where β is not fixed and varies by the decision maker. Each decision maker knows his/her own value

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Figure 1. Example choice experiment scenario.

of β_n and ε_{nj} and will choose the alternative i if it's utility $U_{ni} > U_{nj} \forall j \neq i$. Researchers can observe x_{nj} but not the β_n and ε_{nj} and cannot condition the probability on β. Consequently, the unconditional choice probability is the mixed logit probability and can be written as:

$$P_{nit} = \int \left(\frac{e^{\beta' x_{ni} t}}{\sum_j e^{\beta' x_{nit}}} \right) f(\beta) \mathrm{d}\beta. \tag{2}$$

The model is estimated based on simulated maximum likelihood estimation using 500 Halton draws. WTP estimates were obtained using the following equation:

$$\mathrm{WTP} = -\frac{\beta_k}{\beta_{\mathrm{price}}} \tag{3}$$

Low standard error of price coefficient and large sample size makes WTP distribution approximately normally distributed (Hole, 2007). Thus, we used delta method to calculate confidence intervals of WTP estimates and pairwise t-test to check the difference between WTP estimates across treatment groups.

4. Results

4.1. Sample characteristics

Table 2 contains the summary socio-demographic variables from the sample. A total of 1,304 U.S. consumers participated in the survey. The sample consisted of 69% females, averaged 51 years old, and had 2 adults and 0.5 children in the household. Approximately, 39% had a 4-year bachelor's degree or higher at the time of the study. The average household income in 2022 was $64,854. The sample overrepresented females than the U.S. population (U.S. Census Bureau, 2023). The higher portion of females likely occurred due to screening for individuals with grocery shopping responsibilities. Currently, women still have more household grocery shopping responsibilities than men in the U.S. (Van Hove, 2022). Our sample represents key decision makers of disposable

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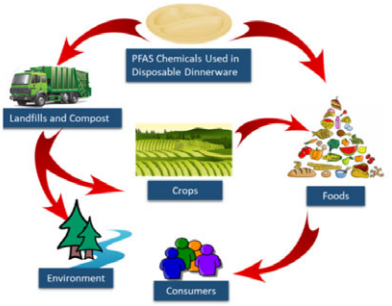
What Are PFAS?

According to the US Food and Drug Administration:

Per- and polyfluoroalkyl substances (PFAS) are chemicals that have been used in a variety of consumer and industrial products since the 1940's due to their resistance to grease, oil, water, and heat. Certain PFAS are authorized by the FDA for limited use in cookware, food packaging, and food processing equipment.

The widespread use of PFAS and their ability to remain intact in the environment means that over time PFAS levels from past and current uses can result in **increasing levels of environmental contamination**. Due to the fact that components of PFAS break down very slowly over time, they are sometimes termed "forever chemicals".



(Source: https://www.fda.gov/food/chemical-contaminants-food/and-polyfluoroalkyl-substances-pfas)

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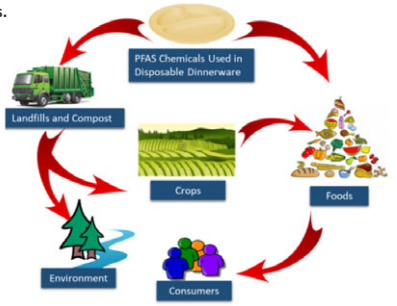
The widespread use of PFAS and their ability to remain intact in the environment means that over time PFAS levels from past and current uses can result in increasing levels of environmental contamination. Due to the fact that components of PFAS break down very slowly over time, they are sometimes termed "forever chemicals". **Accumulation of certain PFAS has also been shown through blood tests to occur in humans and animals. Exposure to some types of PFAS have been associated with serious health effects.**



(Source: https://www.fda.gov/food/chemical-contaminants-food/and-polyfluoroalkyl-substances-pfas)

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Figure 2. Information treatments shown to participants prior to the choice experiment.

dinnerware purchases. As such, our findings are most generalizable to active U.S. consumers of molded dinnerware products.

Table 3 reports the balance of key socio-demographic, knowledge, and awareness variables across the three randomized treatment groups. No statistically significant differences were observed in age, gender, household composition, education, and consumer knowledge measures for PFAS and alternatives. A subtle difference was observed in income ($p = 0.02$), with participants in the environmental health treatment reporting a higher average income when compared to the personal health treatment. Some marginal differences were observed in awareness of the term "forever chemicals" ($p = 0.03$), though the differences in percentages were small. Given the overall balance and random treatment assignment, the results support the validity of treatment comparison for the subsequent analysis.

4.2. Awareness and knowledge of PFAS and bio-based products

In addition to socio-demographic information, we measured respondents' awareness and knowledge of PFAS, forever chemicals, bio-based products, and lignin (Table 4). Only 16.4% of respondents indicated they heard of the term "forever chemicals" and 20.3% had heard of PFAS.

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Table 2. Socio-demographic characteristics of the sample and U.S. population in 2022

		Sample (n = 1,304)		U.S. population[1] 333.29 M
Variable	Definition	Mean	SD	Mean
Age	Age of participant, in years	51.301	17.180	47.8
Female	1 = female; 0 = otherwise	0.692	0.462	0.504
Adult	Number of adults in household	2.061	1.449	2.6 people per household
Child	Number of children less than 18 years old in household	0.470	0.896	–
Education	1 = bachelor's degree or higher; 0 = otherwise	0.392	0.488	0.337
Income	2022 household income ($1,000 USD)	64.854 (mean)	50.153	69.021 (median)
		55.000 (median)		

[1]Source: U.S. Census Bureau (2023).

Table 3. Sub-sample summary statistics and balance test among treatment groups

	Control sample (n = 419)		Treatment: environmental health (n = 422)		Treatment: personal health (n = 463)		
Variable	Mean	SD	Mean	SD	Mean	SD	p-value[1]
Age	52.09	16.78	50.21	17.39	51.57	17.32	0.26
Female	0.67	0.46	0.69	0.45	0.69	0.45	0.68
Adult	2.09	2.04	2.04	0.09	2.03	1.11	0.80
Child	0.47	0.90	0.48	0.99	0.45	0.90	0.82
Education	0.39	0.49	0.41	0.49	0.36	0.48	0.30
Income	65.23	48.16	69.19	54.27	60.55	47.69	0.02
Consumer knowledge							
PFAS	2.12	1.31	1.93	1.26	1.97	1.26	0.64
Forever chemical	2.07	1.36	1.98	1.32	1.85	1.22	0.06
Bio-based products	2.79	1.32	2.89	1.30	2.76	1.26	0.62
Lignin	1.80	1.21	1.71	1.17	1.65	1.09	0.08
Consumer awareness							
	Freq	Percent (%)	Frequency	Percentage (%)	Freq	Percent (%)	
PFAS	92	21.96	83	19.67	89	19.22	0.30
Forever chemical	67	15.99	79	18.72	68	14.69	0.03
Bio-based products	248	59.19	286	67.77	275	59.40	0.052
Lignin	55	13.13	54	12.80	63	13.61	0.14

[1]p-values are from chi-square tests for the difference between categorical variables (e.g., female) and ANOVA with or without equal variances for the other variables.
PFAS = per- and polyfluoroalkyl substances.

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Table 4. Consumer awareness and knowledge of PFAS, bio-based products, and terminologies related to disposable dinnerware (n = 1,304)

	Knowledge rating[1]		Awareness measure[2]	
Variable	Mean	SD	Frequency	Percentage (%)
PFAS	2.01	1.28	264	20.25
Forever chemical	1.96	1.30	214	16.41
Bio-based products	2.81	1.29	809	62
Lignin	1.72	1.16	171	13.11

[1]Knowledge rating is measured using a Likert scale (1 = very unknowledgeable to 5 very knowledgeable). [2]Awareness was directly measured with categorical response to "Are you aware of . . . " question where 1 = yes; 0 = no.
PFAS = per- and polyfluoroalkyl substances.

In contrast, 62% reported awareness of bio-based products, indicating greater familiarity with the term. Awareness of lignin (a plant-based material) was considerably lower at 13.1%. Self-reported subjective knowledge was assessed using a five-point Likert scale (1 = very unknowledgeable; 5 = very knowledgeable). Respondents reported the highest average knowledge level for bio-based products (mean = 2.81), followed by PFAS (mean = 2.01), forever chemicals (mean = 1.96), and lignin (mean = 1.72). These findings suggest that PFAS remains a relatively unfamiliar topic for most consumers. This evidence supports the need for information intervention and provides context for interpreting consumer preferences and responses from the choice experiment.

4.3. Purchasing behavior of disposable dinnerware

To provide a brief context on consumer preferences for molded dinnerware attributes, we examined participants reported purchasing behavior. The majority of participants purchased disposable dinnerware from big-box stores (41.8%), followed by grocery stores (25.7%), and discount stores (16.5%). Occasions for purchase most frequently included everyday use (50.6%), followed by holiday gatherings (19.5%), and parties or celebrations (15.6%; Table 5). On average, respondents reported purchasing disposable dinnerware approximately 13 times per year, with an average annual appending of $289.82 (Table 6). The high standard deviation suggests variability in purchasing intensity across the sample. These findings suggest that disposable dinnerware is a common household item purchased for both routine and special occasions.

4.4. Mixed logit model estimates

The mixed logit model estimates for each treatment are presented in Table 7. Consistencies were observed across treatments in terms of significance and directionality. Price negatively impacted participants utility, which aligns with economic theory that as price increases, utility decreases. The neither option (the optout variable) negatively impacted utility meaning participants received greater utility from selecting one of the product options than selecting the neither option. Plates treated with the bio-based treatment increased utility when compared to those treated with PFAS. Plates that were microwavable or compostable generated great utility relative to plates without those attributes. Participants utility increase for plates that were USDA Certified Biobased, relative to plates that were not. Lastly, plates produced using tree fiber had a negative impact on utility when compared to those made from agricultural byproducts. The standard deviations were significant for optout, bio-based treatment, microwavable, compostable, USDA Certified Biobased, and tree fiber which indicates heterogeneity in participants' preferences for these attributes.

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Table 5. Primary retail location and common occasions for disposable dinnerware purchase (n = 1,304)

Variables	Frequency[1]	Percentage (%)
Retail location		
Big-box stores	545	41.79
Grocery stores	335	25.69
Ware-house clubs	142	10.89
Discount stores	215	16.49
Online	48	3.68
Convenience	16	1.23
Do not know	3	0.23
Occasion of purchase		
Everyday use	660	50.61
Holiday events/gatherings	254	19.48
Outdoor picnics	128	9.82
Parties/celebrations	203	15.57
Work parties or events	15	1.15
Charitable events or donations	7	0.54
Travel	3	0.23
To go containers	21	1.61
Other	13	1

[1]Participants could select all that applied. Responses were coded to equal 1 if selected and 0 otherwise.

Table 6. Summary of disposable dinnerware purchase behavior (n = 1,304)

Purchase behavior	Mean	SD
Annual purchase frequency[1]	13.05	36.24
Annual spending	$289.82	1390.12

[1]Participants indicated the times per year they purchase disposable dinnerware using categorical responses (daily, weekly, bi-weekly, monthly, every other month, 3–4 times per year, 1–2 times per year, annually, every couple of years, never). Based on the selected category, responses were recoded to annual purchases (e.g., weekly was recoded to 52 (for the number of weeks per year)).

4.5. Willingness-to-pay estimates

WTP values were estimated based on the mixed logit results and are presented in Table 8. Overall, bio-based treated plates generated a premium of $1.40 to $2.12 relative to PFAS-treated plates. The attributes microwavable and compostable generated premiums of $1.58 to $1.95 for microwavable and $0.78 to $1.1 for compostable when compared to plates without those attributes. The USDA Biobased Certified generated a premium of $0.40 to $0.85 relative to non-certified plates. Conversely, plates constructed from tree fiber resulted in a discount of −$0.60 to −$0.69 relative to those produced from agricultural byproduct fibers.

Significant differences in WTP values were observed in both treatment groups compared to the control. Specifically for bio-based treated plates, the highest WTP was observed in Treatment 1 – environmental health and Treatment 2 – personal health, both at approximately $2, followed by $1.40 in the control group. Pairwise comparison indicated that the WTP estimates in both

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Table 7. Mixed logit model estimates of factors impacting participants' choice for molded dinnerware

	Model 1 – Control[1,2] (32.1% of sample)		Model 2 – Environmental health (32.4% of sample)		Model 3 – Personal health (35.5% of sample)	
Mean	Coef.	SE	Coef.	SE	Coef.	SE
Price	−0.720	0.029***	−0.630	0.028***	−0.692	0.027***
Optout	−3.673	0.216***	−2.701	0.217***	−3.0	0.120***
Biobased treatment	1.012	0.100***	1.350	0.115***	1.394	0.108***
Microwavable	1.384	0.093***	1.239	0.101***	1.099	0.083***
Compostable	0.632	0.068***	0.698	0.077***	0.542	0.061***
USDA certified biobased	0.291	0.067***	0.542	0.070***	0.514	0.067***
Fiber source – trees	−0.500	0.061***	−0.381	0.061***	−0.451	0.056***
SD						
Optout	2.71	0.180***	2.924	0.178***	2.799	0.174***
Biobased treatment	1.57	0.103***	1.822	0.114***	1.895	0.112***
Microwavable	1.30	0.093***	1.499	0.107***	1.199	0.085***
Compostable	−0.645	0.094***	−0.920	0.090***	−0.501	0.104***
USDA certified biobased	−0.630	0.103***	−0.673	0.104***	0.706	0.098***
Fiber source – trees	−0.391	0.144***	−0.353	0.155***	−0.263	0.156***
n	419		422		463	
Log likelihood	−4054.779		−4068.043		−4510.682	
LR chi2	1318.22		1588.99		1620.92	
Prob > chi2	<0.0001		<0.0001		<0.0001	

[1]***, **, * indicates significance at 1, 5, and 10% levels relative to the base variables (i.e., per- and polyfluoroalkyl substances treatment, not microwavable, not compostable, not USDA Certified Biobased, fiber source – agricultural byproduct).
[2]Models are estimated based on simulated maximum likelihood estimation using 1000 Halton draws in STATA.

treatments were significantly higher than the control ($p = 0.001$), but there was no significant difference between environmental and personal health information. Based on these results, the null hypotheses are rejected (H_{01}, H_{02}) and H_{a1} and H_{a2} are supported.

For the microwavable attribute, the Treatment 1 – environmental health had the highest premium at $1.95, followed by control group at $1.9, and then Treatment 2 – personal health at $1.58 relative to non-microwavable plates (all p-values were <0.001 between treatments). Compostable plates generated the highest premium for Treatment 1 – environmental health participants at $1.10, followed by the control group ($0.87), and Treatment 2 – personal health ($0.78; all p-values were <0.001 between treatments). Treatment 1 – environmental health participants were willing to pay the most for USDA Biobased Certified plates ($0.85), followed by Treatment 2 – personal health ($0.74), and then the control group ($0.40; all p-values were <0.001 between treatments). Regarding the discounts for the tree fiber plates, the control group needed the biggest discount (−$0.69), followed by Treatment 2 – personal health (−$0.65), and then Treatment 1 – environmental health (−$0.60; all p-values were <0.001 between treatments).

5. Discussion and practical implications

The primary objective of this study was to evaluate consumer preferences regarding various attributes of bio-based treated molded plates as an alternative to PFAS treatments and to

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Table 8. Willingness-to-pay (WTP) estimates based on the mixed logit model estimates for disposable dinnerware with different treatments

	Model 1 – Control[1,2] (32.1% of sample)		Model 2 – Environmental health[1,2] (32.4% of sample)		Model 3 – Personal health[1,2] (35.5% of sample)	
	WTP Est.	SE	WTP Est.	SE	WTP Est.	SE
Biobased treatment	$1.40	0.13***,a	$2.12	0.18***,b	$2.00	0.15***,b
Microwavable	$1.92	0.13***,a	$1.95	0.16***,b	$1.58	0.12***,c
Compostable	$0.87	0.09***,a	$1.10	0.12***,b	$0.78	0.09***,c
USDA Certified Biobased	$0.40	0.09***,a	$0.85	0.11***,b	$0.74	0.09***,c
Fiber source – trees	$(0.69)	0.08***,a	$(0.60)	0.09***,b	$(0.65)	0.08***,c

[1]***, **, * indicates significance at 1, 5, and 10% levels relative to the base variables (i.e., per- and polyfluoroalkyl substances treatment, not microwavable, not compostable, not USDA Certified Biobased, fiber source – agricultural byproduct).
[2]Pairwise t-tests were used to estimate WTP significance between models. Different lowercase letters "a", "b," or "c" indicate significance at the 5% level. Estimates that share a common letter (e.g., "b" and "b") indicate no significant differences.

determine their WTP for these attributes. This study focused on the U.S. market. Our findings indicate that people are not indifferent toward the suggested attributes and levels, given the positive and significant coefficients associated with them. The type of treatment used on the molded dinnerware impacted customers' utility for those items. Regardless of the information provided to the participants, the bio-based treatment was strongly preferred and generated a premium relative to the PFAS treatment on molded plates. This preference aligns with customers' interest in more sustainable alternatives in the disposable dinnerware industry (Gill et al., 2020; Notaro et al., 2022; Ruf et al., 2022; Semple et al., 2022) and concerns related to PFAS (USDA – FDA, 2022). Furthermore, by itself, this result implies that increasing consumer knowledge and awareness of PFAS (i.e., control) could result in increased purchasing of PFAS-free (bio-based) alternatives. The inclusion of additional information related to potential human health and environmental impacts amplified this effect. There are potential policy implications as the industry transitions away from PFAS treatment in terms of providing science-based educational information to customers to aid them as they make choices.

Information nudges impacted customer valuation for molded dinnerware. Both the environmental and health information nudges resulted in higher premiums for bio-based treated and USDA Biobased Certified disposable molded plates when compared to the control treatment, assuming they cognitively attended the nudges. However, the environmental nudge generated the highest premiums for molded dinnerware with bio-based treatment, compostable, and USDA Biobased Certified attributes. Supporting evidence indicates customers are very interested in disposable dinnerware with more environmentally friendly attributes (Gill et al., 2019; Notaro et al., 2022; Ruf et al., 2022). The importance of the biodegradability in disposable products was also studied in a comparative analysis of consumer attitudes toward packaging products in France, Germany, and the U.S. (Herbes et al., 2018). Our results confirm the increase in customer interest in environmentally friendly attributes and provide an important contribution to the literature on disposable dinnerware. Currently, there are no studies investigating consumers purchasing decisions and preferences for environmentally friendly disposable dinnerware treatments and related attributes. The results highlight the potential value generated through using these benefits in producing molded plates. Point-of-sale information highlighting these components and how they benefit the environment could amplify the value to the customer.

Generally, customers indicate a preference for agricultural byproduct fiber sources. The fiber source results were supported by the disposable dinnerware and PFAS literature. The disposable dinnerware literature demonstrates consumers valuing fiber sources that were not trees, including wheat straw (Gill et al., 2019). Supporting evidence also identified that deforestation is a key

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concern related to PFAS use (Lynch et al., 2017). Sourcing fiber from non-tree sources may serve as a potential value-added opportunity for farmers and growers, especially if their crops are ones where they can collect an initial payment for the primary crop (e.g., seeds) and an additional payment for the leftover debris (i.e., plant stalks, fibers). Overall, our results indicate consumers value bio-based disposable dinnerware, as they preferred products made from 100% fiber-based sources which are biodegradable over time.

Socio-demographic characteristics are shown to have a significant impact on choosing molded dinnerware (Hirsh, 2010). Specifically, younger individuals and women with a high school education or higher are more likely to choose bio-based molded dinnerware. Interestingly, women in general exhibit more positive attitudes toward both environmental protection and purchasing of bio-based items (Hirsh, 2010). This implies there may be an opportunity to target specific socio-demographic groups with bio-based information to encourage more sustainable purchasing behavior in the molded dinnerware industry.

It is worth noting that the informational treatment groups included both informational content and graphical illustrations (Figure 2). This choice was intentional, as the treatment groups were designed to resemble realistic informational campaigns, which often included visual components to increase messaging salience.

There are several limitations to this study. First, we acknowledge that the color of the molded dinnerware may have influenced respondents' perceptions beyond textual attribute descriptions. The plates were presented using different colors (tan for bio-based; light gray for PFAS treated). Based on our review of commercially available molded dinnerware products, bio-based products are commonly tan in appearance, while PFAS-treated products tend to be light gray. Respondents' preference could have been partially affected by associated color cues because color (tan vs. light gray) and treatment type (PFAS vs. bio-based) were not independently randomized. Future studies may address such issues by using the same color of product. Secondly, similar to many behavioral research studies, this study is subject to experimenter demand bias. To help reduce this impact, participants were reminded to make choices based on their true preferences and that no answers were "wrong." Additionally, when asking for purchasing behavior, several non-target items were asked (e.g., lignin, plant-based) to help reduce this effect. Future studies could use real purchase data from stores with PFAS and PFAS-free alternative molded dinnerware items to test the robustness of the results. Lastly, USDA Biobased Certification was included as an attribute, but participants may have associated it with related attributes (e.g., bio-based treatment; fiber type) which could influence results. The USDA Biobased Certification has set standards that could be incorporated into future studies addressing the perceived relationship between this certification and desirable/undesirable attributes. Additional information related to the certificate may also influence behavior but was outside the scope of this study. Although this study focuses on molded dinnerware, the observed consumer responses to PFAS-related information and sustainable treatment alternatives may hold relevance for other consumer goods industries that use PFAS, such as packaging, textiles, and cookware.

6. Conclusions

Here we address consumer interest in PFAS alternative treatments on molded dinnerware. We found that U.S. consumers are interested in PFAS alternative treatments, specifically bio-based options, on molded dinnerware. Additionally, they indicated interest in other sustainability-related attributes on molded dinnerware including compostable, USDA Biobased Certification, and agricultural byproduct fiber sources. This is important because consumers' choices drive demand and there is a need in the disposable dinnerware industry to find sustainable alternatives to the traditional treatments (PFAS) and petroleum-based materials. The results indicate there is potential to generate premiums among U.S. consumers for molded dinnerware and encourage

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more sustainable purchasing if there are products available in the marketplace with these attributes. Using labels and point-of-sale information to inform customers about these attributes for disposable dinnerware could encourage purchasing behavior and generate value. Our finding indicates that U.S. consumers are inclined to spend more on bio-based molded dinnerware made from plant fibers compared to those made from tree fibers. This gives important information to industry stakeholders about environmental characteristics that encourage U.S. consumers to select bio-based molded dinnerware and the potential premiums they are willing to pay for those characteristics.

U.S. consumers were influenced by environmental and personal health information nudges when selecting molded dinnerware with more sustainable attributes (i.e., bio-based treatments, USDA Biobased Certified). The environmental information nudge also improved consumers' value of the compostable attribute relative to the control treatment. Alternatively, the functional attribute of being microwavable was valued the most when participants received no additional information in the control treatment. This implies that providing environmental and health information related to PFAS treatments encourages people to consider alternative products while not providing that information (i.e., the control treatment) results in heightened customer interest in function-related attributes (i.e., microwavable).

There are clear marketing implications based on these results. Specifically, using information related to the impact of PFAS on the environment can encourage sustainable purchasing of molded dinnerware. Similarly, using personal health information related to PFAS use can also heighten the value of bio-based alternatives and USDA Biobased Certified molded dinnerware among consumers. As the disposable dinnerware industry moves away from PFAS treatments, educating customers about the alternatives and the potential issues of using PFAS treatments is one means to encourage purchasing and improve value among customers. Furthermore, it is imperative for future research to focus on different types of bio-based products across multiple industries. This broader exploration could provide more comprehensive insights into the bio-based products market.

Data availability statement. Data available on request due to privacy/ethical restrictions.

Author contribution. Conceptualization, A.R., N.L., K.R., S.J., K.T., K.J.; Methodology, A.R. and K.J.; Formal Analysis, A.R. and P.B.; Data Curation, A.R.; Writing – Original Draft, A.R., P.B., G.K., Writing – Review and Editing, A.R. and P.B.; Supervision, A.R., N.L., G.K.; Funding Acquisition, N.L., K.R., S.J., K.J.

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