

Summary Report of PFAS Alternative Treatments for Molded Dinnerware from a U.S. Marketplace Feasibility Study, 2024

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Executive Summary

Per- and polyfluoroalkyl substances (PFAS) are used in the disposable dinnerware and food packaging industries to improve product durability through heat, grease and water resistance (USDA – FDA, 2022). However, they do not break down easily, leading to concerns about their accumulation and long-term impacts on the environment and human health (CDC, 2024; Rice et al., 2020). Globally, PFAS levels in waterways have exceeded recommended amounts (Ackerman et al., 2024). It has been estimated that PFAS-attributed disease costs in the U.S. range from \$5.5B to \$62.6B (Obsekov, Kahn, & Trasande, 2023). Based on these concerns and costs, the U.S. Food and Drug Administration (FDA) revoked the use of long-chain PFAS for food-contact situations in 2016 (Perkins Coie, 2023). In response, alternative treatments (e.g., plant-based or lignin treatments) are being explored to aid in improving product durability but in a safe, sustainable fashion.

This report summarizes findings from a 2022 online survey assessing 1,304 U.S. consumers' perceptions of PFAS and PFAS alternative treatments (i.e., plant-based, bio-based) in the context of molded dinnerware and restaurant-to-go containers. Results are applicable to the molded dinnerware, restaurant, food service and grocery industries as they consider future product and promotional strategies to engage end customers. Key findings highlight customers' interest in viable alternatives to molded dinnerware and to-go containers with PFAS treatments. Specifically:

Key Insights

1. The majority (83 percent) of U.S. consumers purchase disposable plates **made from paper**.
2. On average, U.S. consumers buy disposable dinnerware **9.8 times per year**.
3. U.S. consumers primarily buy disposable dinnerware for **everyday use** (vs. special occasions).
4. On average, U.S. customers spend **\$14.91 per purchase event** when buying disposable dinnerware.
5. Disposable dinnerware is primarily purchased at **big box stores**, followed by grocery stores.
6. U.S. consumers have **low awareness** and **low subjective knowledge** of PFAS, lignin, and forever chemicals.
7. Among U.S. consumers, **62 percent** are **aware of bio-based** products.
8. Bio-based treatments are perceived as **better for the environment** than PFAS treatments.
9. **40 percent** of the sample viewed **plant-based treatments** as exhibiting **better overall quality** versus 17 percent thought PFAS treatments had better quality.
10. **PFAS treatments** are perceived as more **durable** and **water/grease resistant** than bio-based treatments.
11. Older participants had more positive perceptions of bio-based treatment durability than younger participants.
12. Participants appreciate having **reusable, biodegradable** and **recyclable** to-go containers from restaurants.
13. To-go container type influences perceptions of a restaurant's food quality, environmental commitment, and healthiness of food with molded fiber containers improve these perceptions.
14. U.S. consumers were **most likely to take home leftover food** if given **molded fiber to-go containers**, followed by plastic containers. They were least likely to take home leftovers if given Styrofoam containers.

Methodology

Study Design

Data was collected using an online survey instrument during December 2022. An online survey was used to capture a geographically diverse sample so results could be extrapolated to the U.S. marketplace. The survey consisted of an informed consent form, screening questions, product use and purchasing behavior questions, a choice experiment, attitudinal questions and demographics. The screening questions were used to identify participants who were in the existing marketplace for molded dinnerware. Specifically, respondents needed to be 18 years old or older and have household grocery shopping responsibilities. If they passed the screening questions, they continued to the remainder of the survey. Upon completion of the study, they were given online points from the panel provider (Qualtrics, LLC) to redeem at different online retailer sites. To reduce potential response bias (i.e., responses that do not align with participants' actual perceptions, attitudes and beliefs due to outside factors such as social desirability, question-order, etc.), we employed question randomization, positive and negative statements, screening questions and balanced response scales. Participation lasted approximately 15 minutes. All study procedures and protocols were approved by the University of Tennessee's Institutional Review Board for compliance with human test subjects (#IRB-22-07051-XM).

Sample

A total of 1,304 U.S. participants consented to the study and passed the screening questions. Table 1 presents their summary demographic statistics and the U.S. population demographics. The sample's mean age was 51 years old, 69 percent were female, 39 percent had a bachelor's degree or higher and their 2021 mean household income was \$64,854. In terms of household composition, they averaged two adults and 0.5 children (<18 years). Twenty-five percent of the sample lived in urban areas, 41 percent lived in the suburban areas, 12 percent in small towns, and 23 percent in rural areas. Compared to the U.S. population, the sample was older, and females were overrepresented (U.S. Census Bureau, 2023). These variances are likely related to U.S. Census data including individuals under 18 years of age, whereas the sample only includes adults. Additionally, the screening questions may have resulted in more female participants due to greater household grocery shopping responsibilities relative to males (Supermarket News, 2023). Lastly, household income was slightly lower in the sample and rural residency was slightly higher than the U.S. population statistics. Although the sample was not nationally representative, it still provides valid insights into U.S. marketplace trends.

Table 1. Socio-demographic Summary Statistics of an Online U.S. Sample Collected in 2022.

Variable	Total Sample N=1,304		U.S. Population 334.9M ¹
	Mean	Standard Deviation	Mean
Age (years)	51.3	17.2	38.8 (median) ¹
Female (%)	69%	46%	50.5% ¹
# of Adults / HH	2.1	1.5	2.57 people per HH ¹
# of Children / HH	0.5	0.9	---
Bachelor's degree + (%)	39%	49%	34.3% ¹
2021 HH Income	\$64,854	50,134	\$75,149 (median) ¹
Urban (%)	25%	43%	81.8% ²
Suburb (%)	41%	49%	---
Small town (%)	12%	32%	---
Rural (%)	23%	42%	18.2% ²

¹Source: U.S. Census Bureau (2023).

²Source: CEIC (2021).

Results

Product Use and Purchasing Behavior

Figure 1 shows the portion of the sample that purchased different types of disposable plates within the past year. Most of the sample purchased paper plates (88 percent of the sample), followed by plastic plates (36 percent), Styrofoam plates (34 percent) and agriculture fiber plates (13 percent).

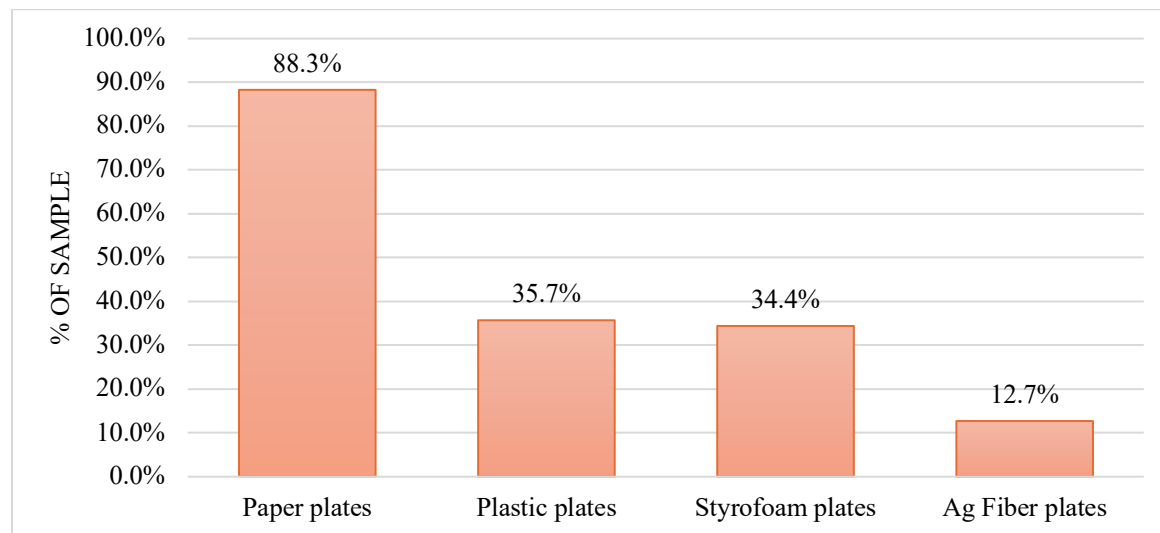


Figure 1. U.S. Participants' Purchasing of Disposable Plates Made from Different Materials from an Online Survey in 2022 (n=1,304).

Generally, participants purchased disposable dinnerware sporadically throughout the year rather than during every grocery trip (Figure 2). Intuitively, this makes sense given that disposable dinnerware is shelf stable and sold in quantities that can last for a greater length of time (e.g., 10, 25, 50, 100 items).

Approximately 76 percent of the sample purchase disposable dinnerware between monthly and one to two times per year with an average of 9.8 times per year. Participants primary reason for purchasing disposable dinnerware was for everyday use (50 percent of the sample; Figure 3). Followed by holiday events/gatherings (19 percent), parties or celebrations (16 percent), outdoor picnics (9 percent), to-go containers (3 percent), other reasons (2 percent), work parties or events (1 percent) and charitable events/donations (0.5 percent).

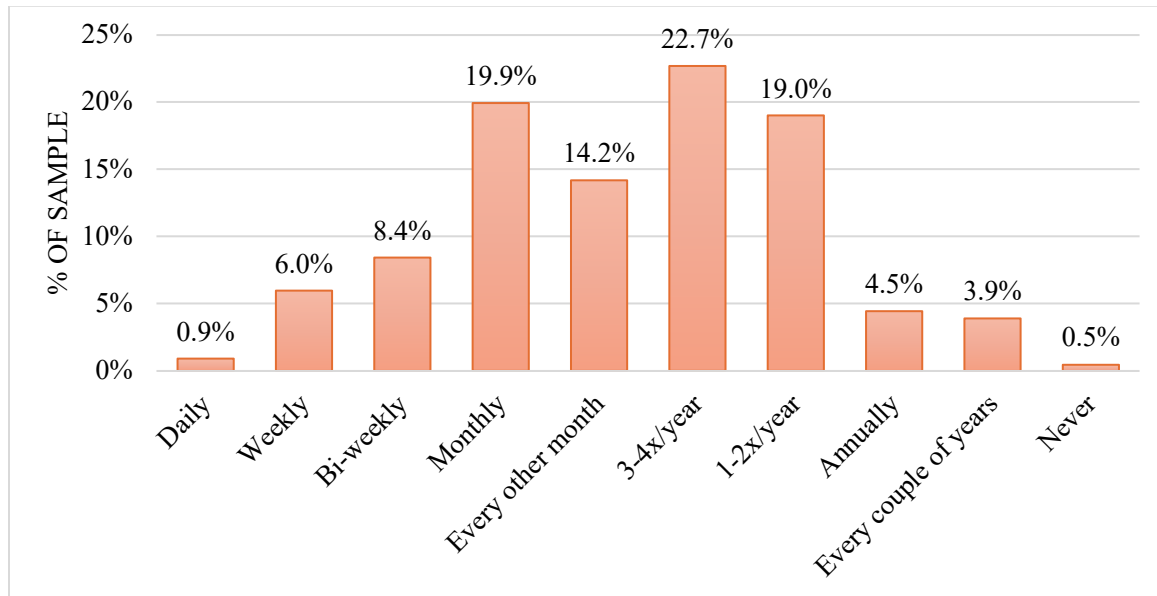


Figure 2. U.S. Participants' Frequency of Purchasing Disposable Dinnerware from an Online Survey in 2022 (n=1,304).

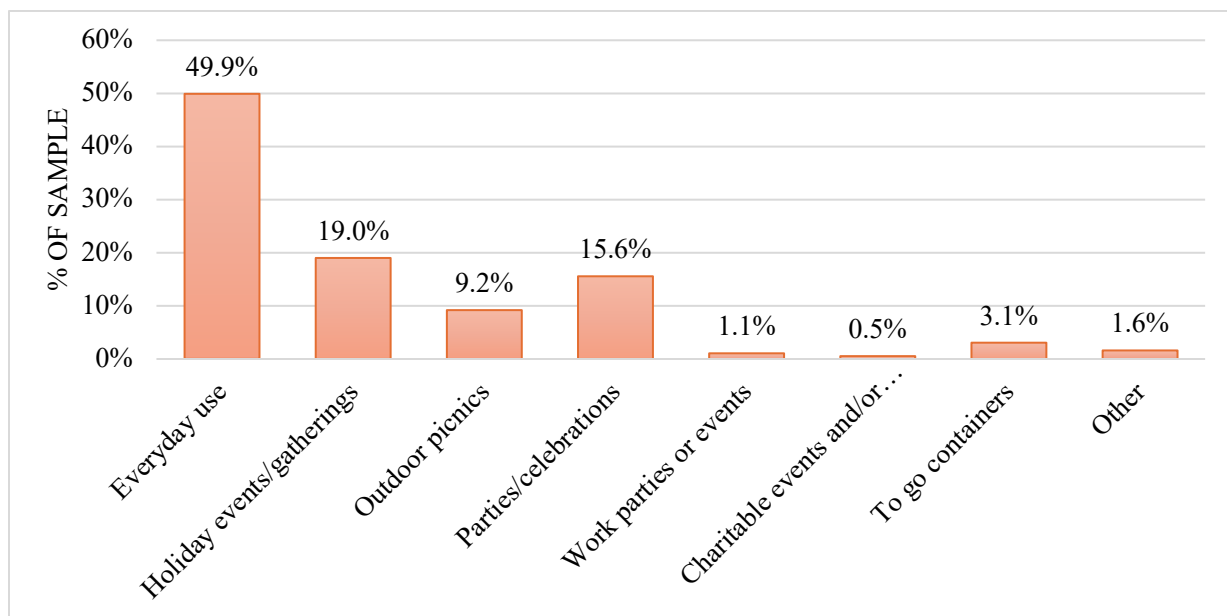


Figure 3. U.S. Participants' Motives behind Disposable Dinnerware Purchases from an Online Survey in 2022 (n=1,304).

Most participants spent between \$0.01 and \$19.99 on disposable dinnerware at each purchase (Figure 4). The mean amount spent was \$14.91 per purchase. The largest portion of participants purchase disposable dinnerware from big box stores (42 percent of the sample), followed by grocery stores (26 percent), discount stores (16 percent), warehouse clubs (11 percent), online retailers (4 percent), other sources (1 percent) and convenience stores (<1 percent; Figure 5).

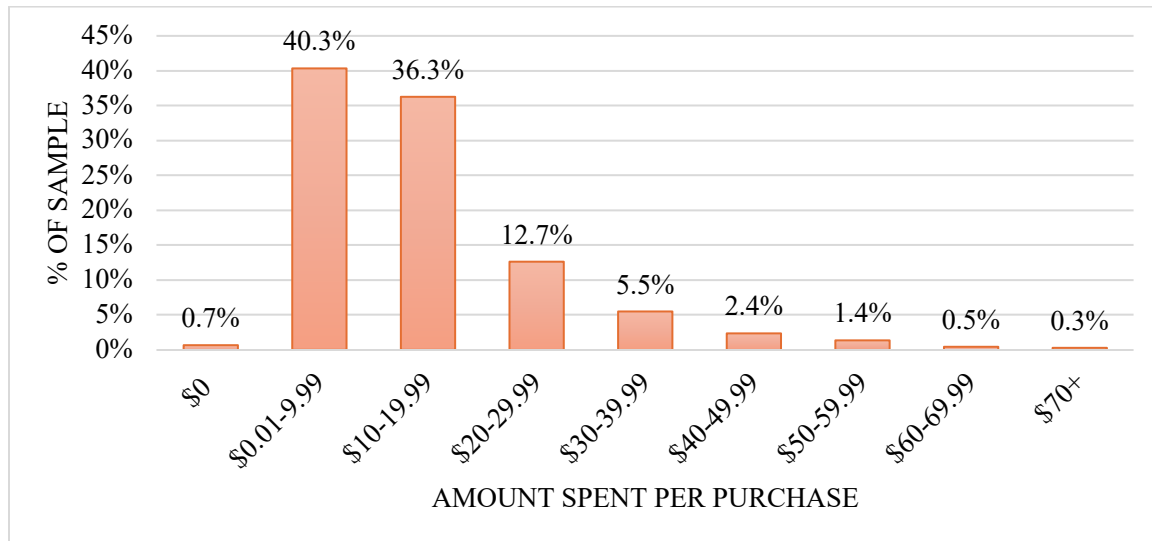


Figure 4. U.S. Participants' Amount Spent on Disposable Dinnerware (per purchase) from an Online Survey in 2022 (n=1,304).

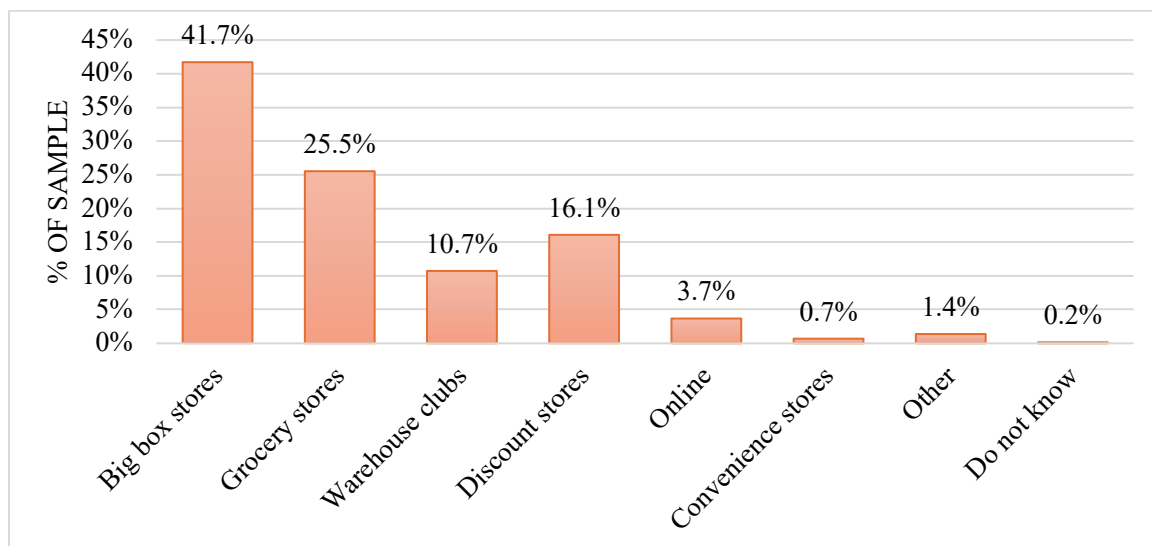


Figure 5. U.S. Participants' Purchase Location (Retailer) for Disposable Dinnerware from an Online Survey in 2022 (n=1,304).

Existing Awareness and Knowledge

Existing studies demonstrate that consumers generally have low awareness of complex scientific terminology (e.g., bio-based, genetic modification, etc.) (Lusk, 2021). However, consumers' existing knowledge can influence their perceptions and purchasing behavior (Kemper et al., 2024; Klerck & Sweeney, 2007). The awareness, knowledge and perceptions of PFAS versus bio-based alternatives results are available in full in Rihn et al. (2024). Here, we summarize a portion of that research, participants' existing awareness for the terms "forever chemicals," "PFAS," "bio-based" and "lignin" (Figure 6). The majority of participants (62 percent of the sample) had heard of bio-based prior to the study, while an additional 19 percent were not certain if they were aware of bio-based and 19 percent indicated they had not heard of bio-based in the past. Conversely, most participants indicated low awareness of forever chemicals (71 percent had not heard of), PFAS (65 percent had not heard of) and lignin (74 percent had not heard of) prior to the study. Forever chemicals had been heard of by 16 percent of the sample, while 12 percent were unsure. Twenty percent of the sample had heard of PFAS, while 15 percent were unsure. Thirteen percent of the sample had heard of lignin and 13 percent were unsure.

Participants reported their perceived subjective knowledge of each of these topics (1=very unknowledgeable; 5=very knowledgeable; Figure 7). For all four topics, participants expressed low knowledge levels. They exhibited the highest knowledge (2.8 out of 5) for bio-based, followed by lignin and forever chemicals (2 out of 5), while PFAS was rated the lowest (1.7 out of 5).

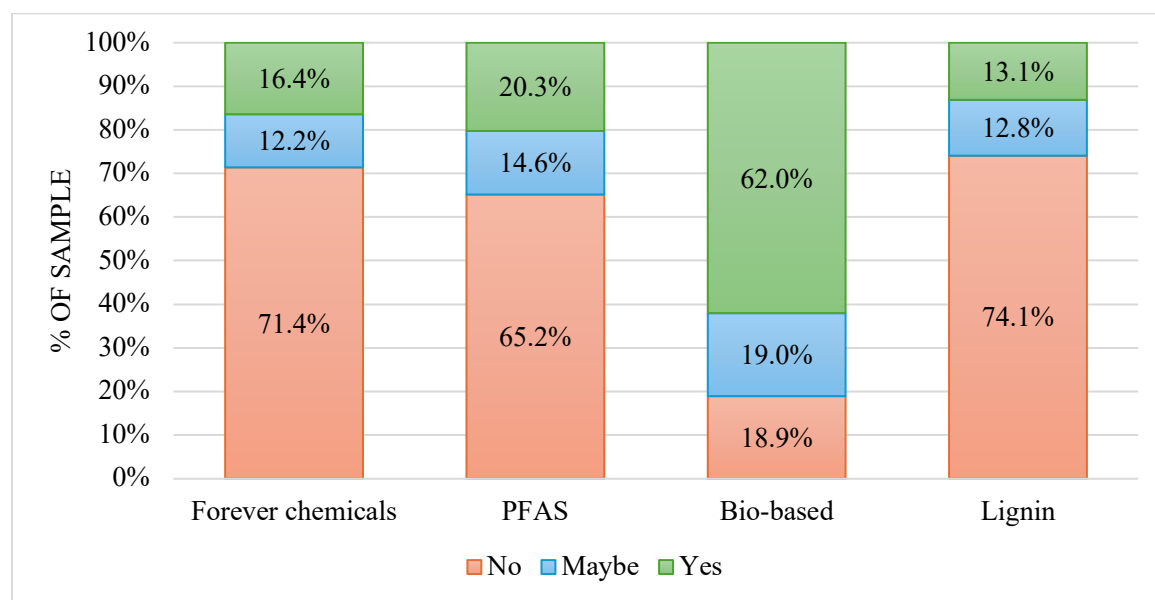


Figure 6. U.S. Participants' Existing Awareness of Forever Chemicals, PFAS, Bio-based, and Lignin Terminology from an Online Survey in 2022 (n=1,304).

Source: Rihn et al. (2024).

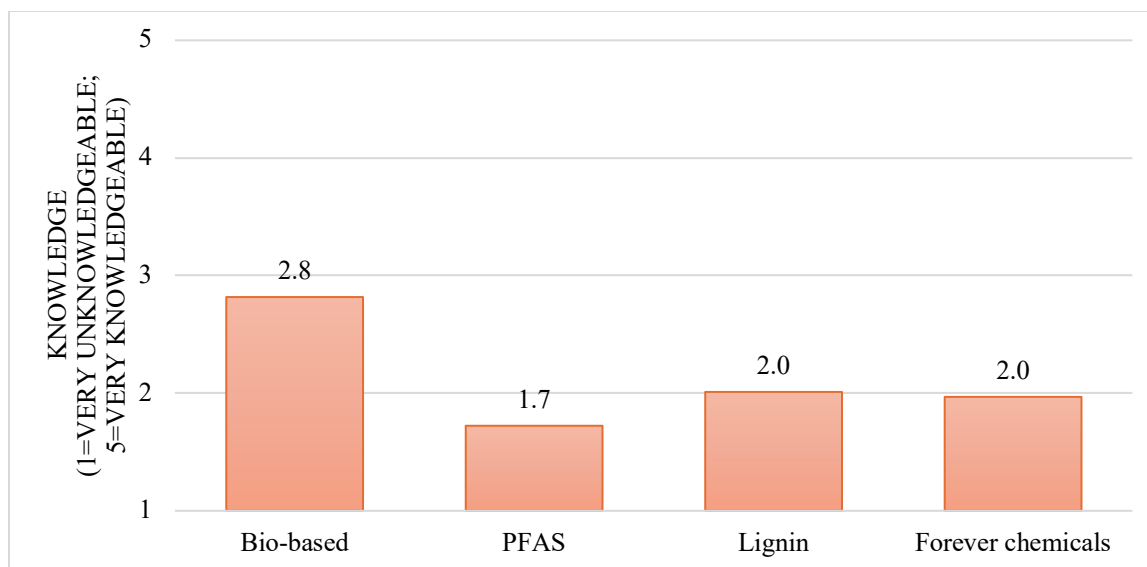


Figure 7. U.S. Participants' Subjective Knowledge of Forever Chemicals, PFAS, Bio-based, and Lignin Terminology from an Online Survey in 2022 (n=1,304).

Source: Rihn et al. (2024).

Perceptions of PFAS and PFAS Alternatives

Participants' perceived risk to themselves and the environment were assessed for disposable plates treated with PFAS or bio-based alternatives (Figure 8). For both personal health and environmental health, PFAS treatments were perceived as much riskier than the bio-based alternatives (2.8 rating for PFAS' impact on personal health vs. 1.9 for bio-based alternatives; 3.1 for PFAS' impact on the environment vs. 1.9 for bio-based alternatives). Further, PFAS treatments were viewed as slightly riskier in terms of the impact on the environment than on personal health, whereas bio-based alternatives were rated equally across the two risk perceptions.

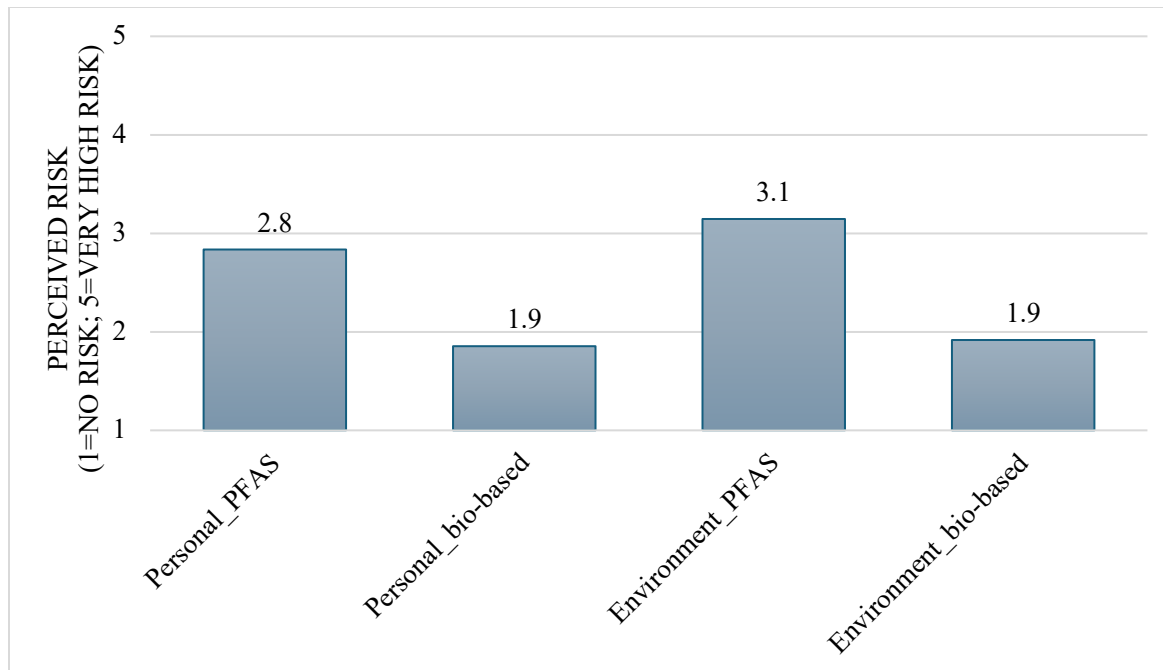


Figure 8. U.S. Participants' Perceived Risk to Personal Health and the Environment of Using Disposable Plates Treated with PFAS or Bio-based Treatments from an Online Survey Conducted in 2022 (n=1,304).

Source: Rihn et al. (2024).

Respondents indicated whether they thought PFAS or plant-based molded dinnerware treatments were better in terms of ten different attributes. Responses were based solely on participants' perceptions of the terminology used given that definitions and trade-offs were not provided in the survey. The attributes were randomized to reduce any order effect. After data collection, they were sorted into practical usage attributes (i.e., grease resistant, water resistant, durable, microwaveable), credence attributes (i.e., better for the environment, better for personal health, recyclable, compostable, made from recycled products) and an overall quality rating. For each of these items, participants could select "PFAS treated is better," "they are the same" or "I do not know," or "plant-based treated is better." The distribution for each attribute is presented in Figure 9. For the practical usage attributes, the largest portion of the sample indicated that the treatments were the same or I do not know ranging from 44 percent for grease resistant to 49 percent for durability. However, for grease resistant and water resistant, PFAS treated captured a larger share of the sample. Conversely, when considering the credence attributes, participants largely selected that plant-based was better, which ranged from 56 percent of the sample for made from recycled products to 74 percent of the sample in the better for the environment attribute. Given that the term "plant" is used in this treatment, it is not surprising that many of the credence attributes are perceived to align with plant-based since most of the attributes are related to the environment (e.g., compost, recycling, environmental health). Lastly, the overall quality rating indicated that 43 percent of the sample viewed the treatments as comparable or did not know. However, the plant-based captured a significantly higher portion of the sample for overall quality (40 percent) than the PFAS-treated option (17 percent).

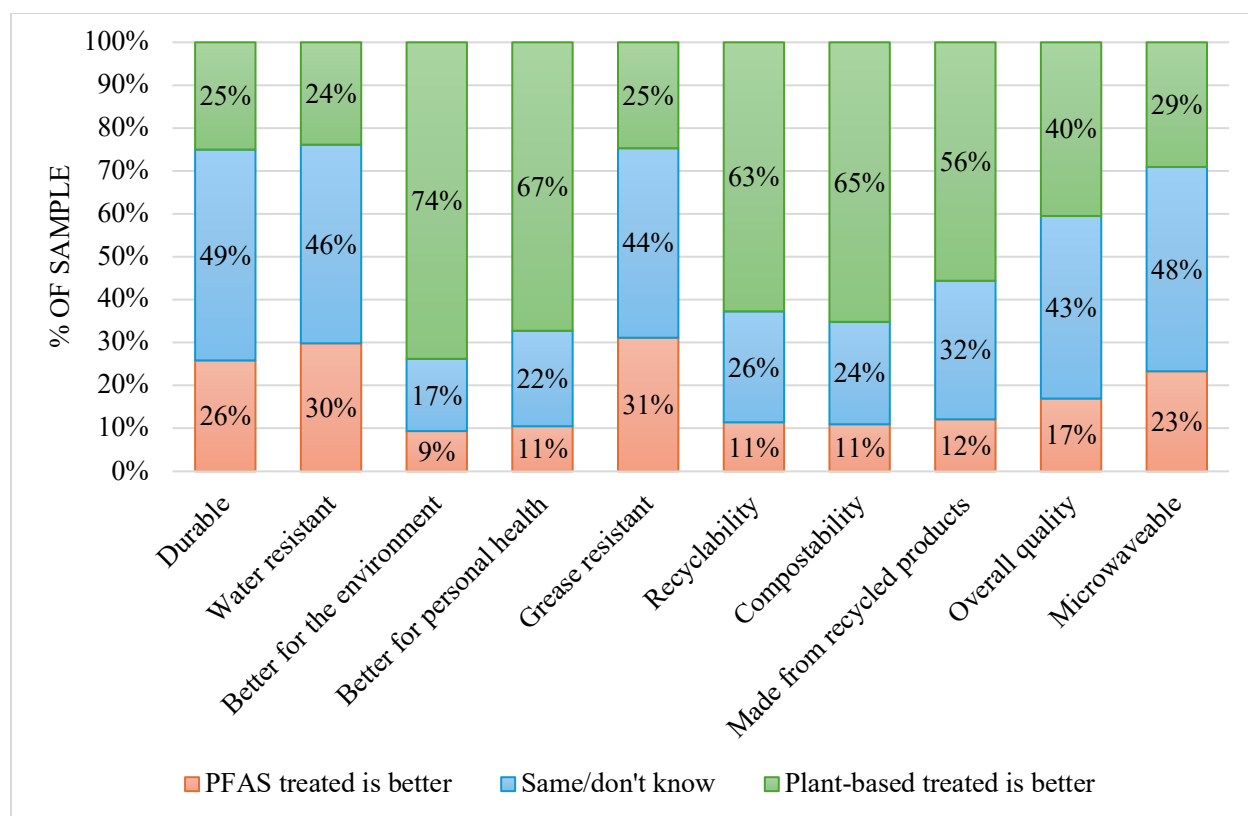


Figure 9. U.S. Consumers Perceptions of PFAS vs. Plant-based Treatments on Molded Dinnerware from an Online Survey Conducted in 2022 (n=1,304).

Source: Rihn et al. (2024).

Analysis was conducted to estimate the marginal effects of participants' awareness, knowledge, risk perceptions and demographics on their perceived attributes for plant-based treatments outperforming PFAS treatments on molded dinnerware. The marginal effect estimates demonstrate how participant awareness, knowledge and risk perceptions increase or decrease the probability of them perceiving plant-based treatments as better than PFAS treatments.

Participants who were aware of bio-based products prior to the study were 5 percent less likely to rate plant-based treatments as better than PFAS treatments for grease resistance, 6 percent less likely to rate plant-based treatments as better for water resistance and 4 percent less likely to rate plant-based treatments as more durable (Table 2). Participants who were knowledgeable about PFAS prior to the survey, were 2 percent more likely to select plant-based treatments as better than PFAS treatments in terms of grease resistance. If participants perceived PFAS as posing a risk to their personal health, they rated plant-based treatments as superior to PFAS for grease resistance, water resistance, durability and being microwavable. If participants perceived bio-based as posing a risk to their personal health, they were more likely to select bio-based as better in terms of microwavable. Conversely, if they perceived bio-based as posing a risk to the environment, they were less likely to select bio-based as microwavable. Age had a slight positive impact on selecting bio-based products as superior across all four attributes. Having a bachelor's degree or higher had a negative impact on the probability of selecting bio-based as better for grease resistance and durability.

Table 2. Influence of Different Factors on U.S. Consumers' Perceived Practical Use Attributes of Plant-based Treatments Performing Better than PFAS Treatments on Molded Dinnerware from an Online Survey Conducted in 2022 (n=1,304).

	Practical Use Attributes			
	Grease Resistant	Water Resistant	Durable	Microwavable
Bio-based aware	-5%	-6%	-4%	
PFAS Knowledgeable	2%			
Personal risk PFAS	6%	7%	6%	6%
Personal risk bio-based				3%
Environment risk bio-based				-3%
Age	0.1%	0.1%	0.1%	0.1%
BS Plus	-5%		-4%	

Note: Only significant results are presented ($\leq 5\%$).

Source: Rihn et al. (2024).

Marginal effects also were estimated for the credence attributes (Table 3). If participants were aware of bio-based products prior to the study, they had an increased probability of perceiving plant-based treatments as superior to PFAS treatments in terms of being better for the environment and personal health and being compostable. Perceiving PFAS as posing a risk to ones' personal health increased the probability of plant-based treatments being perceived as better for the environment, personal health, recyclable, compostable and being made from recycled products. If participants perceived PFAS as posing a risk to the environment, they were more likely to perceive plant-based alternatives as better for the environment and personal health, compostable and made from recycled products, however there was a negative impact on plant-based being perceived as recyclable. Perceptions of the risk of bio-based products to the environment and ones' health had the opposite effects. If they perceived bio-based products as posing a risk to the environment or personal health, they had increased perceptions of plant-based being recyclable while not being better for the environment or personal health, not compostable, nor made from recycled products. This may indicate that people who view bio-based as "risky" have heightened acceptance for plant-based alternatives due to perceiving plant-based as safer. Participants who were aware of PFAS also perceived plant-based as not being recyclable. Females were less likely to perceive plant-based treatments as recyclable but more likely to perceive them as better for the environment. As household size increased, perceptions of plant-based being better for the environment and personal health, recyclable and compostable decreased. Lastly, as income increased, participants' perceptions of plant-based being better for the environment slightly increased.

Table 3. Influence of Different Factors on U.S. Consumers' Perceived Credence Attributes of Plant-based Treatments Performing Better than PFAS Treatments on Molded Dinnerware from an Online Survey Conducted in 2022 (n=1,304).

	Credence Attributes				
	Better for Environment	Better for Personal Health	Recyclable	Compostable	Made from Recycled
PFAS aware			-5%		
Bio-based aware	4%	4%		6%	
Personal risk PFAS	7%	9%	4%	3%	7%
Personal risk bio-based	-7%	-8%	6%		-5%
Environment risk PFAS	10%	10%	-8%	13%	9%
Environment risk bio-based	-7%	-5%	10%	-9%	-5%
Female	5%		-5%		
Household	-2%	-1%	-5%	-1%	
Income	0.1%				

Note: Only significant results are presented ($\leq 5\%$).

Source: Rihn et al. (2024).

Perceptions of Restaurants and To-Go Containers

Beyond disposable dinnerware, molded fiber is often used as to-go containers by restaurants. Questions related to perceptions of to-go containers were asked to capture perception information from this market. Generally, participants agreed that they like to receive reusable to-go containers (mean=4.1 on a 5-point scale; Figure 10). They also agreed that it is important that restaurants use recyclable to-go containers (mean=3.8) and biodegradable to-go containers (mean=3.7). They slightly disagreed with the statement that “I do not pay attention to the type of to-go container restaurants use” (mean=2.8).

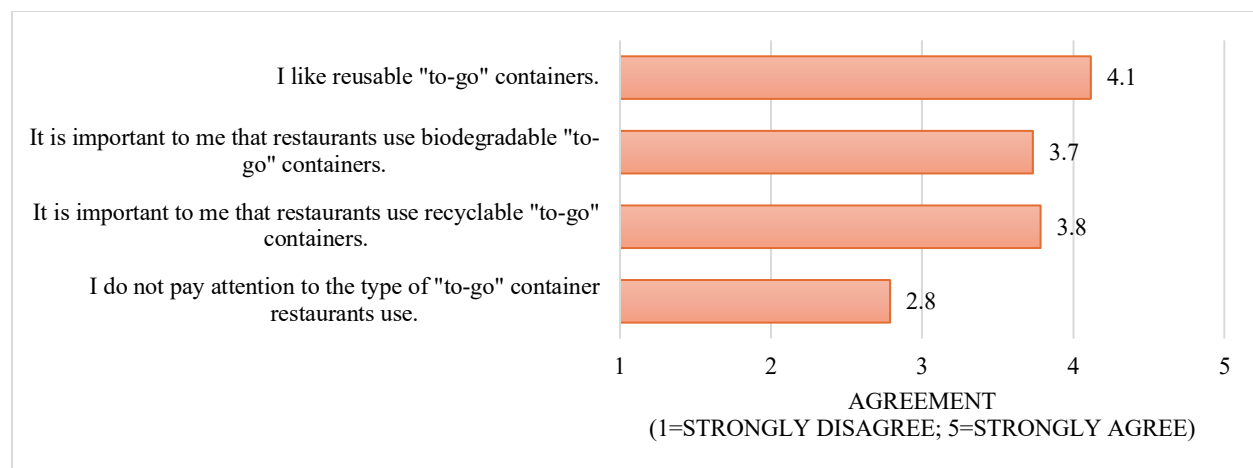


Figure 10. U.S. Participants' Agreement with To-go Container Statements from an Online Survey of U.S. Consumers Conducted in 2022 (n=1,304).

Restaurants may use different types of to-go containers (e.g., Styrofoam, molded fiber, plastic), and this may influence how customers perceive that restaurant. Participants indicated how the type of to-go container impacted their perceptions of the restaurant using 5-point scales (1=strong decrease; 5=strong increase) for food quality, environmental commitment, and healthiness of food perceptions (Figure 11). Across the restaurant perception statements, molded fiber to-go containers rated the highest at a 3.3 rating for food quality and healthiness and a 3.4 rating for environmental commitment. Styrofoam containers rated the lowest, and plastic containers were between the other two types of containers. Both Styrofoam and plastic to-go containers negatively impacted participants' perceptions of the restaurant being committed to the environment.

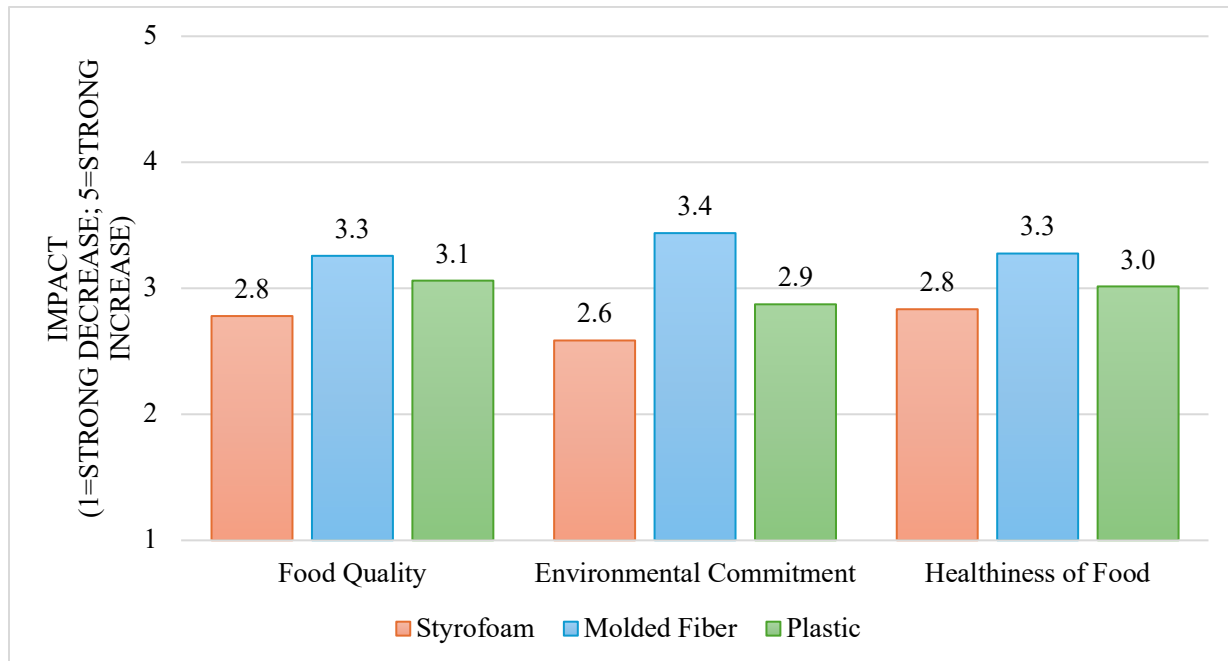


Figure 11. U.S. Participants' Perceptions of To-go Containers from an Online Survey of U.S. Consumers Conducted in 2022 (n=1,304).

Participants indicated that the type of container also influenced their likelihood of taking home leftovers from a restaurant, meaning the type of container could be used by the food service industry to encourage customers to take leftover foods home and potentially reduce food waste (Figure 12). If the leftover container was molded fiber, they were more likely to take the food home (mean=4.5 out of 7). Similarly, a plastic container improved their likelihood of taking leftovers home (mean=4.2). Conversely, they were less likely to take home leftover food if the to-go container was made of Styrofoam (mean=3.9). These results imply that using molded fiber or plastic takeout containers may aid in decreasing foodwaste in the food service industry by encouraging customers to take extra food home.

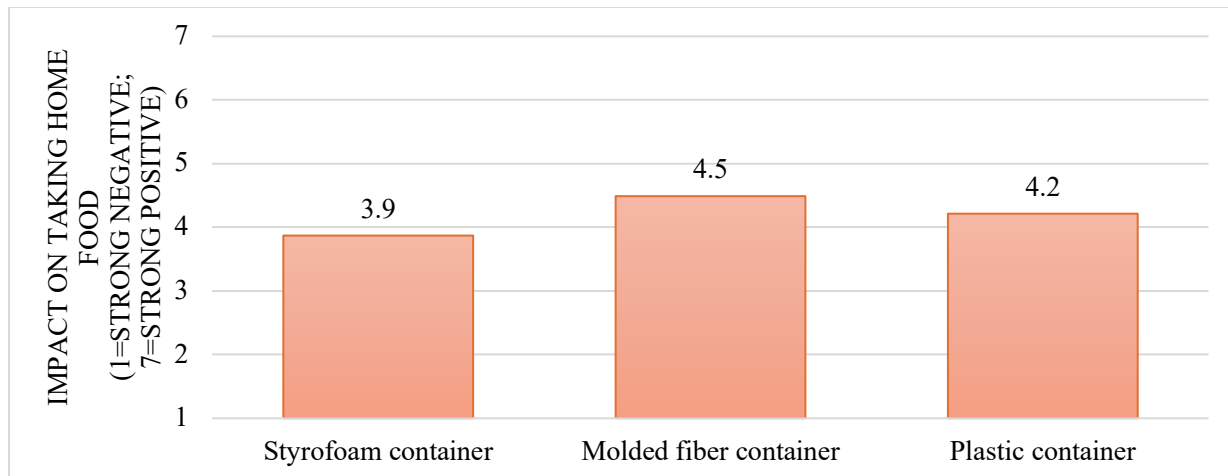


Figure 12. Impact of Type of To-go Container on U.S. Consumers' Likelihood of Taking Home Left-Over Food from a Restaurant from an Online Survey Conducted in 2022 (n=1,304).

Summary

Using an online survey of U.S. consumers, we found that participants perceived PFAS alternatives as viable means of gaining credence (e.g., environmental) benefits from their disposable dinnerware and to-go containers. Consumers primarily purchase disposable dinnerware made of paper for everyday use (vs. events/special occasions), indicating practical and sustainable alternatives may improve customer acceptance due to heightened exposure from frequent use. They expressed low awareness and knowledge of industry specific jargon (e.g., lignin, PFAS), indicating a need for more user-friendly language and educational information. These findings align with the existing literature (Lusk, 2021). Furthermore, to-go container material (plastic, molded fiber, Styrofoam) influenced participants' perceptions of food quality, health and environmental commitment with molded fiber improving these perceptions. To-go containers that were reusable also were desired. Together, the results highlight areas that the disposable dinnerware and to-go container industries could focus on in future product development and marketing strategies as they phase out PFAS treatments on their products. Specifically, using user-friendly language on labels or packaging of disposable dinnerware can be used to educate customers about PFAS alternatives by increasing exposure (i.e., awareness) at the point-of-sale. There is an opportunity to use newer technologies (i.e., QR codes) to allow interested customers to access relevant information about alternatives and their benefits relative to PFAS. Further, the food service industry should consider the materials used in their take-out containers and whether they align with their values because customers' perceptions of the food and restaurant are influenced by the container type.

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