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Effect of Salivary Flow Rate, Particle Size, and Concentration on Sensations and Liking for Fiber-Fortified Beverages

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ABSTRACT

Xerostomia (perceived oral dryness) is a common problem in older adults, often due to hyposalivation, which can cause difficulty in eating and swallowing, resulting in insufficient dietary fiber intake. Recent work shows salivary flow rate, particle size, and concentration are major factors for particle perception in beverages. Given that disliking drives non-consumption, here we explore how particle size, concentration, and salivary flow rate may affect liking in a fiber-fortified model beverage. Beverages made with 2 particle sizes of wheat brans ($D_{90} = 976\,\mu m$ and $209\,\mu m$) in 3 concentrations (5%, 7.5%, 10% w/v) were compared to a control beverage (no fiber added) and 2 commercial fiber-fortified beverages (Detoxifiber, ARG Cellulose) at 7.5% w/v concentration. Under controlled laboratory conditions, 90 adults (30% men, 58% women; age range = 18–79 years) rated beverage liking and the intensity of particles remaining in the mouth/throat. Individuals were divided into low and high salivary flow groups; rinsing time and rinse water weight were also recorded following consumption. As expected, higher particle concentration reduced liking, but particle size showed no main effect on liking. Surprisingly, no significant difference was found between salivary flow groups on liking and remaining particles perception. However, we saw a significant negative correlation ($r = -0.93$) between liking and particles remaining ratings. Collectively, higher concentration reduced liking, but finer particles have less impact on liking at moderate concentrations. Product developers should avoid formulating highly concentrated fiber supplement beverages and consider using finer particles to prevent beverage unacceptability.

1 | Introduction

Texture perception results during a dynamic process of food oral processing, including ingestion, manipulation, swallowing, and cleaning (Saint-Eve et al. 2015). During this process, salivary secretions are stimulated for lubricating and binding food to facilitate ingestion (Liu et al. 2017). The quantity and quality of saliva may alter the perception of food texture in the mouth (Laguna et al. 2021). Thus, saliva plays an important role in food texture perception. Xerostomia (i.e., perceived oral dryness) arising from hyposalivation (i.e., objectively measured salivary dysfunction) is common in older adults and many cancer patients. This can be a major influence on nutritional intake, as it creates a hurdle in food consumption (Galaniha and Nolden 2022). Without sufficient saliva, there is less dilution/decomposition of food to make the food suitable in size, extensibility, and viscosity for swallowing (Chen and Lolivret 2011). Recently, we found older individuals tend to use the texture term "dry" to describe common foods more often than younger adults, and "dry" is also related to lower liking (Ma et al. 2023).

Most studies investigating the importance of saliva in texture perception have focused on solid and semisolid foods, as the incorporation of saliva plays a vital role in forming a food bolus safe for swallowing (Drago et al. 2011; Engelen et al. 2003a; Engelen et al. 2007; Motoi et al. 2013). Fewer studies have explored the role of saliva on the texture perception of liquid foods, including astringent beverages (tea and wine) and emulsions (Laguna et al. 2021). Saliva can induce emulsion flocculation due to electrostatic attraction and depletion flocculation, which can result in sensations such as roughness, dryness, and astringency (Silletti et al. 2007; Vingerhoeds et al. 2009). While no chewing is required and less time is spent consuming liquid foods, saliva still plays a role in mixing and diluting beverages—the focus of the current work. Previously, we explored how different starch particle size, concentration, and dispersion viscosity can change the texture perception in a beverage model. We found that salivary flow influenced the chalky perception of granular starch-containing beverages—participants with lower salivary flow rates reported greater chalkiness than those with higher salivary flow rates. These differences were consistent for both larger starch granule size and greater starch concentration in the beverage. However, it is still not known how differences in oral perception due to salivary flow rate may affect the liking of liquid foods that contain small particles.

Many consumers chose to use fortified beverages to supplement meals with additional micro- and macro-nutrients. Still, most Americans do not consume enough fiber to meet recommended intake, so fiber-fortified beverages such as fiber-infused juices and functional waters have been introduced to the market. Particularly for individuals with low salivary flow rates, the added challenge of forming a food bolus high in insoluble fiber may potentially hinder their ability to consume fibrous foods (Mesas et al. 2010). However, most fiber added in commercial beverages is mostly soluble fiber; insoluble fibers are not used because of their negative impact on food texture, including chalkiness, dryness, and particle perception (Chakraborty et al. 2019). The particle distribution of insoluble fiber falls in the range of 50–300 μm (D_{90}) from corn and rice bran but may differ depending on the source (Jiang et al. 2022; Zhao et al. 2018). It may be important for consumers to increase their intake of insoluble fiber as it can provide regularity and laxative benefits, which soluble fibers do not provide. While coarser wheat brans, rich in insoluble fiber, had a higher laxative effect in increasing stool weight more than the finer ones, a significant increase in fecal bulk was still found with finer wheat brans in the diet in previous studies with less than 20% difference (Brodribb and Groves 1978; Heller et al. 1980; Jenkins et al. 1999). Moreover, finer insoluble fibers from wheat and rice bran and qingke (hull-less barley) have been found to show higher phenolic bioaccessibility and antioxidant properties than coarser ones (Li et al. 2022; Zhao et al. 2018; Zhu et al. 2015).

Here, we compared the effect of food particle size, concentration, and salivary flow rate on the liking in a fiber-fortified model juice beverage. Specifically, we hypothesized (a) liking would increase with decreasing particle size and concentration and (b) any effects of particle size and concentration on liking would be greater in participants with low salivary flow, relative to those with high salivary flow rate. By understanding how differences in salivary flow may affect beverage liking, we hope to inform the development of maximally acceptable fortified beverages in older adults or others experiencing oral dryness to enhance nutrient intake in these individuals.

2 | Materials and Methods

2.1 | Participant Recruitment and Consent

Participants ($n = 90$) were recruited from the campus and community surrounding the Pennsylvania State University in State College, PA. Sensory tests were carried out in semi-isolated testing booths in the Sensory Evaluation Center in the Erickson Food Science Building on the main Penn State campus. All participants provided informed consent and were paid a cash incentive for their time. Exclusion criteria included being below 18 years of age; currently taking medications known to alter taste or smell; having difficulty tasting and smelling; not being in good general health; having a history of choking or difficulty swallowing; having any tongue, cheek, or lip piercings; having dental work in the last month; having smoked tobacco or used nicotine-containing products in the last 30 days; not being fluent in English; having a history of any condition involving chronic pain, in their mouth or elsewhere; currently using any prescription pain medication; having celiac disease or other conditions that prevent the consumption of wheat and not being able to consume foods manufactured in a facility that processes egg, milk, soy, wheat, and tree nuts; having irritable bowel syndrome; and preferring no pulp or lots of pulp in orange juice. Informed consent was documented electronically on the first screen of the online survey via a yes/no question. All procedures, including screening, recruitment, consent, and compensation, were approved by the Institutional Review Board (IRB) at The Pennsylvania State University as an expedited protocol (STUDY00022256).

2.2 | Sample Preparation

We prepared six wheat bran-fortified orange juice samples and compared these to a no-fiber control and two commercial insoluble fiber-added orange juices to assess the effect of particle size, concentration, and salivary flow rate on beverage liking and remaining particle perception in the mouth or throat; see Table 1. Wheat bran (Shiloh Farms; New Holland, PA) was milled using a hammer mill into coarse and fine sizes using 80 and 500 μm sieves, resulting in a coarse size mean D90 of 976 μm and a fine size mean D90 of 209 μm. Three particle concentrations (5%, 7.5%, and 10%, w/v) were chosen for comparing the coarse and fine wheat brans. Two commercial fiber supplements were also used to make beverages at an 5% w/v concentration, including cellulose powder (Allergy Research Group; Salt Lake City, UT) and DetoxiFiber (Garden of Life; Palm Beach Gardens, FL). All beverages were made with the addition of xanthan gum (Bob's Red Mill; Milwaukie, OR) (0.1% w/v) to suspend the particles in the beverage. The beverages were prepared in no pulp orange juice (Tropicana; Bradenton, FL) by blending in xanthan gum in a Vitamix blender Model Pro-750 (Cleveland, OH), then blending in fiber/wheat bran using a KitchenAid Model KHM512TB hand mixer (Benton Harbor, MI). Orange juice was chosen as the beverage medium as it naturally contains particles (pulp)

TABLE 1 | Sample content including particle size, concentration, xanthan gum, aspartame, and vanillin for the 8 starch beverage samples.

Type of fiber	Particle concentration (w/v%)	Xanthan gum (w/v%)
No fiber (control)	0	0.1
Coarse wheat bran	5	0.1
Coarse wheat bran	7.5	0.1
Coarse wheat bran	10	0.1
Fine wheat bran	5	0.1
Fine wheat bran	7.5	0.1
Fine wheat bran	10	0.1
ARG cellulose	7.5	0.1
Detoxifiber	7.5	0.1

and should therefore not alter the beverage liking due to surprise from unexpected particles.

2.3 | Dietary Fiber Analysis

The total dietary fiber, soluble fiber, and insoluble fiber content of coarse and fine wheat brans were analyzed using the AOAC 991.43 method.

2.4 | Design and Rationale

Ratings were collected in Compusense20 software (Guelph, ONT) to understand the effect of particle size and concentration on liking and particles remaining in the mouth.

Prior to tasting any samples, participants were asked to provide a stimulated saliva sample by chewing on a 5×5cm square of parafilm (Parafilm "M", American National CAL, Chicago, USA) for 5min while spitting in a pre-weighed tube every 30s to measure their salivary flow rate (Bots et al. 2004). Prior to the first test sample, a warm-up sample made of coarse wheat bran at 2.5% w/v concentration and 0.1% w/v xanthan gum was given to participants to minimize any first-sample effect. All samples were conditioned at room temperature for about an hour before serving. They were kept at room temperature for no more than 2h for safe consumption. The samples were presented monadically in a randomized and counterbalanced order. Participants were asked to consume each sample beverage in small aliquots (10mL), labeled with three-digit codes, after holding it in the mouth for 5s before swallowing the entire sample. They then rated their liking of the sample and the perception of particles that remained in the mouth/throat after swallowing on a 0–100 Visual Analog Scale (VAS) from "Dislike Extremely" to "Like Extremely" and from "None" to "A lot," respectively. To reduce fatigue, only 5 samples were given in the first session and 4 samples in the second session, which were separated by at least 2days. Between each sample, they were asked to rinse their mouth with water until no particles were left in the mouth/throat, which was timed. The weight of rinse water consumed was also recorded for each sample. Demographics (self-reported age, gender, race, and ethnicity) were collected at the end of the second session, as well as their preference for pulp in orange juice and questions on xerostomia (Thomson et al. 2011).

2.5 | Data Analysis

Data were analyzed using RStudio (version 2024.04.1). To determine how the different fiber-fortified samples and salivary flow rate impact beverage liking and remaining particles perception, Analysis of variance (ANOVA) was performed on a linear mixed-effect model; fixed factors include sample and salivary flow group. Participants were split into two groups (high or low salivary flow) according to the median salivary flow rate using the measurements of the weights of their saliva on both test days and the first test day for those who only attended the first session. Participants were a random factor in the model to take individual differences in the use of scale rating into account. Outliers more than 2.5 standard deviations from the mean residuals were removed to increase the normality of residuals (2 data points with large positive residuals were removed).

To determine how the particle size, concentration, and salivary flow impact beverage liking and remaining particles perception among the wheat bran-fortified beverages, ANOVA was performed on a linear mixed-effect model with fixed factors including particle size, concentration, and salivary flow group. Participants were again a random factor in the model to take individual differences in the use of scale rating into account. Outliers more than 2.5 standard deviations from the mean residuals were removed to increase the normality of residuals (4 data points with large positive residuals were removed; analyses were run with and without outliers and no meaningful changes in the results were observed). ANOVA assumptions including independence, normality, and heteroscedasticity were checked prior to analysis. Tukey's HSD was performed to identify significant differences between the sample beverages using the "agricolae" package (De Mendiburu 2021). A correlation matrix was made comparing beverage liking and remaining particles perception ratings to mouth rinsing time and weight by correlating the mean of the perceptions grouped by sample beverage. Boxplots of beverage liking and remaining particles perception of the different sample beverages were generated using the "ggplot2" package (Wickham 2016). A statistically significant difference was defined as $p < 0.05$.

3 | Results

3.1 | Participants Characteristics

Participant demographics are summarized in Table 2. Of the 90 participants, 80 participants completed both sessions of the test; the 10 participants who only completed the first session were still included in the data analysis as sample sets were counterbalanced, but specific demographic data (i.e., gender and age) were missing for these 10 participants, as our demographic questionnaire was included at the end of the second session. As expected in a nominally healthy sample, we saw large individual differences in the

TABLE 2 | Participant characteristics include gender, age, and salivary flow rate groups.

Characteristics	Mean ± SD
Gender (27 men, 52 women, 11 not known)	
Age (18–79 years old, $n = 80$, 10 not known)	39.3 ± 16.8
Saliva group	
High salivary flow (HSA, $n = 45$, 1.28–3.86 g per min)	1.97 ± 0.6
Gender (18 men, 21 women, 6 not known)	
Age (18–79 years old, $n = 40$, 5 not known)	38.14 ± 16.25
Low salivary flow (LSA, $n = 45$, 0.15–1.28 g per min)	0.85 ± 0.3
Gender (9 men, 31 women, 5 not known)	
Age (18–79 years old, $n = 40$, 5 not known)	40.41 ± 17.44

salivary flow rate of our participants, varying from 0.15 g/min to 3.86 g/min. We tested the effect of salivary flow rate on beverage liking and remaining particles perception by grouping participants into a high-flow group (mean = 1.97 ± 0.59 g/min) and a low-flow group (mean = 0.85 ± 0.31 g/min), which had significantly different mean salivary flow rates [$F(1, 88) = 130.45$; $p < 0.05$]. The distribution of flow rates for our participants showed that the low-flow group had a distribution skewed to the left, while the high-flow group was more variable, with the distribution skewed to the right.

3.2 | Effect of Particle Size, Concentration, and Salivary Flow Rate on Liking

Adding different fibers to orange juice had a significant effect on beverage liking [$F(8, 662) = 41.0$; $p = < 0.001$]. The control sample had the highest liking score among all beverages, as shown in Figure 1, indicating that the addition of fiber decreases the liking of the orange juice. Among the experimental bran-fortified beverages, particle concentration had a significant main effect on beverage liking [$F(2, 409) = 35.13$; $p = < 0.001$]; however, contrary to expectations, particle size did not show evidence of a main effect on beverage liking [$F(1, 414) = 1.07$; $p = 0.302$]. Wheat bran-fortified beverages with a higher particle concentration level were liked significantly less than those at a lower concentration level ($p < 0.05$). A significant interaction between particle size and concentration among the wheat bran beverages was found [$F(2, 409) = 3.58$; $p = 0.0287$]. Differences in liking with concentration were larger for the coarse wheat bran samples compared to the fine wheat bran samples. Notably, both commercial beverages resulted in lower liking compared to both wheat bran beverages made with the same concentration. Contrary to expectations, no evidence of an effect was observed for the salivary flow group on liking [$F(1, 99.7) = 2.1$; $p = 0.1501$], with no significant interaction between sample beverages and salivary flow rate groups [$F(8, 662) = 1.34$; $p = 0.2186$]. While the low-flow group had lower liking scores than the high-flow group for all beverages except for the Detoxifiber-fortified beverage, none of these differences were statistically different. Similarly, the salivary flow group did not show evidence of main effects for particle size [$F(1, 414) = 0.09$; $p = 0.7641$] or concentration [$F(2, 409) = 0.11$; $p = 0.8922$] for beverage liking. Nor were any of the interactions significant.

3.3 | Effect of Particle Size, Concentration, and Salivary Flow Rate on Remaining Particle Perception

As expected, adding different fibers to orange juice had a significant effect on ratings of particles remaining [$F(8, 638) = 89.5$; $p = < 0.001$]. As shown in Figure 2, the control had the lowest ratings of particles remaining among all sample beverages. Within the beverages with added wheat bran, significant effects of particle size [$F(1, 417) = 63.2$; $p = < 0.001$] and concentration [$F(2, 413) = 30.2$; $p = < 0.001$] were seen for particles remaining. Specifically, the coarse wheat bran had higher ratings of remaining particles relative to fine wheat bran at medium and high concentration levels. Opposite to the impact on beverage liking, the increase in concentration levels enhanced the remaining particle perception intensity. There was a significant interaction between particle size and concentration [$F(2, 413) = 12.5$; $p = < 0.001$], showing the remaining particle perception of coarse wheat bran was impacted by the concentration level more than that of fine wheat bran. Unexpectedly, both commercial fiber supplements resulted in higher ratings of particles remaining than that of fine wheat bran, which was unexpected as they have similar particle sizes. No significant salivary flow rate effect was found on the perception of remaining particles [$F(1, 102) = 0.04$; $p = 0.8339$], with no significant interaction between particle size, concentration, and salivary flow rate groups [$F(2, 413) = 0.08$; $p = 0.9234$]. As seen in the bottom of Figure 2, there was no significant difference between the low and high salivary flow groups on the perception of remaining particles ($p > 0.05$). The large range of remaining particle perception intensity of the low salivary flow group may have also contributed to the lack of a difference between the salivary flow groups.

3.4 | Correlation of Liking, Perception of Remaining Particles, and the Removal of Particles

Next, we determined how beverage liking, the perception of remaining particles, and the removal of particles were associated. By correlating group means of the rating of each of the beverages, we find that greater perception of remaining particles decreased beverage liking, as expected, $r(7) = -0.93$ ($p < 0.01$). This is shown in Figure 3. The same trend was found between liking and rinsing time [$r(7) = -0.95$ ($p < 0.01$)] and rinsing weight [$r(7) = -0.82$ ($p < 0.01$)]. As might be expected, ratings of remaining particles had high correlations with both rinsing time [$r(7) = 0.99$ ($p < 0.01$)] and rinsing weight [$r(7) = 0.97$ ($p < 0.01$)]. This indicates strong internal consistency in our data, as perception of remaining particles was strongly related to behaviors required to remove particles via rinsing with water. Collectively, these data suggested that beverage liking was

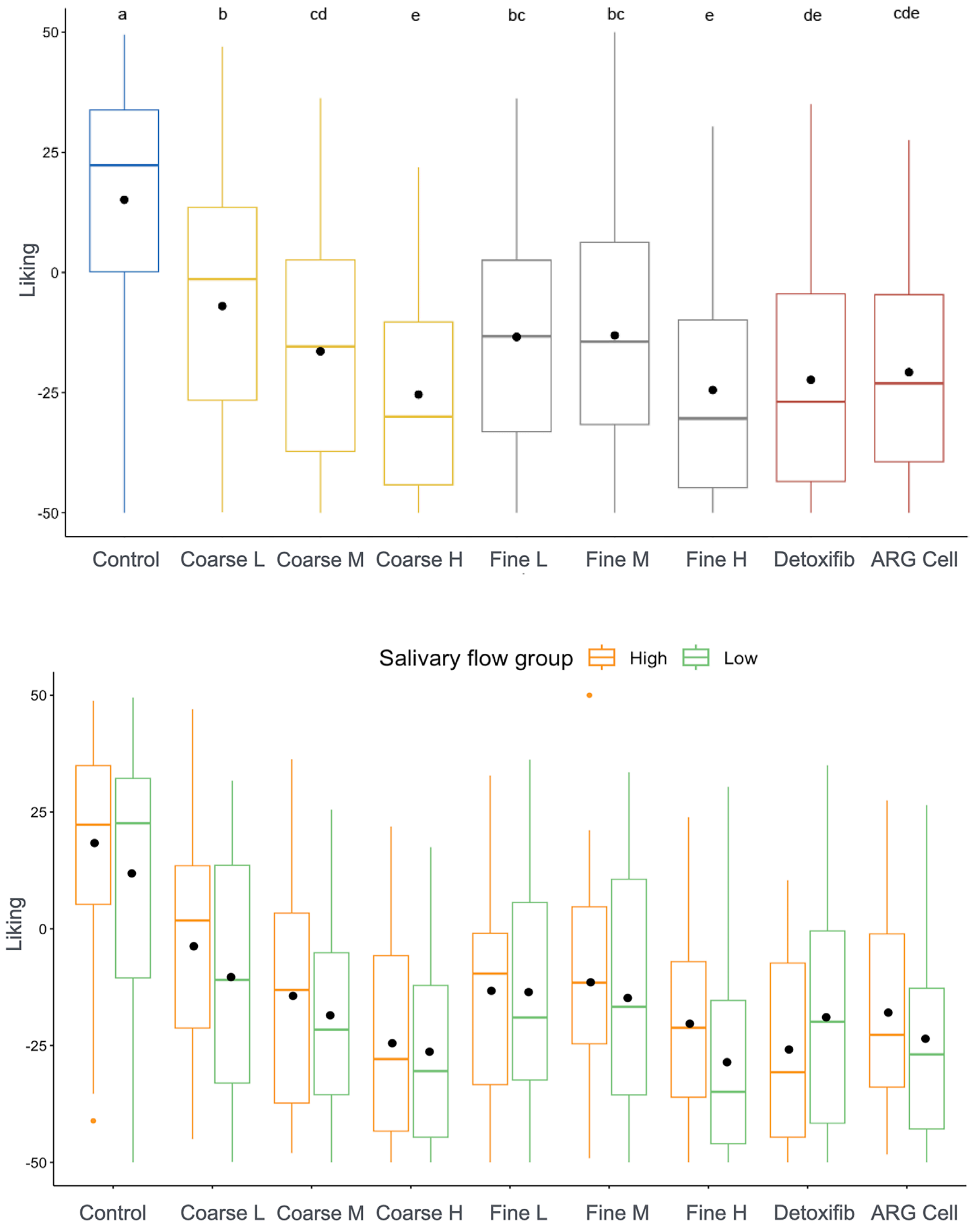

FIGURE 1 | (Top) Boxplot distribution of beverage liking scores of the 8 sample beverages and the control with Tukey groupings and mean labeled. (Bottom) Boxplot distribution of beverage liking scores of the 8 sample beverages and the control comparing the high and low salivary flow groups. C refers to coarse wheat bran, and F refers to fine wheat bran. L, M, and H refer to the low, medium, and high concentration levels, respectively.

negatively correlated with the perception of remaining particles and the rinsing parameters.

4 | Discussion

Here, we explored the effect of adding particles in different sizes and concentrations using a fiber-fortified beverage model on liking and perception of residual particles in the mouth, as a function of high and low salivary flow. In agreement with our hypothesis, the addition of particles to the beverage lowers liking, which is comparable to past studies showing the fortification of high-fiber ingredients in semisolid and liquid foods affected liking (Hashim et al. 2009; Hoppert et al. 2013; Raju and Pal 2014; Tomic et al. 2017). Recently, we identified particle size and concentration as major factors in the perception of chalkiness, which is an unfavorable sensory characteristic, so we expected that these two factors would affect beverage liking

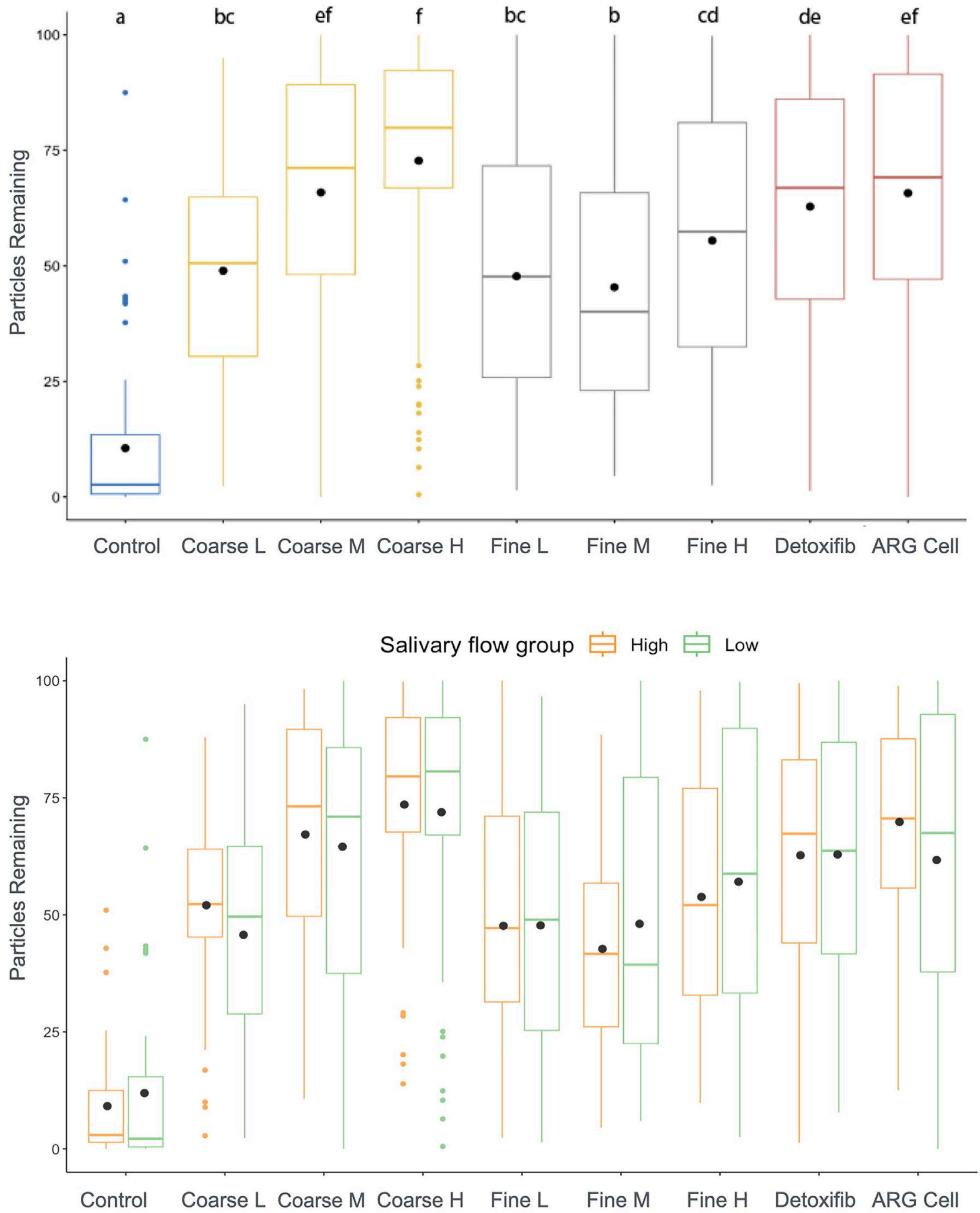

FIGURE 2 | (Top) Boxplot distribution of remaining particles intensity scores of the 8 sample beverages and the control with Tukey groupings and mean labeled. (Bottom) Boxplot distribution of remaining particles intensity scores of the 8 sample beverages and the control comparing the high and low salivary flow groups. C refers to coarse wheat bran and F refers to fine wheat bran. L, M, and H refer to the low, medium, and high concentration levels, respectively.

here. However, only particle concentration was observed to have a significant effect on beverage liking. This was surprising as we expected particle size to have an effect due to large differences in particle size between the wheat brans used (Coarse $D_{90} = 976\,\mu m$, Fine $D_{90} = 209\,\mu m$). However, the coarse wheat bran-fortified beverage at the medium concentration level had lower beverage liking than at the low concentration level, while the beverage liking of the fine wheat bran-fortified beverage at the two concentration levels was not significantly different. This may imply a higher concentration level of fine particles can be added to beverages without adversely affecting liking to some extent.

The effect of remaining particles perception on liking was also investigated. As expected, the perception of remaining particles in the mouth/throat decreases beverage liking. We found that rinsing time and weight served as good behavioral measurements that were highly consistent with the perception of remaining

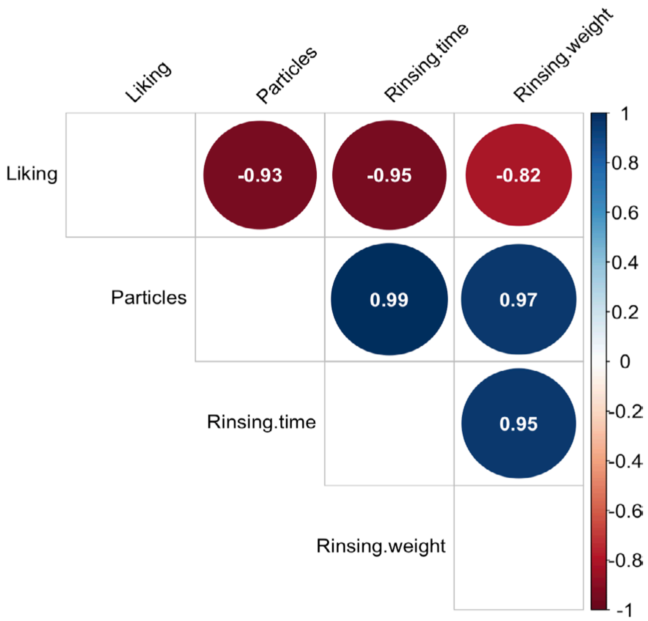

FIGURE 3 | Correlation matrix (r, df = 7) of beverage liking, perception of remaining particles, and rinsing parameters using the means of ratings of each sample.

particles. Although participants were initially screened to only include those who prefer some pulp in orange juice, to avoid bias from those who prefer no pulp, some changed their preference to no pulp when asked again in the questionnaire at the end of the taste test. While this might have potentially decreased the liking scores of the beverages, we do not think this meaningfully impacts our findings because this is reflective of all the fiber-fortified beverages. Originally, we expected that the low salivary flow group would have a higher perception of remaining particles and thus lower liking ratings. However, no difference in the perception of remaining particles was observed between the salivary flow groups. This finding was unexpected given that the perception of chalkiness was recently shown to be impacted by salivary flow differences by our team. A possible reason for this discrepancy might be that orange juice contains citric acid, which is known to be a potent stimulus of saliva production. This might have enhanced a greater volume of stimulated saliva and thus reduced the differential effect of salivary flow rate on the perception of remaining particles (Engelen et al. 2007). Another reason might be that the effect of salivary flow rate is impacted by the food particle size. The wheat bran particle size used in this study is quite large, with $D_{90} > 200\,\mu m$, while our previous study on chalky perception that found group differences used a particle size with $D_{90} < 70\,\mu m$. We can speculate that salivary flow may alter particle perception, but only when the mean particle diameter is below some unknown size. Although numerous prior studies have found that saliva has a great impact on food texture perception (Engelen et al. 2007; Laguna et al. 2021), few have found associations between salivary flow rate and food texture perception (Chaffee et al. 2023; Engelen et al. 2003a; Engelen et al. 2003b; Olarte Mantilla et al. 2022). More work on the impact of salivary flow rate and food texture perception is still needed on smaller food particle sizes.

Particle size and concentration both significantly impacted the perception of particles remaining, showing a slight difference in their impact on beverage liking. This might imply that other factors besides remaining particles perception impacted beverage liking. This result agreed with previous literature that studied the effect of particle size and concentration on particle perception (Imai et al. 1995; Tyle 1993). At higher concentrations, the coarse wheat bran-fortified beverages resulted in higher remaining particles perception intensity than the fine wheat bran. This might be because the fine wheat bran is smaller, allowing quicker removal by saliva. The commercial fiber beverages were perceived to have high intensity of remaining particles, similar to coarse wheat bran-fortified beverages, even though they have a much smaller particle size compared to coarse wheat bran. This may have resulted from the difference in soluble fiber content between the commercial fibers and the wheat brans. Although both fibers contain a high amount of insoluble fiber (> 40%), the amount of soluble fiber in our wheat bran samples (3.5%–4.6%) was higher than that of commercial products (0%–1% reported on the package label). Previous literature studying the texture perception of oat fiber-added beverages found that oat soluble fiber in the beverage was associated with smoothness and sliminess (Chakraborty et al. 2019). These attributes might be attributed to beta-glucan, one of the main soluble fibers in wheat bran, as it could function as a thickener (Kaur and Riar 2020; Lyly et al. 2004). Therefore, the higher soluble fiber content in wheat bran added beverages may have increased the viscosity of the beverage and potentially masked the perception of particles.

Although no salivary flow rate effect was found on the remaining particle perception, the low salivary flow group gave lower average liking scores for almost all beverages, but this difference was not significant. We cannot rule out that a study with more participants (and thus power) might find a difference. Kim and Vickers (2020) had shown that salivary flow rate can affect food texture liking, especially increasing liking of juicy foods. However, the salivary flow rate did not impact the frequency of consumption of juicy foods (Chaffee et al. 2023). Past work has also shown consumers overestimate the impact of liking on consumption, as there are other factors determining consumption behavior (Yoon and Meyvis 2024). Therefore, in the future, the relationship between consumption behavior of these beverages and liking should be explored. Here we were not able to find an observable significant difference in liking and the perception of remaining particles between salivary flow groups. However, it has been reported that people with severe dry mouth usually avoid whole grain products (Quandt et al. 2011). Accordingly, the impact of salivary flow rate on behavioral consumption changes should also be investigated.

Some limitations should be noted. The study results included all 90 participants who fully or partially completed the study (10 participants did not return for the second day). However, we balanced the serving order of the beverage samples and used a mixed model that allows for missing data, so these partial data can still be used. Previous studies suggest age can affect the salivary flow rate, with older adults experiencing a reduced salivary flow rate. Here, 92% of the participants were 65 years old or younger. We did not intend to test for age effects here a priori, but when age was added to the linear mixed model (at the request of a reviewer), no significant main effect was observed for beverage liking or particle perception intensity. This suggests any potential age effect on the data should be limited, so it was not added into our final model for simplicity. Separately, we note that mechanical stimulation was used to collect saliva from participants (as is widely done in the field), but this might not fully reflect evoked salivary flow or composition during sample consumption, as sour taste is also a potent stimulus for saliva production.

5 | Conclusion

This study explored the effect of particle size and concentration on the liking of fiber-fortified beverages between high and low salivary flow groups. Particle concentration significantly affected the liking of beverages, while no observable significant difference in liking was found for the wheat bran particle sizes. However, the particle size impacted the effect of particle concentration on beverage liking. The increase in fine wheat bran concentration from a low to medium level did not significantly change the beverage liking, while coarse bran resulted in significantly lower beverage liking. No significant difference between liking and the perception of remaining particles of the fiber-fortified beverages was found between salivary flow groups. In the future, other factors such as diet and preference of food should be considered to understand the drivers of liking of these beverages. Moreover, the willingness to consume these beverages should also be explored to understand if beverage liking is translational to a change in consumption behavior.

Author Contributions

J.E.H., K.K.M., and N.M.E. conceived the initial idea. K.K.M. was responsible for data collection, analysis, and visualization. K.K.M. wrote the first draft of the manuscript with assistance from J.E.H. this draft was subsequently edited and revised by N.M.E. All authors have approved the final version of this article.

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Ethics Statement

Ethical Review: This study was approved by the IRB of The Pennsylvania State University.

Consent

Informed consent was obtained from all study participants.

Conflicts of Interest

Dr. Hayes has received speaker honoraria, consulting fees, and/or travel expenses from numerous organizations, including federal agencies, universities, nonprofit organizations, trade groups, and for-profit corporations, to present data on taste biology and flavor perception, sensory testing methods, and consumer behavior. Dr. Hayes also holds equity in Redolynt LLC, which he co-founded in 2021; this financial interest has been reviewed and actively managed by the appropriate Conflict of Interest Committee at Penn State. The Sensory Evaluation Center at Penn State routinely conducts product tests for industrial clients to facilitate experiential learning for undergraduate and graduate students. Dr. Hayes is the Director of this facility. None of these entities have had any role in the work presented here, including study design or interpretation, or the decision to publish these data. The remaining authors have indicated they have no financial relationships or other potential conflicts of interest to disclose. All findings and conclusions in this publication belong solely to the author(s) and should not be construed to represent any official U.S. Government determination, position, or policy.

Data Availability Statement

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

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