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Effects of material and softness of the rim of cups on flavor perception

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ABSTRACT

Recently, some researchers have shown that flavor perception varies based on the material and texture of the entire drinking container. However, no research has explicitly focused on how changes in the material and softness of rim of cups affect flavor perception. For example, the lower lip contacts tableware and cutlery during mastication, suggesting that tactile sensations on it might contribute to flavor perception; however, this area remains unexplored. Our study investigates how the material and the firmness of a rim of a cup affect flavor perception based on prior research that indicated that flavor perception can be affected by the weight, thickness, material, and texture of drinking containers. Rims of cups with identical thicknesses but differing materials and softness levels were designed. These rims of cups were attached to 3D-printed cups whose holders' textures, weights, and thicknesses were standardized. Our results indicated that both flavor perception and the sensation of beverage's temperature are affected by the material and softness of rim of cups. Additionally, the impact of these variables on flavor perception varied with different types of beverages. Based on these findings, it is concluded that using a cold and hard rim of cups is optimal for consuming beverages.

1. Introduction

Meals are generally expected to be delightful experiences that bring great joy and happiness, and savoring them contributes to an enjoyable life (Macht et al., 2005; U.S. Department of Agriculture Staff and United States and Department of Agriculture and United States and Department of Health & Human Services, 2000). On the other hand, the dietary habits of millions of people worldwide must be improved to prevent lifestyle-related diseases and obesity, especially controlling excessive salt intake to prevent hypertension (Marcello et al., 2018). Therefore, managing one's diet is indispensable for maintaining a healthy lifestyle. However, this necessity often involves moderating salt/sugar intake and refraining from favorite foods and beverages. Research is developing artificial taste presentations (the five basic tastes) to support healthier lifestyles (Aoyama et al., 2017; Ranasinghe et al., 2019).

Some methods combine chemical substances to artificially reproduce taste (Boudreau, 1980; Maynes-aminzade, 2005; Miyashita, 2021), although the difficulties of handling these chemicals render them impractical for everyday use. In recent years, research has focused on various taste enhancement techniques that are not contingent on chemical substances. For instance, studies have explored using electrical stimulation on the tongue to present the five basic tastes as a form of taste perception (Aoyama et al., 2017; Ranasinghe et al., 2019). Although taste presentation by electrical stimulation on the tongue is possible, issues remain with altering the non-taste aspects of flavor perception, such as in-mouth aroma, aftertaste, intensity of taste, throat feeling, deliciousness, and overall comfort.

Cross-modal technology, which enhances sensory perception by combining such multiple senses as visual and auditory stimuli, is gaining attention in various research fields. Researchers have proposed several methods to modify flavor perception by employing sensory interactions, including visual, auditory, olfactory, and gustatory stimuli (e.g., Nakano et al., 2019; Narumi et al., 2011; Ranasinghe et al., 2017; Weidner et al., 2023; Nishizawa et al., 2016; Narumi et al., 2010; Wang et al., 2019; Wang et al., 2022; Zampini & Spence, 2005).

Others have investigated changes in flavor perception induced by tactile stimuli inside and outside the mouth and on the hands. Researchers have even demonstrated that the weights of plates and drinking containers affect flavor perception (Piqueras-Fiszman et al., 2011; Maggioni et al., 2015). Other studies described how the weight

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and thickness of drinking containers and the rim of the cup can alter the sweetness and bitterness of green tea (Ichimura et al., 2023). Bai et al. showed that a wine glass's volume and shape might influence the aroma of its contents (Bai et al., 2023). Furthermore, various factors of drinking containers reportedly affect flavor perception: the type (Cavazzana et al., 2017), material (Tu et al., 2015), shape (Corona et al., 2022; Ribeiro et al., 2021), texture (Carvalho et al., 2020; Piqueras-Fiszman & Spence, 2012b), color and weight (Mielby et al., 2018; Sakarya & Dortyol, 2021), shape and design (Yang et al., 2019), tactile feel (Pramudya et al., 2020; Wang & Spence, 2018; Lago et al., 2021; Risso et al., 2019), and softness (Krishna & Morrin, 2007). It has also been shown that the color of dish or beverage containers can alter flavor perception (Piqueras-Fiszman et al., 2012; Piqueras-Fiszman & Spence, 2012a; Carvalho & Spence, 2019).

In this way, studies have shown that flavor perception is influenced by tactile and visual information, such as the material, texture, and softness of the entire container. Unfortunately, no research has explicitly investigated how changes in the material and softness of cup rims affect flavor perception. For example, since the lower lip contacts plates and silverware during mastication, perhaps its tactile sensations significantly contribute to flavor perception; however, that area remains unexplored.

Our study investigates how the rim of a cup's material and softness affects flavor perception based on prior research, which argues that flavor perception can be influenced by the weight, thickness, material, and texture of drinking containers. Rims of cups with identical thicknesses are designed, differing in materials and softness levels. These rims of cups are attached to 3D-printed cups, where the holders are weighted to standardize texture, weight, and thickness. Using these fabricated containers, the effects of the rim material and softness on flavor perception are examined.

Additionally, since mastication does not influence the experience of drinking a beverage, it is easier to standardize such flavor perception parameters as throat sensations. Therefore, this study focuses on beverages. The following flavor perceptions are defined based on user experiences: in-mouth aroma, aftertaste, taste intensity, throat feel, deliciousness, comfort, sweetness, saltiness, sourness, bitterness, and umami (a common Japanese savory taste).

As previously mentioned, this study aims to clarify the impact of the material and softness of the rim of a cup on flavor perception during beverage consumption. To achieve this, we utilize cup rims made from various materials commonly used in beverage containers—plastic, wood, ceramic, metal, glass, and paper—as well as three types of gummy rims with differing softness levels to evaluate flavor perception when consuming orange juice, apple juice, and green tea.

2. Material and methods

2.1. Participants

The participants in our experiment consisted of 100 individuals (50 males, 50 females) whose average age was 20.4±1.7 years. The experiment was explained to the participants in advance, and their informed consent was obtained. They were informed that the experiment involved tasting and rating beverages and that they were allowed to withdraw at any time. During this explanation, and with reference to previous studies (Suzuki et al., 2014; Ichimura et al., 2023), it was confirmed that the participants had no particular aversions to the provided beverages or any pertinent allergies. Each person received 1100 yen (roughly 10 dollars) for their participation. This study was approved by the ethics review board of our university (approval number: H22-032).

2.2. Conditions of the rim of a cup

This study investigates how the rim of a cup material and softness affect flavor perception during beverage consumption. Rims of cups were made from plastic, wood, ceramic, metal, glass, and paper to represent the materials commonly used in drinking containers (Fig. 1). Due to the challenges associated with processing glass, pre-made glass cups were utilized. Previous research has shown that the thickness of drinking containers affects flavor perception; therefore, each rim of a cup was made to match the thickness of glass cups (2 mm), as determined by these studies. The rims of cups made from wood and ceramic were waterproofed using Japanese lacquer, which complies with food sanitation regulations.

Next, the size of the rim of a cup is considered. The average thickness of an adult's upper lip is generally reported to have a median of 13.87 mm and a standard deviation of 2.13 mm (Isiekwe et al., 2012). The mouth corner's width is more extended in males, with an average of 49.7 mm and a standard deviation of 3.6 mm (Kouchi & Mochimaru, 2008). Therefore, a cup rim measuring 20 mm × 55 mm was fabricated.

Therefore, a 3D printer was utilized to fabricate cup holders, and ballast was added to the bottom of the cups to standardize the weights and textures of the drinking containers. A prop was included at the bottom of the cups to equalize their height, as the amount of ballast varied depending on the cup rim. The weight was matched to that of the heaviest glass cup, which was 283 g (Fig. 1(c)).

The investigation focused on the changes in flavor perception caused by the softness of cup rims, utilizing three types of odorless and tasteless gummy materials with varying levels of softness. Gummies were selected for their ease of softness adjustment and were primarily composed of sugar, corn syrup, and gelatin, exhibiting the following softness values: gummy A (139 g/mm^2), gummy B (285 g/mm^2), and gummy C (365 g/mm^2). Fig. 2 shows the constructed gummy containers. To prevent the gummies from becoming soggy when making contact with the beverages, an acrylic plate was placed between the cup and the cup holder, and the gummies were affixed to the acrylic plate (Fig. 2(c)).

2.3. Design

In this experiment, the following three beverages were used at room temperature (24 °C): orange juice (a sour flavor) and apple juice (a sweet flavor) (both made by Ehime Beverage Inc.), and green tea (a bitter flavor) (Haruna Produce Inc.). The corresponding reference aroma compounds for each beverage are as follows. Aldehydes, alcohols, esters, and terpenoids are known to play important roles in the aroma of orange juice (Pan et al., 2023). Ethyl 2-methylbutanoate, butyl 2-methylbutanoate, (E)-2-hexenal, butyl propanoate, methyl 2-methylbutanoate, and methional are known to play important roles in the aroma of apple juice (Deshou et al., 2019). (Z)-1,5-Octadien-3-one (metallic, geranium-like), 4-mercapto-4-methyl-2-pentanone (meaty, blackcurrant-like), methional (potato-like), (E,Z)-2,6-nonadienal (cucumber-like), and 3-methylnonane-2,4- dione (green, fruity, hay-like) show high aroma dilution factors in green tea (Kumazawa & Masuda, 2002).

Participants evaluated on a 7-point Likert scale (1: not at all, 7: extremely) the three beverages based on flavor perception, which included in-mouth aroma, aftertaste, intensity of taste, throat feeling, deliciousness, comfort, sweetness, saltiness, sourness, bitterness, and umami. Additionally, they rated the beverage temperature on a 7-point Likert scale (1: very cold, 7: very warm). The following items were included to obtain objective evaluations of flavor perceptions: in-mouth aroma, aftertaste, intensity of taste, and throat feeling. In contrast, deliciousness and comfort were assessed to evaluate the participants' subjective preferences. These items comprised the five fundamental taste aspects for evaluation. In addition to these 11 flavor perception items, beverage temperature assessed changes in how a beverage's temperature is perceived based on the material and softness of the rim of a cup. Participants provided free-response feedback for each trial, detailing their overall impressions and identifying the perceived material of the rim of a cup. Although subjective evaluations depend on

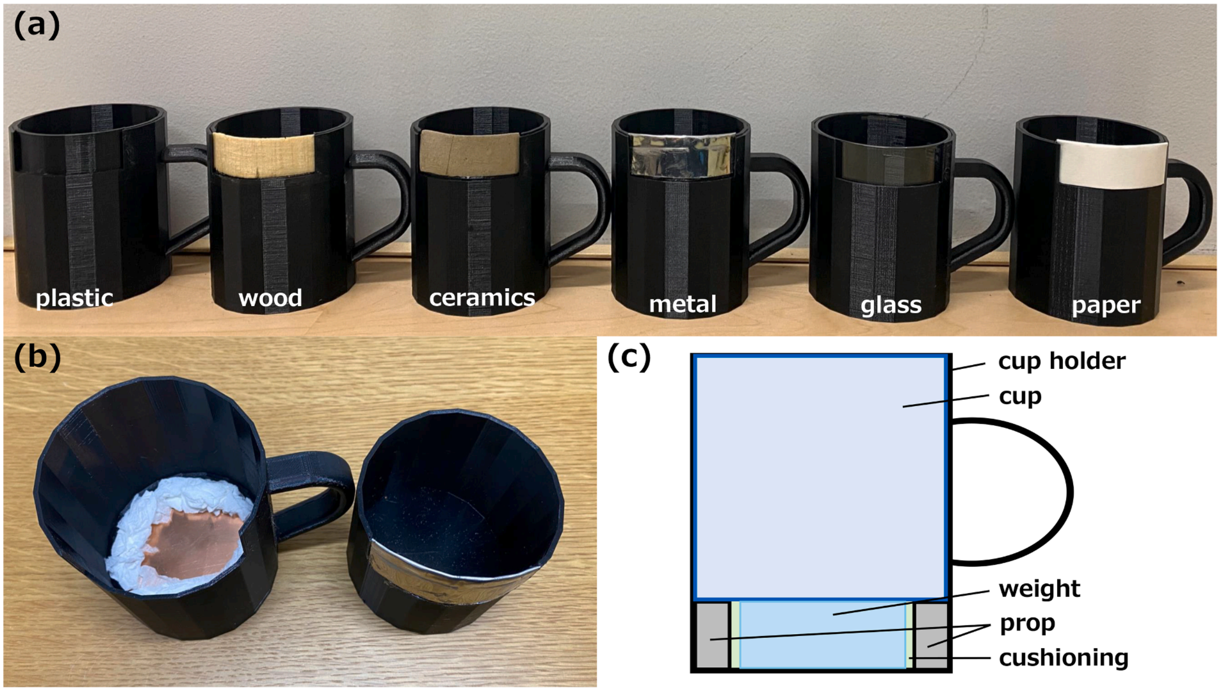

Fig. 1. Drinking containers of rim of cups made from various materials: (a) front view, (b) contents of drinking containers, and (c) composition diagram.

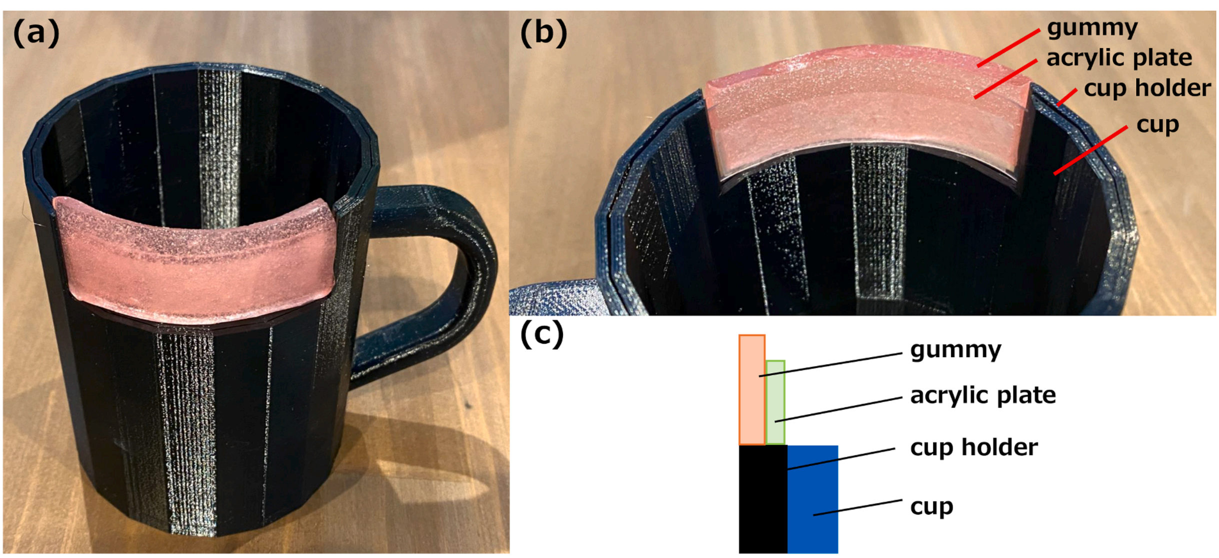

Fig. 2. Drinking container with gummy rim of cups: (a) front view, (b) back view, and(c) c cross-sectional diagram of the rim of a cup.

individual preferences, it is important to determine the general effect of the material and softness of the cup's rim on consumers' psychological responses.

2.4. Procedure

Before the start of the experiment, participants subjectively rated their current level of throat dryness using the Visual Analog Scale method, which ranged from not dry (0) to very dry (100), to minimize its potential impact on the flavor perception ratings. If the rating was 70 or higher, the participants received a small amount of water before the experiment.

Fig. 3 shows the experimental setup. In this experiment, participants were instructed to perceive and evaluate the material and softness of the cup rim using only the tactile sensations from their lower lips. Participants were blindfolded to eliminate visual cues. While blindfolded, the experimenter handed them containers filled with beverages, and they verbally evaluated the flavor perceptions. At the beginning of the experiment, participants wore an eye mask as the experimenter handed them a container filled with water, allowing them to practice drinking.

The nine rim conditions, featuring varying materials and softness levels, were presented in a random order to mitigate potential order effects. The drink's temperature was measured immediately before presentation with an infrared radiation thermometer; each cup contained 10 g of the beverage. The material of the rim of the cups was not disclosed to the participants. They were allowed to taste each beverage as many times as they wished and were not required to consume all ten grams. They were also instructed to sip water between each condition to eliminate possible lingering tastes in their mouths. The experimental

Fig. 3. Experimental setup.

protocol for this study was developed with reference to previous researches (Suzuki et al., 2014; Kamihori et al., 2024).

The room temperature during the experiment was maintained at an average of 24.0±1.4 °C, and the humidity was 45±12 %.

2.5. Statistical analysis

All statistical analyses were performed using R Statistical Software (Version 4.3.1, released in 2023). Shapiro-Wilk tests on the rating data showed that none of the rating items adhered to a normal distribution. As a result, differences between samples were assessed using non-parametric tests at a significance level of 95 % ($p < 0.05$). In Section 3.1, the Friedman test was conducted, followed by multiple comparisons corrected using the Bonferroni method. In Sections 3.2 and 3.3, the Mann-Whitney U test was used.

3. Results

3.1. Changes in flavor perception due to differences in the material and softness of rim of cups

This experiment examined changes in flavor perception influenced by variations in the material and softness of cup rims. The experimental results are presented in Figs. 4 and 5 and describe below the results of each aspect of the flavor perception.

3.1.1. In-mouth aroma ratings

Significant differences or trends were observed between plastic - wood ($p < 0.01$), plastic - paper ($p < 0.1$), plastic - gummy A ($p < 0.01$), plastic - gummy C ($p < 0.05$). Based on these results, the plastic rim of the cup obviously elicited a strong in-mouth aroma of apple juice.

3.1.2. Aftertaste ratings

No significant differences were observed in aftertaste due to differences in the material and the softness of the rim of cups across all beverages.

3.1.3. Intensity of taste ratings

A significant trend was observed for orange juice between paper – metal, paper - gummy A ($p < 0.1$). For apple juice, significant differences or trends were observed between paper - plastic ($p < 0.05$), paper - metal ($p < 0.01$), paper - glass ($p < 0.01$), paper - gummy A ($p < 0.1$), paper - gummy C ($p < 0.01$). For apple juice, significant differences or trends were observed between wood - metal ($p < 0.05$) and wood - glass ($p < 0.1$).

These results showed that, with the juice conditions, the paper rim of a cup elicited a weaker perception of taste intensity. With apple juice, the wooden rim of a cup led to a weaker perception of taste intensity.

3.1.4. Throat feeling ratings

In orange juice, significant differences or trends were observed between metal - wood ($p < 0.05$), metal - ceramic ($p < 0.1$), metal - gummy A ($p < 0.1$), metal - gummy B ($p < 0.05$), metal - gummy C ($p < 0.1$). Additionally, significant differences or trends were found between paper - plastic ($p < 0.01$), paper - wood ($p < 0.05$), paper - ceramic ($p < 0.01$), paper - metal ($p < 0.01$), paper - glass ($p < 0.01$), paper - gummy A ($p < 0.05$), paper - gummy B ($p < 0.05$), paper - gummy C ($p < 0.01$).

For apple juice, significant differences or trends were observed between metal - wood ($p < 0.01$), metal - ceramic ($p < 0.01$), metal - paper ($p < 0.01$), metal - gummy A ($p < 0.05$), metal - gummy C ($p < 0.1$). Significant differences or trends were also observed between glass - plastic ($p < 0.1$), glass - wood ($p < 0.01$), glass - ceramic ($p < 0.01$), glass - paper ($p < 0.001$), glass - gummy A ($p < 0.05$), glass - gummy B ($p < 0.1$). There were also significant differences or trends for paper - plastic ($p < 0.01$), paper - gummy B ($p < 0.1$).

For green tea, significant differences or trends were observed between metal - plastic ($p < 0.05$), metal - wood ($p < 0.01$), metal - paper ($p < 0.01$), metal - gummy A ($p < 0.05$), metal - gummy B ($p < 0.01$), metal - gummy C ($p < 0.05$). Additionally, significant differences or trends were observed between glass - wood ($p < 0.01$), glass - ceramic ($p < 0.1$), glass - paper ($p < 0.01$), glass - gummy A ($p < 0.05$), glass - gummy B ($p < 0.01$). There was also a significant difference for paper - ceramic ($p < 0.05$).

These results showed that metal/glass rim of cups provided a stronger throat feeling; paper rim of cups elicited a weaker throat feeling than ceramic rim of cups.

3.1.5. Deliciousness ratings

For orange juice, significant differences were observed between metal - plastic, metal - wood, metal – ceramic, metal - gummy A, metal - gummy B, metal - gummy C ($p < 0.01$). Additionally, there was a significant trend in glass - paper ($p < 0.1$).

For apple juice, significant differences were found between metal - plastic ($p < 0.05$), metal - wood ($p < 0.01$), metal - ceramic ($p < 0.1$), metal - paper ($p < 0.05$), metal - gummy A ($p < 0.01$), metal - gummy B ($p < 0.01$), metal - gummy C ($p < 0.01$). There was also a significant

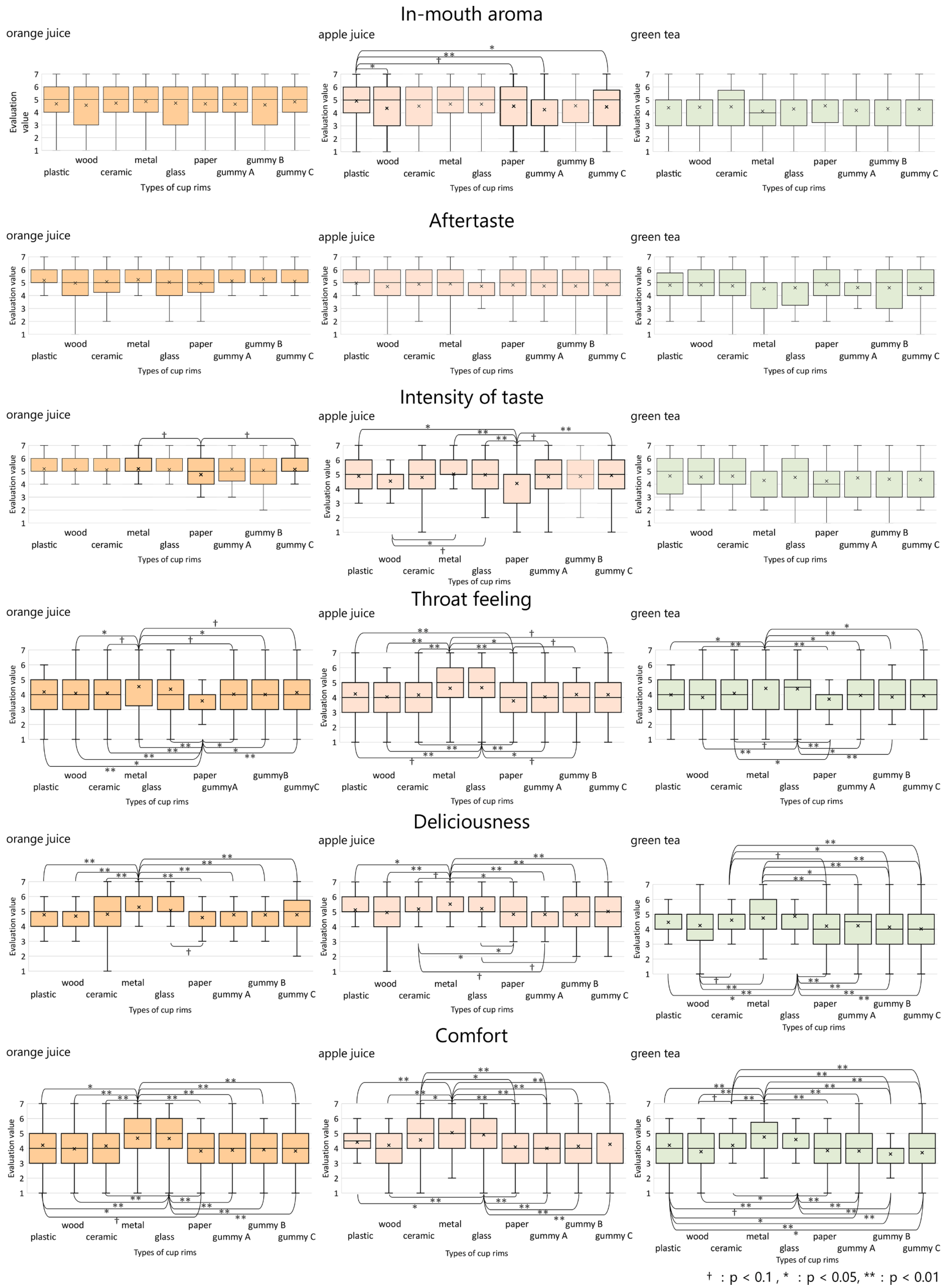

Fig. 4. Results of in-mouth aroma, aftertaste, intensity of taste, throat feeling, deliciousness, and comfort.

difference between paper and glass ($p < 0.05$), and a trend was observed between ceramic - gummy A and glass - gummy B ($p < 0.1$).

For green tea, significant differences or trends were observed between metal - paper ($p < 0.01$), metal - gummy A ($p < 0.05$), metal - gummy B ($p < 0.01$), metal - gummy C ($p < 0.01$), metal - wood ($p < 0.01$). There were significant differences or trends observed in ceramic - wood ($p < 0.1$), ceramic - paper ($p < 0.1$), ceramic - gummy B ($p < 0.05$), ceramic - gummy C ($p < 0.01$). Glass - plastic ($p < 0.05$), glass - wood (p

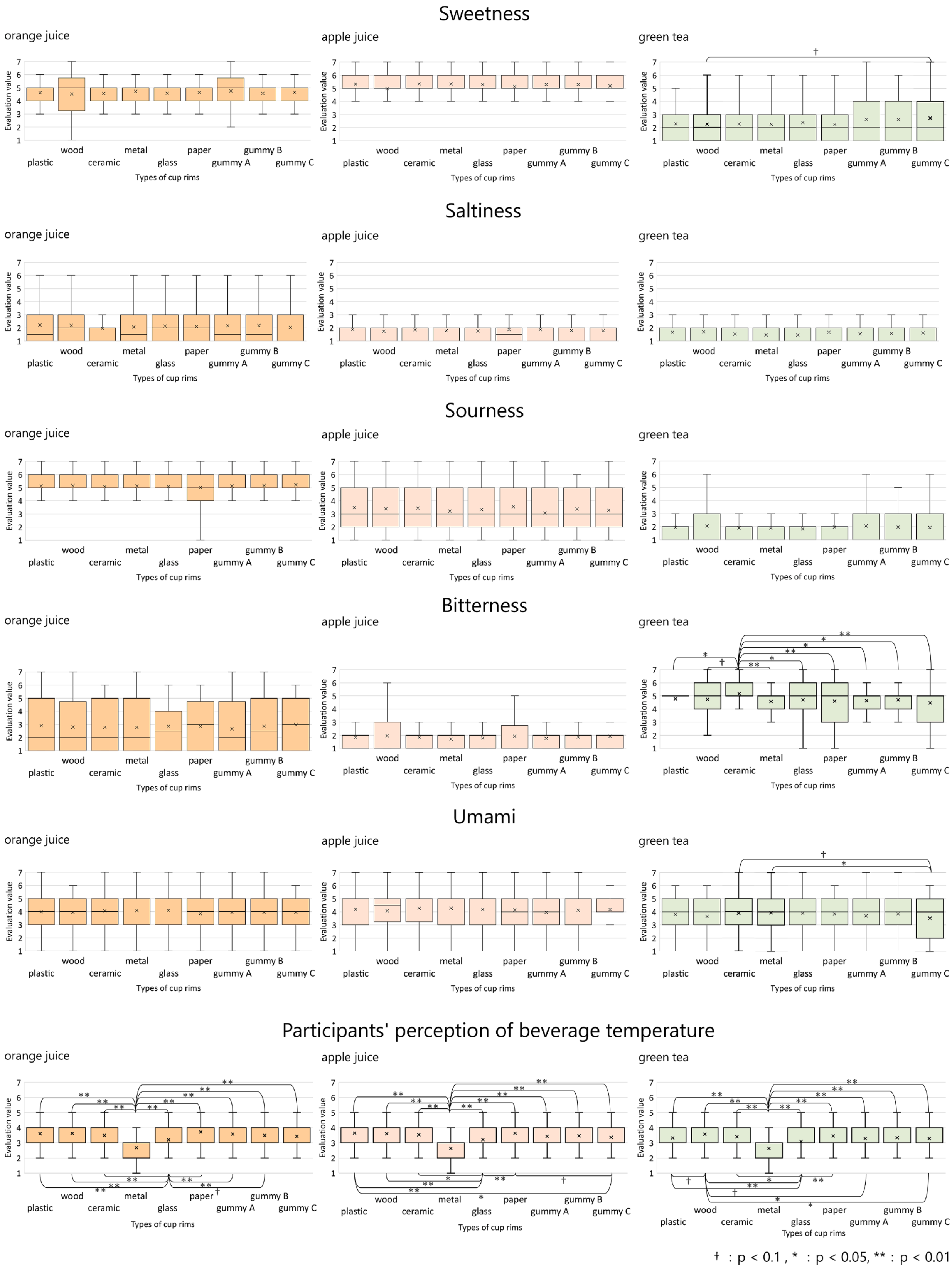

Fig. 5. Results of sweetness, saltiness, sourness, bitterness, umami, and participants' perception of beverage temperature.

< 0.01), glass - paper ($p < 0.01$), glass - gummy A ($p < 0.01$), glass - gummy B ($p < 0.01$), glass - gummy C ($p < 0.01$) exhibited significant differences.

These results show that the metal rim of a cup elicited a stronger perception of deliciousness across every beverage. Specifically, under green tea conditions, both the ceramic and glass rim of cups in addition to the metal rim of a cup elicited a stronger perception of deliciousness.

3.1.6. Comfort ratings

For orange juice, significant differences or trends were observed between metal - plastic ($p < 0.05$), metal - wood ($p < 0.01$), metal - ceramic ($p < 0.01$), metal - paper ($p < 0.01$), metal - gummy A ($p < 0.01$), metal - gummy B ($p < 0.01$), metal - gummy C ($p < 0.01$). There were significant differences or trends observed in glass - plastic ($p < 0.05$), glass - wood ($p < 0.01$), glass - ceramic ($p < 0.01$), glass - paper ($p < 0.01$), glass - gummy A ($p < 0.01$), glass - gummy B ($p < 0.01$), glass - gummy C ($p < 0.01$). Furthermore, a significant trend was observed between plastic - paper ($p < 0.1$).

With apple juice, significant differences or trends were observed between metal - plastic ($p < 0.01$), metal - wood ($p < 0.01$), metal - ceramic ($p < 0.05$), metal - paper ($p < 0.01$), metal - gummy A ($p < 0.01$), metal - gummy B ($p < 0.01$), metal - gummy C ($p < 0.01$). Significant differences or trends were found between glass - plastic ($p < 0.05$), glass - wood ($p < 0.01$), glass - paper ($p < 0.01$), glass - gummy A ($p < 0.01$), glass - gummy B ($p < 0.01$), glass - gummy C ($p < 0.01$). There were significant differences between ceramic - paper ($p < 0.05$) / gummy A ($p < 0.01$).

For green tea, significant differences or trends were observed between metal - plastic ($p < 0.01$), metal - wood ($p < 0.01$), metal - ceramic ($p < 0.01$), metal - paper ($p < 0.01$), metal - gummy A ($p < 0.01$), metal - gummy B ($p < 0.01$), metal - gummy C ($p < 0.01$). There were significant differences or trends observed in glass - plastic ($p < 0.1$), glass - wood ($p < 0.01$), glass - ceramic ($p < 0.05$), glass - paper ($p < 0.01$), glass - gummy A ($p < 0.01$), glass - gummy B ($p < 0.01$), glass - gummy C ($p < 0.01$). There were significant differences or trends observed in ceramic - wood ($p < 0.1$), ceramic - gummy B ($p < 0.01$), ceramic - gummy C ($p < 0.01$). Additionally, significant differences were found between plastic - gummy A ($p < 0.05$), plastic - gummy B ($p < 0.01$), plastic - gummy C ($p < 0.05$).

Based on these results, participants perceived metal and glass rim of cups to evoke a stronger comfort across every beverage. For the green tea case, ceramic and plastic rim of cups were particularly perceived as providing more comfort than gummy rim of cups.

3.1.7. Sweetness ratings

For green tea, a significant trend was observed between wood - gummy C ($p < 0.1$). In other conditions, no significant differences or trends were observed.

3.1.8. Saltiness ratings

There were no significant differences observed in the saltiness perceived due to differences in the rim of cup material and softness across all beverages.

3.1.9. Sourness ratings

There were no significant differences observed in the perceived sourness due to differences in the rim of cup material and softness across all beverages.

3.1.10. Bitterness ratings

For green tea, significant differences were observed between ceramic - plastic ($p < 0.05$), ceramic - wood ($p < 0.1$), ceramic - metal ($p < 0.01$), ceramic - glass ($p < 0.05$), ceramic - paper ($p < 0.01$), ceramic - gummy A ($p < 0.05$), ceramic - gummy B ($p < 0.05$), ceramic - gummy C ($p < 0.01$). These results showed that the ceramic rim of cups elicits a stronger perception of bitterness in green tea.

3.1.11. Umami ratings

In green tea, there was a significant difference and trend in gummy C - ceramic ($p < 0.1$), gummy C - ceramic metals ($p < 0.05$). In other conditions, no significant differences or trends were observed.

3.1.12. Participants' perception of beverage temperature ratings

With orange juice, significant differences were observed between metal - plastic, metal – wood, metal – ceramic, metal – glass, metal – paper, metal - gummy A, metal - gummy B, metal - gummy C ($p < 0.01$). There were significant differences or trends observed in glass - plastic ($p < 0.01$), glass - wood ($p < 0.01$), glass - ceramic ($p < 0.01$), glass-paper ($p < 0.01$), glass - gummy A ($p < 0.01$), glass - gummy B ($p < 0.1$).

In apple juice, significant differences were observed between metal – plastic, metal – wood, metal – ceramic, metal-glass, metal – paper, metal - gummy A, metal - gummy B, metal - gummy C ($p < 0.01$). Additionally, significant differences or trends were observed between glass - plastic ($p < 0.01$), glass - wood ($p < 0.01$), glass - ceramic ($p < 0.05$), glass - paper ($p < 0.01$). There were also significant differences or trends observed for gummy C - plastic ($p < 0.05$) and gummy C - paper ($p < 0.1$).

In green tea, significant differences were observed between metal – plastic, metal – wood, metal – ceramic, metal – glass, metal – paper, metal - gummy A, metal - gummy B, metal - gummy C ($p < 0.01$). There were also significant differences or trends observed for glass - plastic ($p < 0.1$), glass - wood ($p < 0.01$), glass - ceramic ($p < 0.05$), glass-paper ($p < 0.01$). There were also significant differences or trends observed for wood - plastic ($p < 0.1$), wood - gummy A ($p < 0.05$), wood - gummy C ($p < 0.05$).

From these results, participants perceived that beverages felt colder when consumed from metal and glass rim of cups across all types of drinks. For the green tea conditions, the wooden rim of the cup was perceived to make beverages feel warmer compared to other rim materials.

3.2. Changes in flavor perception due to differences in sensation of rim of a cup

The results of the free-response questions regarding the perceived material of the cup rim were categorized into "rough" and "smooth" to investigate how differences in perceived texture influenced flavor perception. The results are presented in Fig. 6.

For orange juice, there were 74 data for rough and 79 for smooth. For apple juice, there were 82 data for rough and 71 for smooth. For green tea, there were 78 data for rough and 82 for smooth.

For orange juice, significant differences or trends were observed in the in-mouth aroma ($p < 0.1$), sweetness ($p < 0.05$), and the perception of beverage temperature ($p < 0.01$). For apple juice, significant differences or trends were found between in-mouth aroma ($p < 0.01$) and comfort ($p < 0.1$). For green tea, there were also significant differences or trends observed for the intensity of taste ($p < 0.05$), bitterness ($p < 0.1$), and the perception of the drink temperature ($p < 0.05$).

These results showed that a rough rim of a cup in the juice conditions perceived a stronger in-mouth aroma.

3.3. Changes in flavor perception due to differences in softness of rim of a cup

Next, the rims of cups made from gummy materials (three conditions) were compared with those made from non-gummy materials (six conditions) to investigate how the hardness and softness of the rim affected flavor perception. The results are presented in Fig. 7.

Orange juice showed significant differences in in-mouth aroma ($p< 0.05$) and comfort ($p < 0.01$). Apple juice showed significant differences in deliciousness and comfort ($p < 0.01$). Green tea showed significant differences or trends in throat feeling ($p < 0.1$), deliciousness ($p < 0.01$), comfort ($p < 0.01$), sweetness ($p < 0.05$), and bitterness ($p < 0.05$).

These results indicate that a hard (non-gummy materials) rim of a cup leads to a stronger sensation of comfort.

4. Discussion

In this experiment, participants evaluated the material and softness of the cup rim based solely on the tactile perception of their lower lip, with black eye masks used to block visual input. Previous studies have

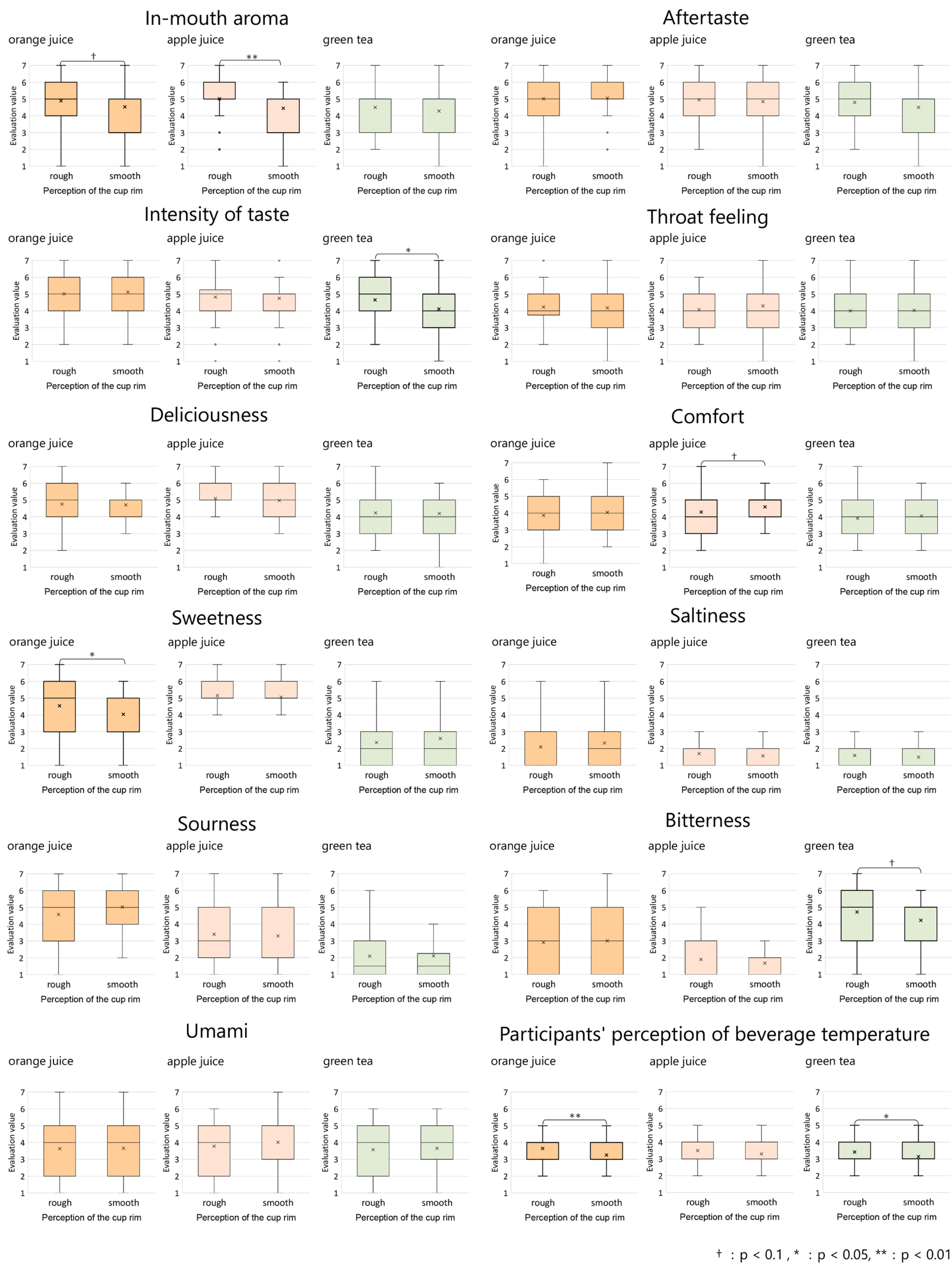

Fig. 6. Results of flavor perception changes due to texture of rim of a cup.

shown that the color of the dining environment can affect flavor perception (Motoki et al., 2021). Thus, it is possible that the black visual field influenced flavor perception.

Our experimental results indicate that the metal and glass rim of cups induce a perception of coldness in beverages and significantly enhance sensations of throat feeling, deliciousness, and comfort. Metal has high thermal conductivity, and glass has a smooth surface that promotes high contact between the rim of a cup and the lower lip, preventing air from

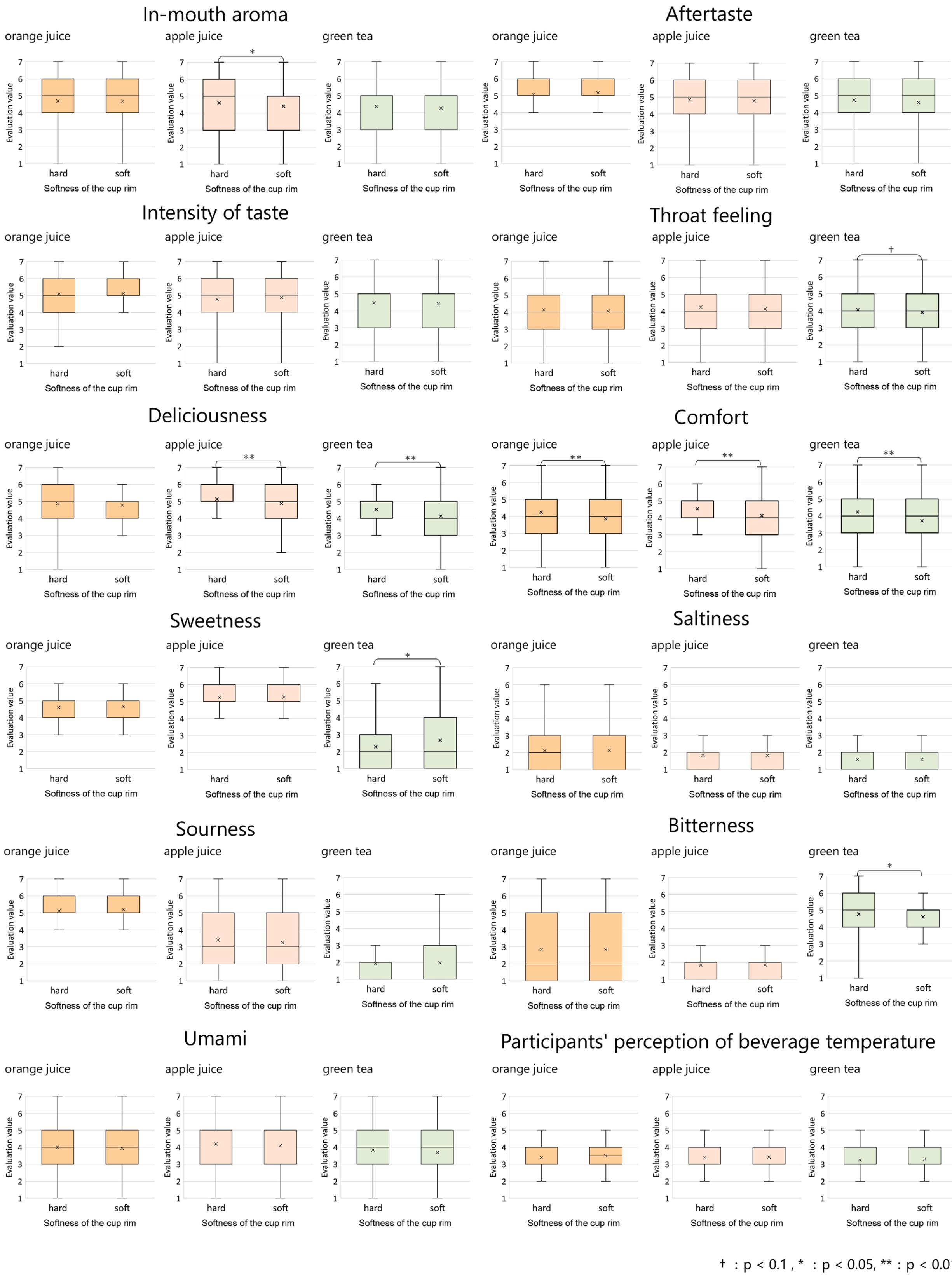

Fig. 7. Results of flavor perception changes due to hardness or softness of rim of a cup.

entering the space between them and contributing to the perception of coldness. Over half of the participants perceived the metal and glass rim of cups as cold based on their free responses. Previous studies have shown that cooling the rim of a cup by 2 °C enhances the perception of its coldness and improves the throat feeling, deliciousness, and comfort (Kamihori et al., 2024). Therefore, perhaps in this experiment, the perceived coldness of the rim of a cup strengthened the feelings in those participants who experienced the beverage as colder and caused stronger sensations of throat feeling, deliciousness, and comfort.

In the green tea condition, the ceramic rim of a cup was associated with stronger perceptions of deliciousness and bitterness. Previous studies concluded that the polyphenols in green tea interact with other food components, such as proteins and lipids, altering sensory perceptions and taste recognition (Jingxian Niu & Qiu, 2023). The porous surface of ceramic allows components to adsorb onto its surface, potentially changing the balance of green tea constituents and intensifying the perceptions of deliciousness and bitterness.

Participants consistently perceived smooth rim of cups as colder. Many rated metal and glass rim of cups as smooth, which likely contributed to their perception of the beverages in them as cold. Our study also concluded that the perception of in-mouth aroma, intensity of taste, and sweetness varied depending on whether the rim of a cup was perceived as rough or smooth. Previous research highlighted that the texture of drinking containers affects flavor perception (Pramudya et al., 2020; Tu et al., 2015; Risso et al., 2019; Wang & Spence, 2018). Based on the results of this experiment, cross-modal effects between tactile sensation and flavor perception occur not only in the hands but also when tactile sensations are applied to the lower lip. In particular, participants experienced a stronger sweetness with rough rim of cups, especially with orange juice. However, previous studies identified a correlation between smooth tactile sensations and sweetness (Riofrio-Grijalva et al., 2020). Previous research utilized basic taste solutions at concentrations above threshold levels; our experiment employed beverages containing various food components. Therefore, the relationship between the tactile sensations of rim of cups and flavor perception may reflect the constituents of the beverage.

In all beverages, a hard rim of a cup increased the perception of comfort. Previous studies have established a preference for containers made of harder materials (Krishna & Morrin, 2007). Our experiment results show that flavor perception varies not only based on the container's overall hardness or softness but also on the hardness or softness of the rim of a cup. Reports from the free-response section of our experiment included "drinking from the soft rim of cups was difficult" and "unfamiliar rim of cups caused discomfort." These findings suggest that changes in flavor perception due to the rim of cups may vary depending on the type of drinking container typically used by individuals. This experiment used flavorless and odorless gummies as a soft cup rim. However, since the gummies were primarily made of sugar, syrup, and gelatin, approximately ten participants perceived the gummies as sweet in their open-ended responses. Since no significant differences in sweetness ratings were observed between gummy and non-gummy rims, except in the case of green tea, the impact of gummy flavor on overall changes in beverage flavor perception appears minimal. Future studies will aim to clarify the relationship between the flavor of the cup rim and the flavor perception of the beverage.

Based on our experiment results, metal and glass rims of cups enhance flavor perception. Moreover, harder rims of cups improve flavor perception more than softer ones. Based on these results, it is considered optimal to use cup rims that are cold and hard when consuming beverages. In Japan, many restaurants increasingly adopt paper straws to replace plastic straws for environmental conservation. However, a significant number of people do not prefer paper straws. This experiment's finding that a "cold and hard rim of the cup" is optimal can be considered one reason for the unpopularity of paper straws.

The results of these experiments revealed that the material and hardness/softness of the rim of the cup influence flavor perception. This suggests that adjusting the container to match specific beverages, such as green tea, can enhance the user's drinking experience. Moreover, this finding extends beyond beverages to include food. For example, the materials used in food packaging and cutlery may also impact flavor perception, thereby enhancing the overall dining experience. In the food industry, selecting materials according to the product's purpose and target consumers can create new markets.

This experiment aims to determine the general effect of the material and softness of the cup rim on consumers' psychological responses, without confirming participants' specific preferences or habitual use of the beverages. Future studies will administer a questionnaire regarding participants' beverage consumption habits and preferences to investigate changes in flavor perception based on differences in consumption habits and preferences.

5. Conclusions

This study investigated the effects of the material and softness of cup rims on beverage flavor perception.

Rims were constructed from plastic, wood, ceramic, metal, and paper, all matching the thickness of glass. Additionally, three types of flavorless and odorless gummies with varying softness levels were utilized. Cup holders were designed to standardize the weight and tactile sensation of the drinking containers.

Orange juice, apple juice, and green tea were used at room temperature in the experiment. Our results revealed that flavor perception and the sensation of beverage temperature varied based on the material and the softness of the rim of a cup.

This experiment found no significant differences in flavor perception among the different softness levels of gummies. However, significant differences were observed between the conditions involving plastic and the gummy materials in green tea. Additionally, comparing the three conditions of gummies with the six conditions of non-gummy materials revealed variations in flavor perception based on the hardness or softness of the rim of a cup. These results suggest the potential impact of the rim of a cup's softness on the flavor perception of green tea, fueling further investigation into the effects of varying levels of hardness and softness on flavor perception. Future studies will also explore flavor perception changes using such gel-like materials as rubber and gummies as soft rim of a cup materials.

Ethical statement

Ethical approval for the involvement of human subjects in this study was granted by the Aoyama Gakuin University Research Ethics Committee, reference number H22-032, dated Jan. 12, 2023.

Ethical statement - studies in humans and animals

All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. This article does not contain any studies with animals performed by any of the authors. Informed consent was obtained from all individual participants included in the study.

CRediT authorship contribution statement

Mai Kamihori: Writing – original draft, Visualization, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Shinsuke Kitanaka:** Writing – review & editing, Resources, Methodology, Investigation. **Kiyoshi Suzuki:** Writing – review & editing, Resources, Methodology, Investigation. **Yuichi Itoh:** Writing – review & editing, Methodology, Investigation, Funding acquisition, Conceptualization.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Mai Kamihori reports financial support was provided by Japan Society for the Promotion of Science. Yuichi Itoh reports financial support was provided by Japan Society for the Promotion of Science. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Data availability

Data will be made available on request.

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