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Advances in Sensory Science: From Perceptions to Consumer Acceptance

Getting hot: Effect of chili pepper addition on sensory perception of liquid and solid foods

Cong Lyu[1] | Anne Hendriks[2] | Lauren N. Geary[2] | Ciarán G. Forde[1] | Markus Stieger[1,2]

[1]Division of Human Nutrition and Health, Wageningen University, Wageningen, The Netherlands

[2]Food Quality and Design, Wageningen University, Wageningen, The Netherlands

Correspondence
Cong Lyu, Division of Human Nutrition and Health, Wageningen University, P.O. Box 17, 6700 AA Wageningen, The Netherlands.
Email: cong.lyu@wur.nl

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Abstract: The impact of trigeminal oral burn and pungency on taste, flavor, and mouth-feel perception of commercially available foods is underexplored. This study aimed to determine the effect of oral burn sensations evoked by the addition of chili powder to tomato soup, beef burger patties, and curried rice on taste, flavor, and mouth-feel perception. Chili powder was added to tomato soups, beef burger patties, and curried rice at four concentrations. A consumer panel comprising $n = 66$ participants (49 women, 25.5 ± 5.8 years, BMI 22.9 ± 2.8 kg/m^2) assessed taste, flavor, trigeminal, and mouth-feel intensity of all samples using Rate-All-That-Apply methodology. Food matrix consistency strongly impacted oral burn sensations with solid food matrices (beef burger patties and curried rice) suppressing oral burn intensity compared to liquid food matrices (tomato soup). With increasing oral burn intensity, perceived intensity of beef flavor decreased significantly for beef burger patties. Tomato flavor, sweetness, and sourness intensity decreased significantly with increasing oral burn intensity for tomato soups. Perceived burn intensity of all food matrices and beef flavor intensity of beef burger patties differed between infrequent and frequent chili pepper consumers. We conclude that increasing oral burn intensity by the addition of chili pepper powder led to only small reductions in taste and flavor intensity of tomato soups and to little or no changes in flavor and mouth-feel perception of beef burger patties and curried rice. We suggest that reductions in taste, flavor, and mouth-feel intensity caused by oral burn might be more pronounced in liquid (tomato soup) than solid foods (beef burger patties and curried rice).

KEYWORDS
chili pepper powder, cross-modal interactions, food matrices, mouth-feel perception, RATA analysis, taste/flavor attributes

Practical Application: There is a growing public and scientific interest in the development of strategies to increase the sensory appeal of healthy foods and beverages. Incorporation of trigeminal stimuli, such as chili peppers or capsaicin (pungent component of chili peppers), can be a strategy to increase sensory appeal of foods and beverages. Little is known about how trigeminal oral burn and pungency influence taste, flavor, and mouth-feel perception of commercially available foods, although it has been well established that taste, flavor, mouth-feel, and trigeminal sensations contribute to product acceptance. By investigating the sensory impact of oral burn on flavor and mouth-feel perception of foods, this study may help to better understand how trigeminal stimuli can be applied to moderate flavor and mouth-feel perception of foods to optimize sensory appeal.

1 | INTRODUCTION

Chili pepper is one of the most commonly encountered chemesthetic food ingredients and is commonly used to boost flavor complexity and overall flavor impression, as well as consumer acceptability and satisfaction (Green, 1996; Spencer et al., 2018; Spencer & Dalton, 2020; Spencer & Guinard, 2018). Food sensory perception is a multimodal process involving gustatory, olfactory, trigeminal, and texture sensations. Numerous studies have demonstrated that those sensory properties are jointly experienced as multisensory neurons can respond to isolated and combinations of gustatory, olfactory, trigeminal, or texture stimuli, so that modifications of food properties in one sensory modality can impact the perception in another sensory modality (de Araujo et al., 2005; McCabe & Rolls, 2007; Rolls & Baylis, 1994; Spencer & Dalton, 2020; Thomas-Danguin et al., 2016).

Cross-modal interactions among visual, auditory, gustatory, olfactory, trigeminal, and texture perception of foods have been studied extensively (Bolliet et al., 2016; Demattè et al., 2006; Forde & Delahunty, 2004; Lyu et al., 2021; Marks, 2004; Nasri et al., 2011; Piqueras-Fiszman & Spence, 2014; Spence, 2018). Using simple model stimuli, it has been demonstrated that oral burn suppressed the intensity of gustatory, olfactory, and texture sensations. A decrease in perceived taste intensity after capsaicin pretreatment was observed for different taste modalities, including sweetness of sucrose solutions (Prescott & Stevenson, 1995; Simons et al., 2002), bitterness of PROP or quinine hydrochloride solutions (Green & Hayes, 2003; Lawless & Stevens, 1984), sourness of citric acid solutions (Karrer & Bartoshuk, 1995; Lawless et al., 1985; Lawless & Stevens, 1984), saltiness of NaCl solutions (Gilmore & Green, 1993; Lawless et al., 1985), and umami of monosodium glutamate solutions (Simons et al., 2003, 2002). Several studies reported that taste intensity (sourness or sweetness) decreased when capsaicin was presented in a mixture with citral or sucrose (Lawless et al., 1985; Lawless & Stevens, 1984; Prescott et al., 1993). Regarding retronasal olfactory perception, prior work highlighted a decrease in aroma intensity after capsaicin pretreatment or in mixtures of capsaicin with different odorants like citral (lemon odor), celeriac (celery odor), vanilla, and orange odor (Lawless et al., 1985; Prescott & Stevenson, 1995; Silver et al., 1985; Yang et al., 2020). For texture perception, Lyu et al. (2021) reported that oral burn sensations caused by capsaicin increased thickness discrimination thresholds of simple liquid model foods independently of reported chili pepper intake. Two mechanisms have been proposed to explain the observed suppression effect. The first proposed mechanism is a potential attentional effect as burn sensation can draw attention away from taste, smell, and texture sensations when the stimulation is sufficiently high (Clark & Lawless, 1994). The second proposed mechanism might be that neural noise increases as a result of competition among sensory inputs in the central nervous system (Lawless et al., 1985).

In contrast to the studies summarized above which reported suppression of taste, aroma, and texture perception by oral burn sensations, several studies demonstrated the opposite effect that oral capsaicin had no impact on or increased gustatory, olfactory, and texture perception in simple model stimuli. For taste, Cowart (1987) reported that oral capsaicin did not influence taste intensity of mixtures of capsaicin with taste compounds. Narukawa et al. (2011) found an enhancement of saltiness of NaCl solutions when capsaicin was added. Wang et al. (2022) showed that the application of either single capsaicin or the combination of capsaicin and pepper oleoresin enhanced saltiness of NaCl solutions. Regarding retronasal smell, Prescott and Stevenson (1995) tested the effects of capsaicin on strawberry flavor and did not find evidence for flavor intensity suppression by capsaicin. Frasnelli et al. (2009) examined the effect of oral capsaicin on smell perception and demonstrated that oral capsaicin failed to alter aroma thresholds and perception of suprathreshold odors. Conversely, Yang et al. (2021) demonstrated that capsaicin increased aroma perception without affecting in vivo aroma release. Concerning texture perception, Lv et al. (2020) observed a small decrease in thickness discrimination thresholds of maltodextrin solutions after stimulation with capsaicin. One possible mechanism that has been proposed to explain an enhancement of taste, smell, or texture perception by trigeminal stimuli is a synergistic, cognitive effect that enhances sensory intensity when different sensory qualities are perceived simultaneously together (Keast & Breslin, 2003; Wang et al., 2022).

In contrast to the extensive literature exploring cross-modal interactions between trigeminal and taste, smell, flavor, and texture perception of simplified model stimuli, surprisingly few studies explored cross-modal interactions between trigeminal and other sensory modalities in complex food matrices or commercially available foods (Gilmore & Green, 1993; Spencer & Dalton, 2020; Thomas-Danguin et al., 2016). Prescott et al. (1993) observed that capsaicin reduced sweetness of tomato soups. They determined sweetness, saltiness, oral burn, and total mixture intensity of tomato soups but did not assess flavor and mouth-feel perception. Forde and Delahunty (2002) compared sensory perception and preference of liquid (vegetable soups with white pepper), semisolid (chocolate-flavored yogurt with menthol), and solid (cheese-flavored waffle with capsaicin) foods with trigeminal stimuli between young and elderly. They demonstrated that higher levels of chemical irritation were preferred by older consumers. Reinbach et al. (2007) investigated the interactions among oral burn, meat flavor, and instrumental texture in pork patties with added trigeminal stimuli (chili powder and minced chili), showing that meat flavor intensity decreased with increasing burn intensity, whereas texture modifications of the pork patties did not affect burn nor meat flavor intensity. Mouthfeel of the pork patties was not assessed. Kostyra et al. (2010) added capsaicin and chili pepper powder to various liquid foods (water solution, starch gruel, soup, and sauce) and demonstrated that oral burn intensity evoked by capsaicin was strongly affected by the kind of carrier and its complexity, whereas the effect of oral burn on flavor and texture perception was not determined. Djekic et al. (2021) evaluated dynamic burn intensities of grilled pork meats coated with three types of hot sauces showing that intensity and duration of pungency sensations were possibly related to sauce type. To summarize, cross-modal interactions between trigeminal stimuli and taste, smell, flavor, and mouth-feel perception in complex food matrices or commercially available foods are underexplored.

Therefore, the aim of this study was to determine the effect of oral burn sensations caused by the addition of chili pepper powder to tomato soup, beef burger patties, and curried rice on taste, flavor, and mouth-feel perception. Tomato soup, beef burger patties, and curried rice were chosen as food matrices to represent commonly consumed staple foods in the Netherlands. These foods offer examples of different global cuisines with large sensory differences and facilitated a preliminary comparison of the effect of oral burn on taste, flavor, and mouthfeel across different food forms (liquid/solid) and different textures of solid foods (burger/rice). Sensory properties of these commercially available foods are relatively complex and recognizable. The preparation procedure of these foods made it possible to control the addition of chili pepper powder to the foods and to ensure homogenous mixing of the test stimulus (chili pepper powder) throughout the different food matrices. It has been reported that perception of oral burn depends on intake and consumption frequency of chili peppers, with infrequent consumers reporting more intense burn and lower liking of oral burn compared to frequent consumers (Byrnes & Hayes, 2013; Choi & Chan, 2015; Lawless et al., 1985; Lyu et al., 2021; Nolden & Hayes, 2017; Stevenson & Yeomans, 1993). Hence, participants' chili pepper intake frequency and preference for chili peppers and spicy foods were assessed using questionnaires, and they were categorized into infrequent and frequent chili pepper consumers. For each food matrix (tomato soup, beef burger patty, and curried rice), four concentrations of chili pepper powder were added to produce four levels of oral burn intensity. Taste, flavor, and mouth-feel properties of all foods were assessed using the Rate-All-That-Apply (RATA) methodology with naive consumers differing in habitual chili pepper and spicy food intake.

2 | MATERIALS AND METHODS

2.1 | Consumer panel

2.1.1 | Participants

Sixty-six participants (49 women and 17 men, 25.5 ± 5.8 years, BMI 22.9 ± 2.8 kg/m^2) of varying ethnicities were recruited from the Wageningen campus and surroundings using social media and a database of volunteers with an interest in human studies of Wageningen University. Using a power calculation, we estimated the sample size of the study to be $n = 64$ participants assuming a power of 80%, an effect size of 0.50, and $\alpha = 0.05$. The majority of participants were students of Wageningen University. Written informed consent was obtained from all participants. All participants were reimbursed for their participation. The study did not meet the requirements to be reviewed by the Medical Research Ethical Committee of The Netherlands according to the "Medical Research Involving Human Subjects Act" of The Netherlands (WMO in Dutch). The study was conducted in agreement with the ethics regulations laid out in the Declaration of Helsinki (2013).

2.1.2 | Inclusion criteria

Selected participants met the following inclusion criteria: 18–60-year old, having complete dentition, no chewing or swallowing problems, BMI of 18.5–30 kg/m^2, being willing to eat (moderately) spicy foods, no food allergies for any of the foods used in this study, no energy-restricted diet or having a weight change of more than 5 kg in the last 2 months, not pregnant or intentions to become pregnant, not breastfeeding, not taking any medication that may affect the function of taste, smell, mastication or salivation, and nonsmoker. Participants meeting these criteria filled in the chili pepper questionnaire to assess their liking and habitual intake of a variety of foods containing chili peppers (Byrnes & Hayes, 2013, 2016; Choi & Chan, 2015; Lawless et al., 1985; Lyu et al., 2021; Nolden & Hayes, 2017; Reinbach et al., 2007). Participants showed a wide variation in an intake frequency of a variety of foods containing chili peppers with an interquartile range of 24–182 intake times per year. A median split based on annualized chili pepper intake frequency was used to categorize participants as infrequent (n = 33; 27 women; mean intake frequency of foods containing chili peppers 25 times per year) and frequent (n = 33; 22 women; mean intake frequency of foods containing chili peppers 181 times per year) chili pepper consumers.

2.2 | Sample preparation

Three food matrices (beef burger patty, curried rice, and tomato soup) differing in chili pepper powder concentration were prepared. The concentrations of chili pepper powder added to the three food matrices were determined in a pilot study, with the intention to obtain four levels of oral burn intensity: barely detectable, low, medium, and high burn. In the pilot study, a broad range of concentrations of chili pepper powder were added to the food matrices, and oral burn intensity was rated by 12 participants (6 women and 6 men; participants involved in the pilot study did not participate in main study [RATA evaluation]) using a general Labeled Magnitude Scale with labels placed at 1.4 (barely detectable), 6 (weak), 17 (moderate), 35 (strong), and 51 (very strong), respectively (Bartoshuk et al., 2003; Byrnes & Hayes, 2013; Lyu et al., 2021; Nolden & Hayes, 2017). After the pilot study, four concentrations of chili pepper powder were chosen for each food matrix, which were likely to provoke barely detectable, low, medium, and high oral burn intensity. All food ingredients were purchased from a local supermarket (Albert Heijn, Wageningen, The Netherlands), including chili pepper powder (100% chili powder, Verstegen Spices & Sauces N.V.), minced beef (16% fat, Albert Heijn), curry paste (Korma, Patak's), coconut milk (kokosmelk, Fairtrade Original), indica rice (pure basmati rice, Tilda), eggs (size M, Albert Heijn), salt (NaCl, LoSalt, Klinge Foods), wheat flour (Albert Heijn), and tomato soup (Unox Romige Tomaten Soep; Unilever Nederland B.V., Rotterdam). Standardized cooking procedures were used for sample preparation to ensure consistency. All foods were prepared in a kitchen (Axis Building, Wageningen University). All samples were kept warm in a water bath (60°C) before the sensory evaluation. All samples were served in standardized bite-size (7 g beef burger patty cube of 1.0 × 1.0 × 1.0 cm^3 served on an aluminum dish, 8 g curried rice served on a tablespoon, and 15 g tomato soup served in a plastic medicine cup) for the sensory evaluation.

2.2.1 | Beef burger patty

The beef burger patty consisted of minced beef (75%), water (10%), salt (1%), eggs (10%), flour (3%), and chili pepper powder (0.05%, 0.3%, 0.8%, or 1.6%; in the following, the four concentrations of added chili pepper powder are referred to as barely detectable, low, medium, and high oral burn sensation). Minced beef was mixed with salt for 30 s at speed 2 in a mixer (Bosch MFQ2600, Stuttgart, Germany). Chili powder was added and mixed for 60 s at speed 2. The remaining ingredients were added and mixed for 90 s at speed 3. Each raw beef burger patty (around 150 g) was formed using a hamburger patty maker (diameter: 11 cm; height: 1.5 cm) to ensure uniformity. The patties were stored at −20°C immediately after preparation. On the day of each session, patties were thawed for 1 h at room temperature and then roasted at 200°C for 10 min on each side in a universal combi-oven (Self Cooking Center, SCC WE 61G. Rational AG, Landsberg am Lech, Germany). After roasting, beef burger patties were cut into cubes of 1.0 × 1.0 × 1.0 cm^3.

2.2.2 | Curried rice

Curry sauce was prepared by combining coconut milk (70%) and curry paste (30%) in a saucepan which was heated over medium–low heat for 5 min, whilst occasionally stirring. Chili pepper powder (0.05%, 0.3%, 1.2%, or

2.2%; in the following, the four concentrations of added chili pepper powder are referred to as barely detectable, low, medium, and high oral burn sensation) was added to the sauce after cooling and mixed by hand with a whisk. Indica rice was prepared on the day of the test session by rinsing it with water three times, and cooking in an electric rice cooker (Russell Hobbs MaxiCook rice cooker, Oldham, UK) with water at a 1:1.9 ratio for 30 min (Ayabe et al., 2009). Cooked rice was mixed with the curry sauce at a 4:1 w/w ratio.

2.2.3 | Tomato soup

Tomato soup was prepared by adding chili pepper powder (0.01%, 0.03%, 0.2%, or 0.4%; in the following, the four concentrations of added chili pepper powder are referred to as barely detectable, low, medium, and high oral burn sensation) to the ready-to-use tomato soup. The tomato soup was mixed and heated in a pan until boiling.

2.3 | Characterization of mechanical properties

2.3.1 | Texture analysis

The hardnesses of beef burger patties and curried rice differing in chili powder concentrations were determined using a texture analyzer (TA-XT plus, Stable Micro Systems) with a cylindrical probe (P/75, 75 mm stainless cylinder). Compression tests were performed on beef burger patty cubes ($1.0 \times 1.0 \times 1.0$ cm^3) and curried rice (5 g) placed as a single layer of grains. Hardness was defined as the peak force (N) required to compressing beef burger patties to 80% strain and curried rice to 90% strain, respectively. Measurements were repeated six times for each sample.

2.3.2 | Rheological properties

Flow curves of tomato soup differing in chili pepper concentrations were recorded using a rheometer (MCR 301, Anton Paar, Graz, Austria) with a concentric single gap cylinder geometry (C-CC17/T200/TI) at 60°C. Continuous flow measurements were performed by increasing the shear rate in logarithmic steps from 1 to 500 s^{-1} and then decreasing from 500 to 1 s^{-1}. Fitting of flow curves with the Ostwald–de Waele power-law model was done in the shear rate range of 1–100 s^{-1} to obtain consistency index k and power-law exponent n (Aguayo-Mendoza et al., 2019; Lyu et al., 2021). Measurements were done in triplicate.

2.4 | Sensory evaluation: Rate-All-That-Apply (RATA)

The RATA assessments comprised a familiarization session and an evaluation session. One familiarization session of 60 min was used to acquaint participants with the definitions of sensory terms (Table 1), the RATA method, the use of the 9-box scale, and its anchors to rate the intensity of sensory terms, as well as the cleansing procedure (Jaeger et al., 2013; Oppermann et al., 2017). The list of terms (Table 1) was generated by the research team, combining previously published studies from qualitative consumer studies (Elzerman et al., 2011; Nishida et al., 2021; Reinbach et al., 2007), which were later refined and modified based on group discussion among the research team. During the familiarization session, participants completed brief familiarization with the stimuli by tasting beef burger patties containing 0.05% and 1.6% chili pepper powder, curried rice containing 0.05% and 2.2% chili pepper powder, and tomato soup containing 0.01% and 0.4% chili pepper powder. Hence, participants were familiarized with all three food matrices using the lowest and highest concentrations of added chili pepper powder. After tasting, participants selected the sensory attributes that applied to describe a sample by clicking a "non-perceivable" label (intensity = 0) in case the term was not considered applicable to describe a given sample, or by rating the perceived intensity on a 9-box scale with end-point anchors 1 = "low" and 9 = "high." This procedure was followed to acquaint participants with the level of burn intensity of samples and to illustrate the sensory attributes. After the familiarization session, participants reported that it was clear to them how to perform the test and use the scales in the evaluation session. Prior to the start of the evaluation session, participants were asked if the procedure was still clear and explained again if necessary.

During the evaluation session of 60 min, RATA data were collected using EyeQuestion software (Version 3.9.7, Logic8 EyeQuestion software) in meeting facilities (Agrotechnology and Food Sciences Group, Wageningen University) equipped with table separators to create individual sensory booths. Participants received three types of foods (beef burger patty, curried rice, and tomato soup) in three blocks containing four beef burger patty samples presented in one block, followed by four curried rice samples within one block, and finally four tomato soup samples within one block. Within a block, participants received samples in a fixed order of ascending chili pepper powder concentration to help minimize potential desensitization, starting with the concentration corresponding to barely detectable followed by low, medium, and high oral burn sensation. The order of the blocks was randomized and counterbalanced across participants. Sensory terms were

TABLE 1 Sensory attributes and definitions used during the Rate-All-That-Apply (RATA) evaluation

Sensory attribute	Definition	Beef burger patty	Curried rice	Tomato soup
Flavor/taste				
Beef flavor	Distinctive taste of beef	X		
Curry flavor	Distinctive taste of curry		X	
Rice flavor	Distinctive taste of rice		X	
Tomato flavor	Distinctive taste of tomato			X
Sweetness	Sensation of basic sweet taste		X	X
Sourness	Sensation of basic sour taste			X
Saltiness	Sensation of basic salty taste	X	X	X
Overall flavor	Overall flavor perceived in the mouth	X	X	X
Trigeminal				
Burn	Total intensity of oral burn perceived in mouth and throat	X	X	X
Mouthfeel				
Hardness	Effort or force required to bite through the sample with the teeth	X	X	
Thickness	Ease to deform the food between tongue and palate and perceived resistance to flow			X
Graininess	Presence of particles in the mouth, perceived inhomogeneity	X	X	
Juiciness	Presence of liquid in the mouth	X		
Dryness	Dry and rough feeling on the tongue and oral cavity		X	
Fattiness	Amount of fat that is perceived when having the sample in the mouth for several seconds	X		
Chewiness	Need to chew or difficulty to chew	X	X	
Creaminess	Sensation of thick, smooth, velvety mouthfeel			X

Note: Different attribute lists were used for the evaluation of beef burger patty, curried rice, and tomato soup.

randomized within blocks (flavor/taste, trigeminal, and mouth-feel perception) for each participant following a balanced design for presentation order. For each term, participants first selected whether the term applied to describe the sample, and only if so, rated its perceived intensity on a 9-box scale from "low" to "high." Between sample evaluations within a block, participants had a 2.5 min break to cleanse their mouth with crackers and water (Lyu et al., 2021; Nasrawi & Pangborn, 1990; Nolden & Hayes, 2017). This break was enforced using the EyeQuestion software. At the end of the 2.5 min break, participants were asked if they still perceive an oral burn sensation ("yes" or "no"). Participants were given additional time to cleanse their mouths when they answered the question with "yes" indicating that they still perceive an oral burn sensation.

2.5 | Statistical data analysis

Statistical data analyses were performed using IBM SPSS Statistics 25.0 (SPSS Inc., USA). One-way analyses of variance (ANOVAs) were conducted separately to compare the mechanical properties of three sets of foods with different concentrations of chili powder. RATA data were analyzed following the procedure described by Ares et al. (2014) and Meyners et al. (2016). In terms of RATA intensity scores, non-checked attributes were treated as intensity = 0. RATA intensity scores (0–9) were treated as continuous data (Meyners et al., 2016; Oppermann et al., 2017). Univariate ANOVAs (with burn sensation as fixed factor and panelist as random factor) were carried out for all sensory terms to determine differences among the foods in terms of flavor/taste, trigeminal, and mouth-feel intensity. Independent samples *t*-tests were conducted to compare group differences between infrequent and frequent consumers of chili peppers. In the case of significant differences, post hoc tests were performed with Tukey's Honest Significant Difference test at a 95% confidence level.

3 | RESULTS AND DISCUSSION

3.1 | Mechanical properties of food matrices

As shown in Table 2, there is no significant difference ($p > 0.05$) in instrumental hardness of beef burger

TABLE 2 Mechanical properties of foods differing in oral burn sensation

	Food				
	Beef burger patty	Curried rice	Tomato soup		
Burn sensation	Hardness (N)	Hardness (N)	Consistency K (mPa s)	Viscosity$_{50s-1}$ (mPa s)	Flow behavior index n
Barely detectable	53.7 ± 7.1	28.7 ± 2.4	3031.2	204.8 ± 6.5	0.31
Low	58.6 ± 8.5	28.0 ± 4.0	2871.0	202.3 ± 5.1	0.31
Medium	55.4 ± 9.6	27.6 ± 2.7	2930.2	204.6 ± 5.8	0.31
High	54.3 ± 2.6	27.3 ± 2.8	2921.1	206.5 ± 7.6	0.32
p-Value	0.66	0.86	–	0.10	–

Note: Consistency K and flow behavior index n were obtained by fitting the averaged experimental data with the Ostwald–de Waele power-law model.

patties and curried rice differing in the concentration of added chili pepper powder. Apparent viscosity at a shear rate of 50 s^{-1} (η_{50s-1}) of tomato soups (Table 2) was not significantly affected ($p > 0.05$) by chili pepper powder concentration. Consistency K corresponding to viscosity at a shear rate of 1 s^{-1} and flow behavior index n indicating the magnitude of shear-thinning behavior ($0 < n < 1$) obtained by fitting the experimental flow curves with the Ostwald–de Waele power-law model were also similar between tomato soups differing in the concentration of added chili pepper powder. These findings are in-line with the results of Lyu et al. (2021) and Reinbach et al. (2007), which suggested that the addition of chili powder does not influence the instrumental hardness of curried rice and beef burger patties nor the flow behavior of tomato soup. This suggests that any potential differences in mouth-feel perception between foods differing in chili pepper powder concentration are caused by cross-modal effects of the trigeminal burn on mouth-feel perception rather than by changes in the instrumental texture properties of the foods induced by chili pepper powder addition.

3.2 | Rate-All-That-Apply (RATA)

The mean intensity scores for all sensory attributes of beef burger patties, curried rice, and tomato soup with different levels of chili pepper powder are shown in Table 3 and are illustrated as spider web diagrams in Figure 1. As expected, with an increasing concentration of added chili pepper powder oral burn intensity significantly increased for all food matrices. Averaged burn ratings increased significantly ($p < 0.001$) and considerably from 0.5 to 6.3 for beef burger patties, from 0.6 to 6.6 for curried rice, and from 0.9 to 7.0 for tomato soup, respectively. Within a food category (beef burger patties and tomato soup), the four samples were perceived as significantly different in terms of oral burn intensity demonstrating that increasing the concentration of added chili pepper powder led to four distinct levels of oral burn intensity. For the curried rice, only the medium and high burn curried rice (4.0 and 6.6) did not differ significantly from each other in oral burn intensity.

Figure 1 and Table 3 show that increased oral burn sensations resulted in a significant ($p < 0.05$) reduction in the intensity of certain sensory attributes for beef burger patties and tomato soup, whereas it had no significant ($p > 0.05$) impact on any taste, flavor, and mouth-feel intensity of curried rice. Increased oral burn significantly decreased beef flavor intensity of beef burger patties from 7.7 to 7.0, tomato flavor intensity of tomato soup from 7.3 to 6.3, sweetness intensity of tomato soup from 4.9 to 3.5, and sourness intensity of tomato soup from 5.0 to 3.7, respectively. These results suggest that, overall, a large enhancement of oral burn intensity leads to only small reductions in taste and flavor intensity for tomato soups, and to small reductions or no changes in flavor intensity for beef burger patties and curried rice. Mouth-feel perception was not significantly affected by oral burn in liquid and solid food matrices. It seems that very large differences in oral burn intensity are needed to achieve small reductions in taste, flavor, and mouth-feel intensity. The intensity scores for the overall flavor of all three food matrices, though there was no statistically significant difference ($p > 0.05$), tended to increase with increasing level of burn. The mean ratings for overall flavor increased from 6.0 to 6.4 for beef burger patties, from 4.5 to 5.1 for curried rice, and from 6.1 to 6.8 for tomato soup, respectively. This was in-line with previous studies indicating that the addition of chili pepper boosts the overall flavor impression, dimensionality, and perceived complexity (Green, 1996; Spencer & Dalton, 2020; Spencer & Guinard, 2018).

In order to achieve comparable burn intensity, different concentrations of chili pepper powder are needed depending on the food matrix. Although the concentration of added chili pepper powder was the lowest for tomato soups (0.01%, 0.03%, 0.2%, and 0.4%), the oral burn intensity was similar or even higher compared to beef burger patties (0.05%, 0.3%, 0.8%, and 1.6%), and curried rice (0.05%, 0.3%, 1.2%, and 2.2%). For example, oral burn intensity of tomato soups containing 0.4% chili pepper powder was 7.0. To provoke comparable oral burn intensities in beef burger patties (7.0) and curried rice (6.6), the concentration of added chili pepper powder needed to be increased 4×- to 5.5×-fold (1.6% for beef burger patties; 2.2% for

TABLE 3 Perceived intensities of all sensory attributes (Rate-All-That-Apply [RATA], $n = 66$) of three food matrices

	Oral burn sensation				
Attribute	**Barely detectable**	**Low**	**Medium**	**High**	**p-Value**
(a) Beef burger patty					
Beef flavor	**7.7 ± 1.3^{a}**	**7.5 ± 1.3^{a}**	**7.0 ± 1.6^{b}**	**7.0 ± 1.5^{b}**	**0.006**
Saltiness	5.2 ± 2.0^{a}	5.2 ± 1.9^{a}	4.9 ± 2.0^{a}	4.7 ± 2.1^{a}	0.213
Burn	**0.5 ± 0.8^{a}**	**3.1 ± 1.9^{b}**	**4.7 ± 2.0^{c}**	**6.3 ± 1.8^{d}**	**<0.001**
Hardness	3.2 ± 1.9^{a}	3.4 ± 1.7^{a}	3.2 ± 1.6^{a}	3.4 ± 1.7^{a}	0.534
Chewiness	5.5 ± 2.1^{a}	5.3 ± 1.8^{a}	5.2 ± 1.8^{a}	5.0 ± 1.9^{a}	0.692
Juiciness	5.0 ± 2.0^{a}	4.8 ± 1.8^{a}	4.7 ± 1.8^{a}	4.3 ± 1.8^{a}	0.652
Graininess	4.2 ± 2.3^{a}	4.0 ± 2.2^{a}	3.8 ± 2.0^{a}	3.9 ± 2.0^{a}	0.961
Fattiness	4.5 ± 2.0^{a}	4.5 ± 1.9^{a}	4.4 ± 1.9^{a}	4.2 ± 2.0^{a}	0.792
Overall flavor	6.0 ± 1.9^{a}	6.3 ± 1.8^{a}	6.2 ± 1.7^{a}	6.4 ± 1.8^{a}	0.579
(b) Curried rice					
Curry flavor	4.9 ± 2.4^{a}	5.1 ± 2.2^{a}	5.0 ± 2.2^{a}	5.2 ± 2.3^{a}	0.805
Rice flavor	6.3 ± 2.0^{a}	6.1 ± 2.0^{a}	5.7 ± 1.9^{a}	5.8 ± 2.0^{a}	0.355
Saltiness	2.5 ± 1.8^{a}	2.4 ± 1.8^{a}	2.7 ± 1.8^{a}	2.7 ± 1.7^{a}	0.713
Sweetness	2.2 ± 1.7^{a}	2.4 ± 1.5^{a}	2.3 ± 1.8^{a}	2.3 ± 1.8^{a}	0.895
Burn	**0.6 ± 1.0^{a}**	**2.0 ± 1.7^{b}**	**4.0 ± 2.0^{c}**	**6.6 ± 2.1^{c}**	**<0.001**
Hardness	2.8 ± 1.7^{a}	2.9 ± 1.8^{a}	2.8 ± 1.6^{a}	2.8 ± 1.5^{a}	0.962
Chewiness	3.4 ± 2.0^{a}	3.5 ± 2.0^{a}	3.7 ± 1.9^{a}	3.5 ± 1.8^{a}	0.875
Graininess	4.5 ± 2.6^{a}	4.6 ± 2.6^{a}	4.5 ± 2.5^{a}	4.6 ± 2.5^{a}	0.990
Dryness	4.6 ± 2.2^{a}	4.6 ± 2.1^{a}	4.2 ± 1.9^{a}	4.3 ± 2.0^{a}	0.702
Overall flavor	4.5 ± 2.1^{a}	4.8 ± 2.1^{a}	5.1 ± 2.0^{a}	5.1 ± 2.1^{a}	0.380
(c) Tomato soup					
Tomato flavor	**7.3 ± 1.4^{a}**	**7.0 ± 1.4^{ab}**	**6.5 ± 1.6^{b}**	**6.3 ± 1.8^{b}**	**<0.001**
Saltiness	4.6 ± 1.9^{a}	4.4 ± 2.0^{a}	4.2 ± 1.8^{a}	3.8 ± 2.1^{a}	0.108
Sweetness	**4.9 ± 2.0^{a}**	**4.6 ± 2.1^{a}**	**4.0 ± 2.2^{b}**	**3.5 ± 2.2^{b}**	**0.005**
Sourness	**5.0 ± 2.5^{a}**	**4.7 ± 2.3^{a}**	**4.1 ± 2.0^{b}**	**3.7 ± 2.0^{b}**	**<0.001**
Burn	**0.9 ± 1.4^{a}**	**3.6 ± 1.9^{b}**	**6.0 ± 1.8^{c}**	**7.0 ± 1.9^{d}**	**<0.001**
Thickness	4.9 ± 2.0^{a}	4.6 ± 1.9^{a}	4.5 ± 2.0^{a}	4.5 ± 1.9^{a}	0.487
Creaminess	5.8 ± 1.9^{a}	5.5 ± 2.0^{a}	5.3 ± 2.0^{a}	5.0 ± 2.1^{a}	0.103
Overall flavor	6.1 ± 1.6^{a}	6.2 ± 1.5^{a}	6.5 ± 1.8^{a}	6.8 ± 1.9^{a}	0.253

Note: Mean values are shown with standard deviation. Attributes with significant differences between samples are highlighted in bold. Samples not sharing superscript letters are significantly different ($p < 0.05$).

curried rice) in the two solid food matrices. This demonstrates that the consistency of the food matrix impacts oral burn sensations with beef burger patty and curried rice suppressing oral burn intensity compared to tomato soup. We speculate that the availability and release of capsaicin in tomato soups are higher than in beef burger patties and curried rice. In tomato soup, the chili pepper powder is dissolved, and hence, availability to the trigeminal receptors is high compared to solid food matrices which need to be broken down during mastication to release capsaicin. Kostyra et al. (2010) found that the burning intensity caused by capsaicin was highest in water solution and reduced with the kind of liquid food matrix following the sequence: Intensity $_{\text{(water solution)}}$ > Intensity $_{\text{(starch gruel)}}$ > Intensity $_{\text{(model soup)}}$ > Intensity $_{\text{(model sauce)}}$, suggesting that burn intensity evoked by capsaicin was strongly affected by the kind of liquid matrix and its complexity. Luo et al. (2019) reported that the perceived burn intensity of whey protein emulsion gels containing capsaicinoids was negatively correlated with the degree of breakdown during mastication, possibly because increased gel hardness led to a lower release of capsaicinoid causing lower mouth burn intensity.

Although not significant, the intensity of taste, flavor, and mouthfeel tended to be reduced with increasing oral burn intensity of tomato soups (Figure 1c) as sensory

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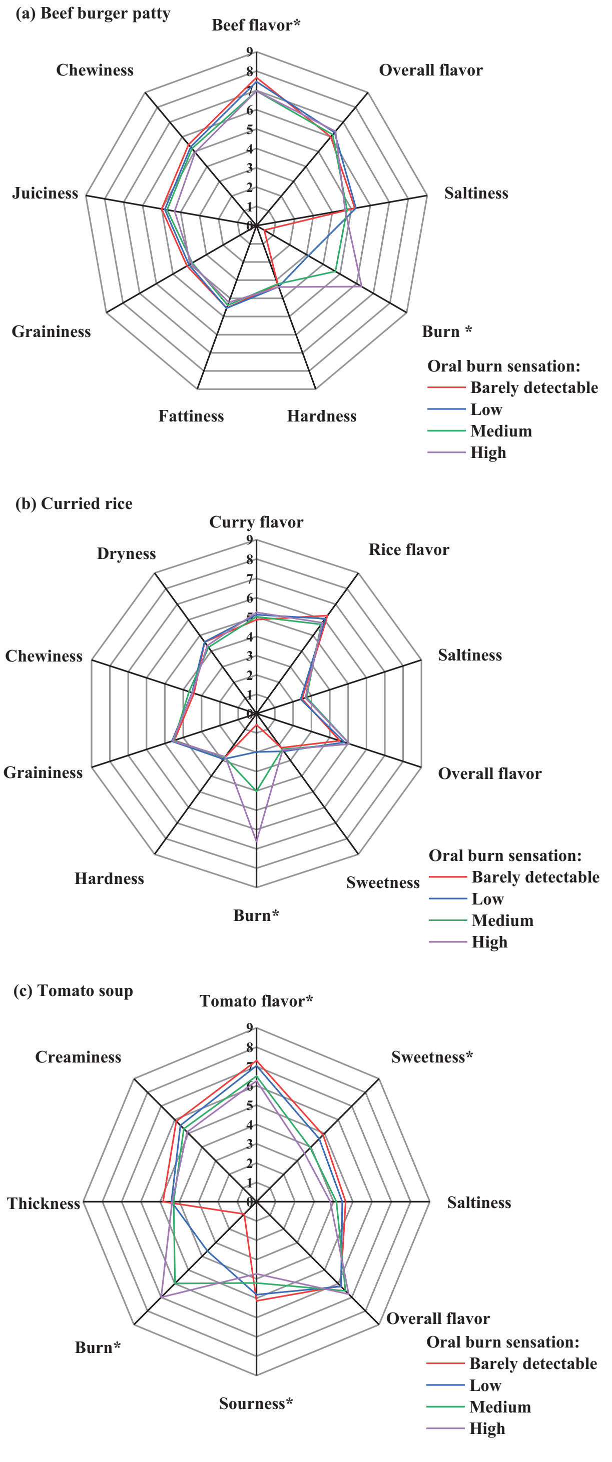

FIGURE 1 Spider web diagrams representing the mean intensity scores for all sensory attributes (Rate-All-That-Apply [RATA], $n = 66$) for the three food matrices: (a) beef burger patty, (b) curried rice, and (c) tomato soup. "*" Indicates attributes with significant differences between samples.

profiles of the tomato soups with high oral burn tended to be closer to the origin of the spider web than the sensory profiles of the tomato soups with barely detectable burn. In contrast, for the two solid foods (Figure 1a,b), the sensory profiles of the beef burger patties and curried rice differing in chili pepper concentration seem to overlap closer compared to the tomato soups differing in chili pepper concentration. The lack of significant differences in taste, flavor, and mouth-feel intensity between tomato soups differing in chili pepper powder concentration might be caused by the limited power of the study. We suggest that reductions in taste, flavor, and mouth-feel intensity caused by oral burn might be more pronounced in tomato soup than beef burger patty and curried rice. Further studies are needed to confirm this. Further studies are also needed to determine whether the findings of this study can be generalized toward other liquid and solid foods. Future studies could also explore the impact of oral burn on the temporal dynamics of taste, flavor, and mouth-feel perception using temporal sensory methodologies. As oral burn is well known to be a dynamic sensation, future studies could investigate the interplay between the temporal dynamics of oral burn caused by various trigeminal stimuli and the temporal dynamics of taste, flavor, and mouth-feel perception.

Our results are in agreement with Reinbach et al. (2007) who showed that meat flavor intensity was negatively correlated with burn intensity for pork patties. Possible mechanisms have been proposed to explain the observed decrease in flavor or taste intensity. Clark and Lawless (1994) suggested a potential attentional effect or "halo effect," that is, chemical irritant stimulation or burn sensations can draw attention away from the taste, smell, and mouth-feel perception when irritancy is sufficiently high. In other words, participants' ability to perceive tastants, odorants, and mouthfeel might have been reduced due to the dominant burn sensation that attracted the attention of consumers and determined overall judgments. Another explanation has been proposed by Lawless et al. (1985) who suggested that reduced taste or flavor intensity may result from the competition among sensory inputs in the central nervous system because the number of receptors and nerve fibers is limited, which might cause an increase of neural noise in the signal and thus possibly a neural inhibition. In this way, increased neural noise with increasing capsaicin concentration might cause a decline in sensory perception.

3.3 | Variability in taste, flavor, and mouth-feel intensity between infrequent and frequent consumers of chili peppers and spicy foods

Based on the questionnaire developed by Lawless et al. (1985), participants were classified as infrequent and frequent chili pepper consumers using a median split. For the three food matrices, the intensity scores of sensory attributes between infrequent and frequent chili pepper consumers were compared (Table 4). Between intake groups, significant differences in perceived burn

TABLE 4 Perceived intensities of sensory attributes (Rate-All-That-Apply [RATA]) for frequent ($n = 33$) and infrequent ($n = 33$) consumers of chili and spicy foods for three food matrices

Consumer groups	Infrequent consumers (n = 33)				Frequent consumers (n = 33)			
Oral burn sensation	**Barely detectable**	**Low**	**Medium**	**High**	**Barely detectable**	**Low**	**Medium**	**High**
(a) Beef burger								
Beef flavor	$\mathbf{7.1 \pm 1.4^{aA}}$	$\mathbf{6.9 \pm 1.3^{aA}}$	$\mathbf{6.6 \pm 1.6^{aA}}$	$\mathbf{6.6 \pm 1.5^{aA}}$	$\mathbf{8.1 \pm 0.9^{aB}}$	$\mathbf{7.9 \pm 1.0^{abB}}$	$\mathbf{7.3 \pm 1.5^{bB}}$	$\mathbf{7.3 \pm 1.4^{bB}}$
Saltiness	5.2 ± 2.0^{aA}	4.8 ± 1.8^{aA}	4.5 ± 2.0^{aA}	4.5 ± 1.9^{aA}	5.5 ± 2.0^{aA}	5.6 ± 1.9^{aA}	5.1 ± 2.0^{aA}	4.9 ± 2.3^{aA}
Burn	0.5 ± 0.9^{aA}	2.9 ± 1.6^{bA}	4.8 ± 2.1^{cA}	6.4 ± 1.6^{dA}	0.4 ± 0.7^{aA}	3.2 ± 2.3^{bA}	4.7 ± 1.9^{cA}	6.3 ± 1.9^{dA}
Hardness	2.8 ± 1.8^{aA}	3.0 ± 1.6^{aA}	2.7 ± 1.2^{aA}	2.6 ± 1.3^{aA}	3.1 ± 2.0^{aA}	3.7 ± 1.7^{aA}	3.6 ± 1.7^{aA}	4.0 ± 1.9^{aA}
Chewiness	5.1 ± 2.0^{aA}	5.1 ± 1.9^{aA}	4.9 ± 2.0^{aA}	4.6 ± 2.0^{aA}	5.4 ± 2.2^{aA}	5.4 ± 1.8^{aA}	5.4 ± 1.6^{aA}	5.1 ± 1.8^{aA}
Juiciness	4.9 ± 1.9^{aA}	4.7 ± 1.6^{aA}	4.7 ± 1.5^{aA}	4.3 ± 1.7^{aA}	5.2 ± 2.1^{aA}	5.0 ± 2.0^{aA}	4.9 ± 2.1^{aA}	4.3 ± 2.0^{aA}
Graininess	4.2 ± 2.5^{aA}	3.7 ± 2.3^{aA}	3.8 ± 2.1^{aA}	3.7 ± 1.9^{aA}	4.2 ± 2.1^{aA}	4.2 ± 2.1^{aA}	3.8 ± 1.9^{aA}	4.0 ± 2.0^{aA}
Fattiness	4.5 ± 1.9^{aA}	4.7 ± 1.7^{aA}	4.5 ± 1.8^{aA}	4.7 ± 2.0^{aA}	4.5 ± 2.1^{aA}	4.4 ± 2.1^{aA}	4.3 ± 2.1^{aA}	3.8 ± 2.0^{aA}
Overall flavor	5.7 ± 1.9^{aA}	6.1 ± 1.6^{aA}	6.1 ± 1.8^{aA}	6.2 ± 1.6^{aA}	6.2 ± 1.7^{aA}	6.4 ± 1.8^{aA}	6.2 ± 1.7^{aA}	6.5 ± 1.9^{aA}
(b) Curried rice								
Curry flavor	4.8 ± 2.2^{aA}	5.0 ± 2.3^{aA}	4.9 ± 2.3^{aA}	5.2 ± 2.2^{aA}	5.0 ± 2.6^{aA}	5.2 ± 2.0^{aA}	5.1 ± 2.2^{aA}	5.3 ± 2.4^{aA}
Rice flavor	6.4 ± 1.9^{aA}	6.2 ± 1.8^{aA}	5.7 ± 1.7^{aA}	5.9 ± 1.7^{aA}	6.1 ± 2.2^{aA}	5.9 ± 2.3^{aA}	5.7 ± 2.0^{aA}	5.7 ± 2.2^{aA}
Saltiness	2.6 ± 2.0^{aA}	2.6 ± 1.9^{aA}	2.8 ± 1.6^{aA}	2.8 ± 1.7^{aA}	2.4 ± 1.6^{aA}	2.3 ± 1.7^{aA}	2.7 ± 2.1^{aA}	2.6 ± 1.8^{aA}
Sweetness	2.3 ± 1.6^{aA}	2.4 ± 1.3^{aA}	2.3 ± 1.7^{aA}	2.2 ± 1.5^{aA}	2.0 ± 1.9^{aA}	2.4 ± 1.7^{aA}	2.2 ± 2.1^{aA}	2.4 ± 2.0^{aA}
Burn	$\mathbf{0.8 \pm 1.3^{aA}}$	$\mathbf{2.1 \pm 1.7^{bA}}$	$\mathbf{3.8 \pm 1.9^{cA}}$	$\mathbf{6.9 \pm 2.1^{dA}}$	$\mathbf{0.4 \pm 0.6^{aA}}$	$\mathbf{1.9 \pm 1.7^{bA}}$	$\mathbf{4.2 \pm 2.1^{cA}}$	$\mathbf{6.1 \pm 2.1^{cB}}$
Hardness	2.4 ± 1.4^{aA}	2.5 ± 1.5^{aA}	2.6 ± 1.5^{aA}	2.5 ± 1.5^{aA}	3.2 ± 2.0^{aA}	3.3 ± 2.0^{aA}	3.0 ± 1.7^{aA}	3.0 ± 1.5^{aA}
Chewiness	3.2 ± 2.0^{aA}	3.2 ± 2.0^{aA}	3.4 ± 1.8^{aA}	3.4 ± 1.9^{aA}	3.6 ± 2.0^{aA}	3.8 ± 2.0^{aA}	3.9 ± 1.9^{aA}	3.6 ± 1.8^{aA}
Graininess	3.9 ± 2.7^{aA}	4.2 ± 2.6^{aA}	4.3 ± 2.4^{aA}	4.3 ± 2.4^{aA}	5.0 ± 2.5^{aA}	5.0 ± 2.7^{aA}	4.8 ± 2.5^{aA}	4.8 ± 2.5^{aA}
Dryness	4.4 ± 2.0^{aA}	4.3 ± 2.0^{aA}	4.2 ± 1.9^{aA}	4.5 ± 2.0^{aA}	4.8 ± 2.3^{aA}	4.9 ± 2.1^{aA}	4.3 ± 2.0^{aA}	4.2 ± 1.9^{aA}
Overall flavor	4.5 ± 1.9^{aA}	4.7 ± 1.8^{aA}	4.9 ± 2.0^{aA}	5.2 ± 2.0^{aA}	4.6 ± 2.3^{aA}	4.9 ± 2.4^{aA}	5.2 ± 2.0^{aA}	5.0 ± 2.1^{aA}
(c) Tomato soup								
Tomato flavor	7.3 ± 1.5^{aA}	6.8 ± 1.5^{abA}	6.3 ± 1.8^{abA}	5.9 ± 1.8^{bA}	7.3 ± 1.2^{aA}	7.2 ± 1.4^{aA}	6.6 ± 1.5^{aA}	6.6 ± 1.7^{aA}
Saltiness	4.5 ± 2.0^{aA}	4.4 ± 1.9^{aA}	4.0 ± 1.7^{abA}	3.5 ± 2.1^{bA}	4.6 ± 1.8^{aA}	4.3 ± 2.0^{aA}	4.3 ± 1.7^{aA}	3.9 ± 2.0^{aA}
Sweetness	4.8 ± 1.8^{aA}	4.4 ± 1.9^{abA}	3.8 ± 2.0^{abA}	3.4 ± 1.9^{bA}	4.9 ± 2.2^{aA}	4.7 ± 2.3^{aA}	4.1 ± 2.2^{aA}	3.8 ± 2.4^{bA}
Sourness	4.7 ± 3.7^{aA}	4.7 ± 1.9^{aA}	3.4 ± 2.0^{aA}	3.2 ± 1.8^{aA}	5.3 ± 2.3^{aA}	4.7 ± 2.3^{aA}	4.6 ± 1.8^{aA}	4.1 ± 2.0^{aA}
Burn	$\mathbf{1.2 \pm 1.3^{aA}}$	$\mathbf{4.1 \pm 1.9^{bA}}$	$\mathbf{6.0 \pm 1.9^{cA}}$	$\mathbf{7.4 \pm 1.9^{cA}}$	$\mathbf{0.7 \pm 1.5^{aA}}$	$\mathbf{3.2 \pm 1.8^{aB}}$	$\mathbf{5.9 \pm 1.8^{cA}}$	$\mathbf{6.6 \pm 2.0^{cB}}$
Thickness	4.8 ± 1.8^{aA}	4.6 ± 1.8^{aA}	4.5 ± 1.7^{aA}	4.4 ± 1.7^{aA}	4.9 ± 2.1^{aA}	4.5 ± 2.0^{aA}	4.4 ± 2.1^{aA}	4.6 ± 2.0
Creaminess	5.8 ± 1.7^{aA}	5.6 ± 1.6^{aA}	5.2 ± 1.7^{aA}	5.0 ± 1.9^{aA}	5.9 ± 2.1^{aA}	5.4 ± 2.2^{aA}	5.3 ± 2.2^{aA}	4.9 ± 2.2^{aA}
Overall flavor	6.0 ± 1.7^{aA}	6.1 ± 1.7^{aA}	6.4 ± 1.9^{aA}	6.7 ± 2.1^{aA}	6.2 ± 1.5^{aA}	6.3 ± 1.6^{aA}	6.5 ± 1.8^{aA}	6.9 ± 1.7^{aA}

Note: Mean values are shown with standard deviation. Lowercase superscript letters denote comparisons between samples across oral burn levels (samples not sharing lowercase letters are significantly different ($p < 0.05$)). Uppercase superscript letters denote comparisons between infrequent and frequent consumers (samples not sharing uppercase letters differ significantly between frequent and infrequent consumers ($p < 0.05$)). Attributes showing significant differences between frequent and infrequent consumers are highlighted in bold.

intensities (particularly at high burn sensation) were found for curried rice ($p = 0.03$) and tomato soup ($p = 0.02$), showing frequent consumers reported significantly lower burn intensity compared to infrequent consumers. These results were in-line with previous studies indicating that infrequent chili pepper consumers were more sensitive to capsaicin or chili compared to frequent consumers (Lawless et al., 1985; Lyu et al., 2021; Nolden & Hayes, 2017). However, no significant differences were observed in beef burger patties ($p = 0.12$). Although frequent and infrequent consumers differed regarding their perception of oral burn intensity, these differences did not affect the perception of any taste, flavor, and mouth-feel attribute. For curried rice and tomato soup, no significant differences were observed between frequent and infrequent chili pepper consumers for any taste, flavor, and mouth-feel attribute. Although intake groups perceived the burn intensity differently, these differences did not lead to differences in the perception of other sensory modalities.

For beef burger patties, results were overall similar with the exception that beef flavor differed between intake groups with frequent consumers perceiving the beef flavor significantly ($p < 0.05$) more intensive than infrequent consumers. Notably, our results conflict with a previous study that indicated eaters of chili perceived meat flavor as less intensive compared to non-eaters (Reinbach et al., 2007). In that study, $n = 8$ assessors were recruited after undergoing three training sessions, and the time-intensity method was used to record the intensity of chili burn and meat flavor during pork patties consumption. Reinbach et al. (2007) observed that non-eaters of chili ($n = 6$) rated the perceived meat flavor significantly higher than eaters of chili ($n = 2$), speculating chronic desensitization by capsaicin may produce chronic decrements in taste or flavor intensity which could explain why eaters of chili experience meat flavor less intense. The current study used more participants ($n = 33$ per group), so we do not believe that our discrepant results are due to a lack of statistical power in the present study. The observed discrepancies between the studies were possibly related to the levels of chili powder/capsaicin used and procedural variation of sensory evaluation. Further research is required to better understand the underlying reasons.

4 | LIMITATIONS

The study has some potential limitations that should be acknowledged. First, this study used 66 participants, which were segmented into infrequent ($n = 33$) and frequent ($n = 33$) chili pepper consumers. Even though the study was powered sufficiently to observe significant effects of the addition of chili pepper powder on oral burn intensity and significant effects of oral burn on beef flavor intensity of beef burger patties and tomato flavor, sweetness, and sourness of tomato soups, our study might have been not sufficiently powered to detect small differences in taste, flavor, and mouth-feel intensity as significant and to observe significant differences in sensory perception between infrequent and frequent chili consumers. Future studies, including more participants, are recommended to validate the findings of the current study. Second, it should be acknowledged as limitation that the study did not include samples without added chili pepper powder. Therefore, although the burn intensity of the lowest concentration of added chili pepper powder was barely detectable, it might have influenced the perception of taste, flavor, and mouthfeel in comparison to samples without added chili pepper powder. At the lowest concentrations of added chili pepper powder (barely detectable burn), burn intensity rating ranged from 0.5 to 0.9 on a 9-box RATA scale which is relatively close to 0. However, it remains unknown whether similar rating between 0.5 and 1.0 would have been obtained in foods without chili pepper powder. Third, in this study, comparable intensities of perceived burn across the different food matrices were chosen, rather than using the same chili powder concentration across the food matrices. Using the same concentration may have facilitated a direct head-to-head comparison at equivalent concentrations but would have led to dramatically different perceived intensities, as chili pepper powder is much more active in tomato soups compared to beef burger patties or curried rice. Although it is acknowledged that it may have been reasonable to use the same chili pepper concentrations in all three food matrices, a choice was made not to do this as this comparison would have lacked ecological validity and was unlikely to reflect how chili powder is used by consumers in a real-life setting (i.e., adding unrealistically high concentrations of chili pepper powder to tomato soups that stimulate a very strong burn sensation is not common). Hence, it was chosen to match the perceived burn intensities across the three food matrices.

5 | CONCLUSIONS

This study aimed to determine the effect of oral burn sensations caused by chili powder addition to tomato soup, beef burger patties, and curried rice on taste, flavor, and mouth-feel perception. The addition of chili powder significantly increased oral burn intensity in all three food matrices, whereas perceived burn intensity caused by chili powder was strongly affected by the kind of food matrix. Added chili pepper powder suppressed perceived intensity of beef flavor in beef burger patties and suppressed tomato flavor, sweetness, and sourness intensity in tomato soups but had little impact on mouth-feel perception. Overall, we conclude that the large enhancement of oral burn leads to only small reductions of taste and flavor intensity for tomato soups, and small or no reductions of flavor intensity for beef burger patties and curried rice. Mouth-feel perception of these liquid and solid food matrices was not significantly affected by oral burn. Between infrequent and frequent habitual chili pepper consumers, significant differences in perceived burn intensity were found in all food matrices with frequent consumers reporting lower burn intensity compared to infrequent consumers. Only beef flavor of beef burger patties differed between intake groups with frequent consumers reporting more intensive than infrequent consumers. It is suggested that reduced taste and flavor intensities might be the result of either increased neural noise or attentional effects.

AUTHOR CONTRIBUTIONS

Cong Lyu: Data curation; methodology; formal analysis; investigation; validation; writing – original draft; writing – review; and editing. **Anne Hendriks**: Data curation; methodology; formal analysis; investigation; validation. **Lauren N. Geary**: Data curation; methodology; formal analysis; investigation; validation. **Ciarán G. Forde**: Conceptualization; supervision; writing – review; and editing. **Markus Stieger**: Conceptualization; supervision; writing – original draft; writing – review; and editing.

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CONFLICTS OF INTEREST

The authors declare that we have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

ORCID

Cong Lyu https://orcid.org/0000-0002-3322-6909

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