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Variation in Orosensory Responsiveness to Alcoholic Beverages and Their Constituents—the Role of the Thermal Taste Phenotype

Stephanie Small-Kelly[1] · Gary Pickering[1,2,3,4]

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Abstract

Introduction Orosensory perception strongly influences food and beverage liking and consumption. Differences between individuals in orosensation present an opportunity to conceptualize and commercialize products based on consumer "taste" responsiveness. The main objective of this study was to examine how the thermal taste phenotype associates with orosensory responsiveness to beer and cider, and more generally to examine differences in and relationships between responsiveness to alcohol-relevant stimuli and to beer/cider.

Methods Sixty participants (31 thermal tasters (TTs) and 29 thermal non-tasters (TnTs)) rated the intensity of aqueous solutions of beer- and cider-relevant tastants: iso-α-acid (bitterness), ethanol (irritation, bitterness, sweetness), dextrose (sweetness), and citric acid (sourness) at concentrations typically found in commercial products on generalized labeled magnitude scales (gLMS). Intensity ratings (gLMS) of multiple orosensations elicited by six beer and two cider samples differing in iso-α-acid and ethanol content were also collected.

Results TTs scored the bitterness of ethanol more intensely than did TnTs ($p(t) < 0.05$) and rated the bitterness, sourness, astringency, and overall taste intensity of sampled beers and ciders higher than TnT ($p(F) < 0.05$).

Conclusions Thermal taste status is an important determinant in the perception of beer and cider flavor.

Implications These results may assist product developers in designing beers and ciders targeted to specific consumer segments that differ in orosensory responsiveness, and inform broader understanding of the sources of variation in human perception of alcohol constituents and beverages.

Keywords Thermal taste status · Taste responsiveness · Beer flavor · Cider flavor

Introduction

Flavor is a psychological construct that encompasses three sensory modalities used when assessing food quality; (i) olfaction (colloquially known as "smell"), (ii) the prototypical tastes (sweet, sour, salty, bitter, umami, and oleogustus), and (iii) chemesthetic and somatosensory sensations (e.g. astringency, heat, creaminess). The term "orosensation" has been used to capture the latter two modes (e.g., Duffy et al. 2010; Mitchell et al. 2019). While a range of psychosocial and market factors influence what humans eat—particularly price and availability—flavor is widely acknowledged as a key driver in determining the food and beverages that are consumed and consequently nutritional and diet-related health status (Drewnowski 1997; Duffy 2007; Tepper 2008).

Therefore, an understanding of the individual differences in perception of flavor is important to several stakeholder communities, as greater insight into individual variation may lead to better understanding of more general population

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✉ Gary Pickering
gpickering@brocku.ca

Stephanie Small-Kelly
ks14yz@brocku.ca

[1] Department of Biological Sciences, Brock University, St. Catharines, ON L2S 3A1, Canada

[2] Cool Climate Oenology and Viticulture Institute, Brock University, St. Catharines, ON L2S 3A1, Canada

[3] Department of Psychology, Brock University, St. Catharines, ON L2S 3A1, Canada

[4] National Wine and Grape Industry Centre, Charles Sturt University, Wagga Wagga, NSW, Australia

consumption behaviors. For instance, it may further elucidate the relationship between national obesity epidemics and individual-level habitual dietary behavior. Additionally, understanding these differences can aid in the optimization of flavor and marketing of food products. Such opportunities include informing sensory and consumer panel selection during product development when considering their "representativeness'" of product users, and conceptualizing and exploiting consumer demand by segmenting the market based on orosensory sensitivity (Pickering and Cullen 2010).

Taste Phenotypes

Individuals differ in their perception of oral sensations. This variation is due to many factors including gender (Bartoshuk et al. 1994; Hort et al. 2016), age (Mojet et al. 2001), ethnicity (Williams et al. 2016), and salivary composition and flow rate (Spielman 1990). Arguably the most important factor influencing individual differences in orosensation is genetic variation. Over eight decades ago, the chemist A. L. Fox discovered that some individuals perceive the compound phenylthiocarbamide (PTC) to be bitter while to others it is tasteless (Fox 1932). Responsiveness to PTC and later its chemical relative 6-n-propylthiouracil (PROP) has historically been used as a marker of genetic variability in the perception of oral sensations. Importantly, some literature supports a link between taste phenotypes and diet-related health outcomes or risk factors, including those associated with alcohol use (reviewed in Thibodeau and Pickering 2017). For instance, low PROP responsiveness has been associated with a higher body mass index and adiposity in women (Goldstein et al. 2005), and sweet liking has been linked to increased alcohol consumption in males (Robb and Pickering 2019).

Another more recently reported marker of individual variation in orosensation is thermal taste status (TTS). Thermal tasters (TTs), who constitute 20–50% of the population, experience a phantom taste (e.g., sweet, sour) with thermal stimulation of certain areas of the tongue (Cruz and Green 2000; Green and George 2004; Bajec and Pickering 2008 2010; Qian et al. 2014; Yang et al. 2014). The specific sensations elicited vary with the location of the tongue stimulated (middle, left, right) and temperature regime used (cooling or heating). Thermal non-tasters (TnTs) do not experience any sensations, and individuals not meeting either classification criteria ("uncategorizables") are typically eliminated from thermal taste studies (Thibodeau et al. 2019). To date, the mechanisms underlying thermal taste are largely unknown. However, indication from *Trpm5* knockout mice suggests that TRPM5, a cation channel essential for transduction of sweet, umami, and bitter taste, plays a role in thermal tasting (Talavera et al. 2005). More recently, Hort et al. (2016) suggested that thermal tasting may be a result of cross-wiring between trigeminal and gustatory nerves.

Importantly, thermal tasters tend to experience prototypical tastants and chemesthetic stimuli more intensely than thermal-non tasters, whether applied locally to the oral cavity or taken as whole mouth samples (e.g., Green and George 2004; Bajec and Pickering 2008). There is also some evidence that this enhanced responsiveness may extend to some odorants (Green and George 2004; McDermitt 2008). Extending these findings beyond simple aqueous solutions, Pickering et al. (2016) reported an overall trend of thermal tasters giving higher intensity ratings for the main orosensations elicited by 20 common food and beverage products, including vegetables, milk products, sweet treats, textured foods, and salty snacks. In contrast, Pickering and Klodnicki (2016) reported no differences in intensity ratings between TTs and TnTs for sampled foods in a female cohort.

Alcoholic Beverages

In addition to their role in habitual diet-related disease risk and health outcomes, alcoholic beverages represent sensorially complex matrices that allow for the association between orosensory responsiveness and consumer perception and preference to be more fully explored.

Annually, approximately 397 billion liters of beer and cider, 26 billion liters of wine and 23 billion liters of spirit are consumed globally (Canadean 2014). Worldwide, there has been an overall increase in per capita alcohol consumption driven mostly by China and India (World Health Organization 2014). Drinking patterns and preferred beverage style vary between geographical regions and over time. For example, among Canadians, beer is the most consumed alcoholic beverage, while the category consisting of cider and other refreshment beverages is experiencing double digit (10.7%) growth (Statistic Canada 2016). More broadly, interest in micro-beers and ciders, including hopped ciders, has exploded in many western markets recently. Understanding the variation in how these products and their constituents are perceived may elucidate market behavior and assist with identifying new retail offerings in these categories.

Cider and beer are complex beverages containing numerous volatile and non-volatile constituents. In beer, they may be primary (ethanol, bitter compounds from hops, carbon dioxide) or secondary (iso-amyl acetate, ethyl butyrate, non-volatile compounds such as polyphenols, organic acids and sugars) flavor constituents (Clapperton et al. 1976; Parker 2012). The sensory profile of cider is more similar to wine than beer and includes multiple sensory active compounds, including ethanol, sugars, organic acids, polyphenols and a range of aromatic constituents (Lea and Piggott 2003).

The main orosensations elicited by beer and cider are bitterness, sourness, sweetness, astringency and carbonation (Langstaff et al. 1991; Jolicoeur 2013). In beer and cider, sweetness arises from unfermented or "priming"

sugars and sourness from organic acids such as tartaric, malic, and citric acid. Bitterness is predominantly imparted by iso-α-acid from hop addition in beer and some cider styles, and ethanol in both beer and cider, while astringency is elicited by polyphenols from the malt (Bamforth 2009).

The oral sensations elicited by beer and cider depend on the concentration of the individual components, which are modified during the production process to give a specific beer or cider style. Historically, scientists have used psychophysical techniques to quantitatively investigate the relationship between sensory stimuli and human perception. One relevant example is the study of Nolden and Hayes (2015) with aqueous solutions of ethanol, the principal ingredient in all alcoholic beverages. Bitterness was reported as the dominant oral sensation at 4%, 8%, and 16% *v*/*v* ethanol and burning/tingling at 32% and 48% *v*/*v* (Nolden and Hayes 2015), showing that the orosensations elicited by ethanol are dependent on concentration. Another sensorially important compound found in beer and more recently incorporated into some cider styles is iso-α-acid. The duration of iso-α-acid bitterness has been shown to increase with repeated ingestion of beer, while bitterness intensity remains constant (Guinard et al. 1986). These individual components of beer and cider contribute to their overall flavor and likely play a critical role in liking and consumption of these beverages.

A limited number of studies have examined the relationship between TTS and perception of alcoholic beverages. Pickering et al. (2010b) reported that TTs rated the sweetness, sourness, bitterness, astringency, and overall taste intensity elicited by white and red wine higher than TnTs. Pickering et al. (2010a) investigated the relationship between TTS and the flavor intensity elicited by seven beer styles (wheat beer, brown ale, pale ale, low-alcohol lager, standard lager, high-alcohol lager, and stout). A strong trend was observed of TTs scoring the dominant oral sensations and overall flavor intensity higher than thermal non-tasters, with these differences statistically significant in many instances. This study however had several limitations. Firstly, the sample size was small ($n = 40$), under-powering the examination of a TTS effect. Astringency was not assessed, despite its acknowledged role as an important sensation elicited by beer (Meilgaard et al. 1979; Langstaff et al. 1991). Finally, the study did not examine whether differential sensitivity to specific beer constituents accounted for the differences in orosensory responsiveness observed for the sampled beers. Additionally, to our knowledge, the association of taste phenotypes, or orosensory responsiveness more generally, with perception of and preference for cider has not been reported in the literature. These considerations inform the current study.

The Current Study

The main objective is to determine if TTS associates with intensity ratings of oral sensations elicited by beer- and cider-relevant tastants and sampled beer and cider. We also wish to determine the association between responsiveness to individual beer- and cider-relevant tastants and responsiveness to sampled beer and cider. We have three main corresponding hypotheses:

H_1: TTs will rate the intensities of oral sensations elicited by beer- and cider-relevant tastants higher than TnTs.
H_2: TTs will have heightened taste responsiveness to sensations elicited by sampled beer and cider.
H_3: Orosensory responsiveness to beer- and cider-relevant tastants will positively associate with that of sampled beer and cider.

Materials and Methods

Participants

One hundred sixty-four participants were recruited from Brock University and the surrounding communities through flyers and personal communication and included student, staff, and faculty members. Participants were only eligible if they were 19 years or older and were healthy, that is, did not have any conditions or illnesses (e.g., allergies to the stimuli being tested) that prevented them from tasting normally. Both drinkers and non-drinkers who did not avoid alcohol for solely moral or religious reasons were encouraged to participate. Participants consisted of 109 females, 51 males, and 4 persons who did not report their sex, with a mean age of 23.2 years ± 5.9 SD. 61.9% of participants reported White as their ethnicity, 11.9% Chinese and 26.2% were from other ethnic groups. Incentive for participation was offered in the form of entry into a monetary/gift card draw or alternatively, participation credit was given towards specific business and psychology courses. Prior to the commencement of the study, informed consent was obtained from all participants and all procedures were cleared by the Brock University Research and Ethics Board (REB 15–176).

All training and evaluation took place in the controlled Sensory Evaluation Laboratory at Brock University, with data collected over three sessions. Session 1 involved all participants and lasted for approx. 120 min. It consisted of filling out background information questionnaires/surveys, training on the prototypical tastes and chemesthetic sensations, familiarizing the scale, and determining thermal taster status. If thermal taster status could be clearly established, participants where invited back for subsequent sessions. Sessions 2 and

3 lasted approx. 60 min each, during which participants rated the intensity of sensations elicited by aqueous solutions of 4 beer- and cider-relevant tastants (Session 2) and 8 beer and cider samples (Session 3).

Scale Acclimation

Two intensity scales, the generalized visual analogue scale (gVAS) and the generalized labeled magnitude scale (gLMS) were used for psychophysical data collection. The gVAS is a vertical scale anchored at the bottom (0 mm) with "NS-No sensation" and with "SE-strongest sensation of any kind experienced" at the top (100 mm). Three unlabeled equidistant line anchors at 25 mm, 50 mm and 75 mm respectively break up the line into quadrants. The gLMS is a vertical quasi-logarithmic scale anchored at the base (0 mm) with "No sensation", "Barely Detectable" (1.4 mm), "Weak" (6.1 mm), "Moderate" (17.2 mm), "Strong" (35.4 mm), "Very Strong" (53.3 mm) and the top "Strongest Imaginable" (100 mm). Participants were familiarized with the appropriate scales to ensure correct usage using the approach of Bajec and Pickering (2008) by rating 5 remembered sensations "brightness of the sun when staring directly at it", "sweetness of cotton candy", burning sensation from eating a whole hot pepper", "pain from biting your tongue", and "touch sensation of a pill on your tongue".

Following training, the gVAS was used to rate sensation intensity of basic taste solutions, whereas the gLMS was used to collect responses to thermal taste elicitation and to score sensations elicited by the beer- and cider-relevant tastants and the beer and cider samples.

Prototypical Taste Training

Aqueous solutions of tastants were presented to participants to assist with identification of sensations elicited during the thermal taste determination procedure and to give additional practice using the gVAS. All solutions were prepared volumetrically using pure water (Millipore RiOs 16 Reverse Osmosis System, MA, USA) stored in the dark at 2–4° C and brought to room temperature 2 hours prior to testing. Solutions were kept for 7 days except for quinine hydrochloride (discarded after 3 days), aluminum sulphate, and cupric sulphate (both discarded after 3 h).

Labeled 20 mL aqueous solutions representing sweet (250 mM sucrose—Ultra Pure, Bioshop, ON, Canada), sour (3.25 mM citric acid anhydrous, Fisher Scientific, NJ, USA), bitter (0.0275 mM quinine monohydrochloride dihydrate, SAFC Supply Solutions, MO, USA), salty (180 mM sodium chloride, ACP Chemicals Inc., QC, Canada), umami (125 mM L-glutamic acid monosodium hydrate, Sigma-Aldrich, MO, USA), metallic (1.00 mM cupric sulphate pentahydrate, BioShop, ON, Canada), and astringent (0.88 mM aluminum sulphate, Sigma-Aldrich, MO, USA) were presented in plastic SOLO® cups. Participants were asked to take the entire sample in their mouth swish for 5 s and expectorate. Following a 10 s wait, participants rated the maximum intensity of the sensation elicited on individual gVAS scales. A minimum 1 min inter-stimulus break was enforced between each sample, during which participants were asked to thoroughly rinse with filtered water (Brita®, ON, Canada) and unsalted soda crackers (no name®, ON, Canada) were available ad libitum. After this exercise, a short break was taken during which participants completed a questionnaire. Next, participants repeated the above procedure using blind-coded randomized samples and were instructed to identify the orosensations (sweet, salty, sour, bitter, umami, metallic, or astringent) in addition to rating the maximum intensity of the elicited sensation. If participants were unable to identify a blind coded sample correctly they were given the named solution to review, followed by another set of blind coded samples to identify.

Thermal Taster Status Determination

Thermal taster status was determined according to the method of Bajec and Pickering (2008). Briefly, a 64 mm^2 computer-controlled Peltier device with a thermocouple feedback attached to a toothbrush-sized water-circulated heat sink (thermode) was applied to the participant's tongue by the researcher. The procedure had two different cycles; a warming cycle followed by a cooling cycle. Participants rated any sensations elicited using six single sheets with six separate gLMS scales labeled "heat" or "cold" (depending on whether the cooling or heating cycle was being assessed), "sweet", "salty", "sour", "bitter", "umami", "metallic", and "other". Warming trials always preceded cooling trials at each location to avoid adaptation from the intense cold stimulation (Green and George 2004). For thermal taster status categorization, thermal tasters (TTs) were defined as those that reported the same taste sensation, rated above weak, at the same location, and temperature regime in both replicates. Thermal non-tasters (TnTs) were defined as those who did not perceive any taste sensation in any trial (Green and George 2004; Bajec and Pickering 2008; Bajec et al. 2012).

Preparation of Beer- and Cider-Relevant Tastants

Aqueous solutions of four components typically found in commercial beers and ciders ("beer- and cider-relevant tastants") were prepared in pure water (Millipore RiOs 16 Reverse Osmosis System, MA, USA), stored in the dark at 2–4 °C and brought to room temperature 2 hours prior to testing. Dextrose (Canadian Homebrew Supplies Corn sugar, Brampton, ON, Canada), citric acid (Fisher Scientific, NJ, USA), iso-α-acid (Kalsec Isolone® Isomerized Hop Extract,

Table 1 Concentration of beer- and cider-relevant tastants and oral sensations assessed

Component	Oral sensations assessed	Concentration	Units
Dextrose	Sweetness	7, 40, 80	g/L
Citric acid	Sourness	56, 230, 550	mg/L
iso-α-acid	Bitterness	10, 20, 50	mg/L
Ethanol	Sweetness, bitterness, Irritation/burning	2, 4, 5, 7, 10	% *v/v*

Kalamazoo, MI, USA), and ethanol (Storechem Alcohols Ltd. Ethyl Alcohol 95% Kosher, London, ON, Canada) were chosen as these compounds elicit a range of orosensations, including the main sensations elicited by beer and cider. After extensive bench testing, the final concentrations were selected to cover the array of commercial beer and cider styles sold in the Liquor Control Board of Ontario (LCBO). The concentration series and the corresponding oral sensations assessed are given in Table 1.

Evaluation of Beer- and Cider-Relevant Tastants

20 mL samples of the tastants were served at room temperature in plastic cups (SOLO cup company IL, USA), fitted with clear plastic lids (Dart container corporation MI, USA) and coded with random three-digit codes. Samples were presented randomly using the Williams Latin Square Design (Macfie et al. 1989). Prior to taste evaluation participants were verbally oriented to the Compusense®5 (Compusense, Guelph, ON, Canada) computer program that was used to collect the intensity ratings.

Participants were instructed to take the whole content of the cups into their mouth, swish each solution on their palate for 5 s, expectorate, wait approximately 10 s and then rate the maximum intensity of the elicited oral sensations being assessed (see Table 1) on a gLMS by clicking the mouse. A minimum inter-stimulus break of 1 min was enforced between each sample within a concentration series and 2 min between the different tastant series to reduce sensory fatigue and carryover effects. Additionally, participants were instructed to rinse thoroughly with filtered water (Brita® ON, Canada) before and after tasting each sample and unsalted soda crackers (no name® ON, Canada) were available ad libitum.

Preparation of Beer and Cider Samples

A lightly hopped, low alcohol lager beer and an unsweetened non-carbonated cider were provided by a local commercial brewery and winery, respectively and used as the base matrices for the study. They were selected based on availability and their relatively neutral sensory profiles, and their physiochemical properties are given in Table 2.

These base products were modified to produce six beer and two cider samples to represent a range of commercially available styles. The still cider was carbonated using sodastream® PLAY™, and target iso-α-acid and ethanol levels were achieved by the addition of a commercially available food grade solution of isomerized hop extract (30% *w/w* Kalsec®) and kosher ethanol (95% *v/v* Storechem), respectively. The iso-α-acid and ethanol concentration of the beers and ciders are given in Table 3.

Beer samples were prepared from the base beer 2 h in advance of sensory evaluation. After additions were completed, the bottles were covered with Parafilm wrap (Parafilm

Table 2 Physiochemical parameters of base beer, cider, and isomerized hop extract

Sample	Parameter	Value (±standard deviation)	Units	Analysis method
Beer	Ethanol	4.9 ± 0.01	% *v/v*	GC-FID[a]
	pH	3.65		pH meter[b]
	Titratable acidity (TA)	2.14 ± 0.01	g/L	NaOH titration[b]
	Residual sugar (RS)	< 0.07	g/L	Enzyme kit[c]
	iso-α-acid (IAA)	3.41 ± 0.17	mg/L	ASBC beer-23F[d]
Cider	Ethanol	7.4 ± 0.01	% *v/v*	GC-FID[a]
	pH	3.38		pH meter[b]
	Titratable acidity	5.12 ± 0.01	g/L	NaOH titration[b]
	Residual sugar	< 0.07 g/L	g/L	Enzyme kit[c]
Isomerized hop extract	iso-α-acid	941.5 ± 42.10	mg/L	ASBC Beer-23F[d]

[a] Agilent 6890 Series Gas chromatography system with flame ionization detector (FID)

[b] Methods as described by Iland et al. (2000)

[c] D-fructose and D-glucose assay enzyme kit (Megazyme International, Ireland)

[d] American Society of Brewing Chemist (ASBC) Beer—23F

Table 3 Iso-α-acid and ethanol concentration of the beers and ciders

Sample type	iso-α-acid[a] concentration/(mg/L)	Ethanol[b] concentration/(% *v*/*v*)
Beer	3.41	4
Beer	13.41	4
Beer	43.41	4
Beer	3.41	5
Beer	3.41	7
Beer	3.41	10
Cider	0	7
Cider	18.41	7

[a] Kalsec Isolone® Isomerized Hop Extract, Kalamazoo, MI, USA

[b] Storechem Alcohols Ltd. Ethyl Alcohol 95% Kosher, London, ON, Canada

M®, Sigma-Aldrich, MO, USA), gently mixed and immediately transferred to cold storage (2–4 °C) until sensory evaluation.

Beer and Cider Tasting

All beer and cider samples were poured 10 min before evaluation and presented to participants at 6 ± 2 °C as 40 mL samples in black ISO tasting glasses coded with random 3-digit codes. Each glass was covered with a plastic petri dish to reduce loss of carbonation. The samples were presented in a randomized order, and each sample was evaluated monadically and expectorated. Participants were instructed to cleanse their palates with water (Brita, ON, Canada) prior to and after each sample, and unsalted soda crackers (no name®, ON, Canada) were available ad libitum. Prior to taste evaluation participants were verbally oriented to the Compusense® 5 (Compusense, Guelph, ON, Canada) computer program that was used to collect all beer and cider intensity ratings. They were instructed to take the sample in their mouth, swish on their palate for 5 s, expectorate and wait 10 s before rating the maximum intensity of "sweetness", "bitterness", "sourness", "irritation/burning", "carbonation/prickling', "warming", and "overall taste intensity", regardless of when it occurred during the preceding 15 s on individual gLMS (Bajec and Pickering 2008). Each sample was tasted in the presented sequence. After the eight samples (6 beers and 2 ciders) had been assessed, the exercise was repeated after a 10 min break with fresh re-randomized samples to obtain duplicate ratings for each sample. To reduce sensory fatigue and carryover effects, a minimum inter-stimulus break of 2 min was enforced between each sample.

Data Treatment and Analysis

An alpha level of 0.05 was used when interpreting significance for all data analysis performed. All analyses were conducted using XLSTAT Version 2017.19.05.46974 (Addinsoft,

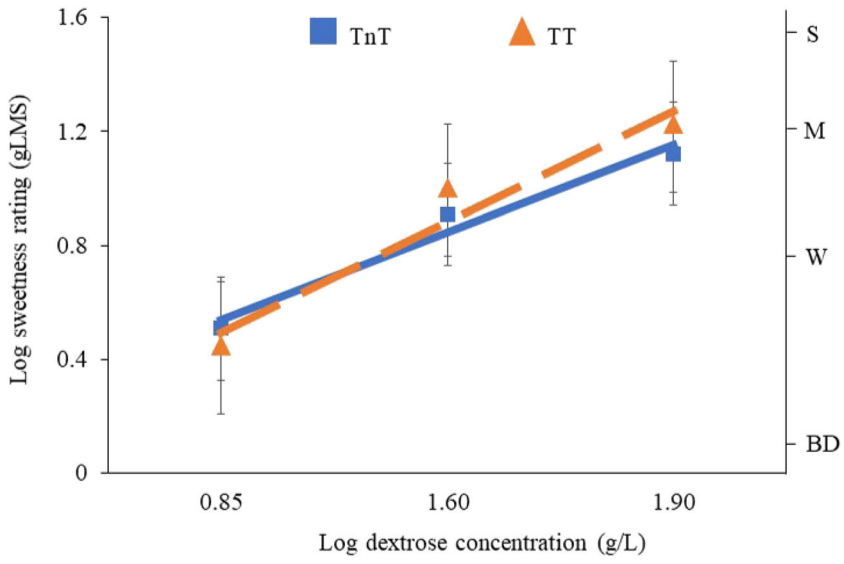

Fig. 1 Dextrose sweetness intensity ± SE mean for thermal tasters (TT) ($n = 31$) and thermal non-tasters (TnT) ($n = 29$). Log concentration represents 7, 8, and 40 g/L dextrose. Secondary scale indicates labels on the gLMS: BD = barely detectable, W = weak, M = moderate, S = strong

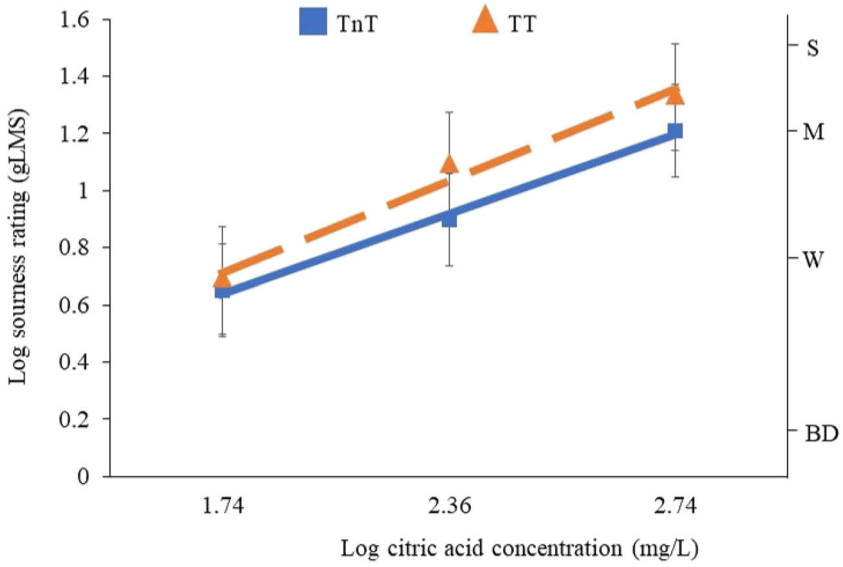

Fig. 2 Citric acid sourness intensity ± SE mean for thermal tasters (TT) ($n = 31$) and thermal non-tasters (TnT) ($n = 29$). Log concentration represents 56, 230 and 550 mg/L. Secondary scale indicates labels on the gLMS: BD = barely detectable, W = weak, M = moderate, S = strong

NY, USA) and Microsoft® Excel® for PC 2016 (Microsoft®, ON, Canada). The intensity rating data for both beer- and cider-relevant tastants as well as sampled beer and cider underwent a $\log_{10}$ transformation to improve normality (Shapiro-Wilks).

A linear regression was performed for each participant for each beer- and cider-relevant tastant, using individual intensity ratings as the dependent variable and beer- and tastant concentration as the independent variable. A coefficient (β) was generated from each linear regression for each participant, and these individual coefficients were pooled for each TTS group and t tests conducted to examine whether β for each sensation: stimulus pairing differed between TTs and TnTs.

Two-way analysis of variance (ANOVA) was used to examine the main effect of TTS and tastant concentration and their interaction on intensity of sensations elicited by the beer- and cider-relevant tastants. Tukey's HSD was used as the mean separation test following significant ANOVA. Two-way ANOVA (TTS and sample) was run to examine the effect of TTS and their interaction on the intensity of oral sensations elicited by the sampled beer and cider. Correlations between sensations elicited by beer- and cider-relevant tastants and sensations elicited by sampled beer and cider were examined using Pearson's r.

Results

Of the 164 participants who took part in session 1, 60 completed all 3 sessions. TTS categorization yielded 31

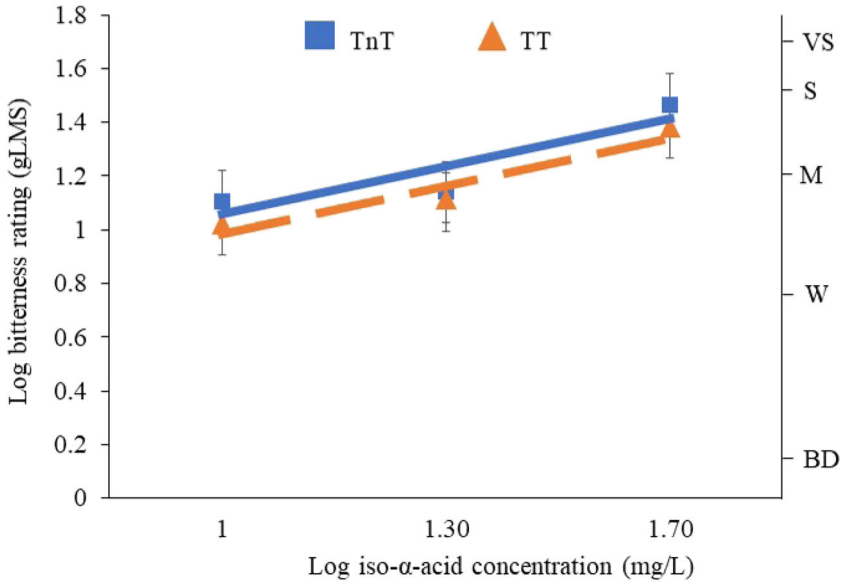

Fig. 3 iso-α- acid bitterness intensity ± SE mean for thermal tasters (TT) ($n = 31$) and thermal non-tasters (TnT) ($n = 29$). Log concentration represents 10, 20, and 50 mg/L. Secondary scale indicates labels on the gLMS: BD—barely detectable, W—weak, M—medium, S—strong, VS—very strong.

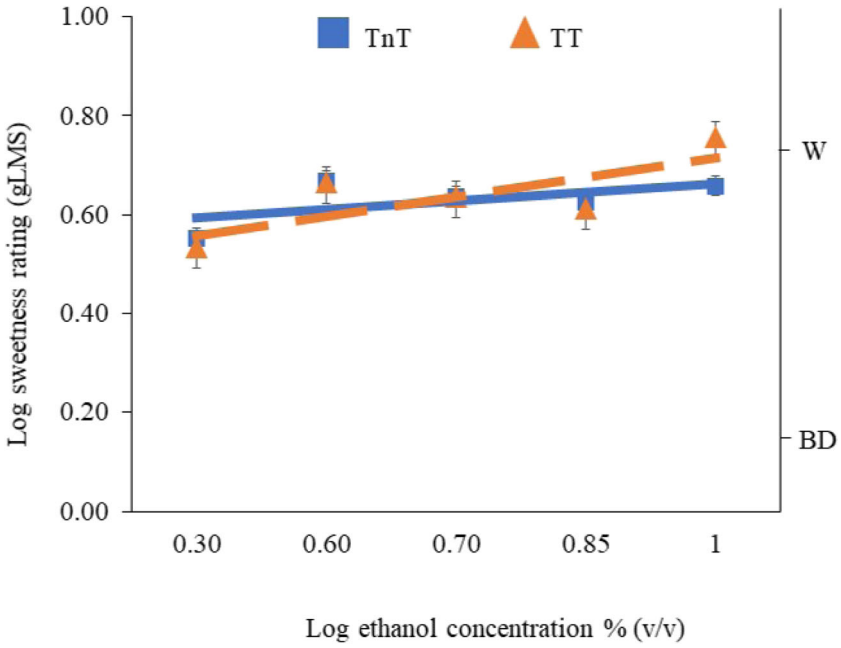

Fig. 4 Ethanol sweetness intensity ± SE mean for thermal tasters (TT) ($n = 31$) and thermal non-tasters (TnT) ($n = 29$). Log concentration represents 2, 4, 5, 7, and 10% *v/v*. Secondary scale indicates labels on the gLMS: BD—barely detectable, W—weak

TTs (21 females, 9 males, and 1 unreported) and 29 TnTs (17 females and 12 males).

Orosensory Responsiveness and Perception of Beer- and Cider-Relevant Tastants

Mean logged intensity ratings for all beer-and cider-relevant tastants increased with concentration, except for ethanol sweetness (see Figs. 1 and 2, Supplementary Material).

t tests conducted on β generated from the slopes of the linear regression of TTs and TnTs (pooled individual results of each group) showed no difference between the phenotypes for dextrose sweetness ($t = 0.446$, $p = 0.657$), citric acid sourness ($t = 0.171$, $p = 0.865$), iso-α-acid bitterness ($t = 0.116$, $p = 0.250$), ethanol sweetness ($t = 0.930$, $p = 0.356$), ethanol bitterness ($t = 1.747$, $p = 0.086$), or ethanol irritation ($t = 1.693$, $p = 0.096$), although the latter two approached significance. The corresponding psychophysical curves are shown in Figs. 1, 2, 3, 4, 5, and 6.

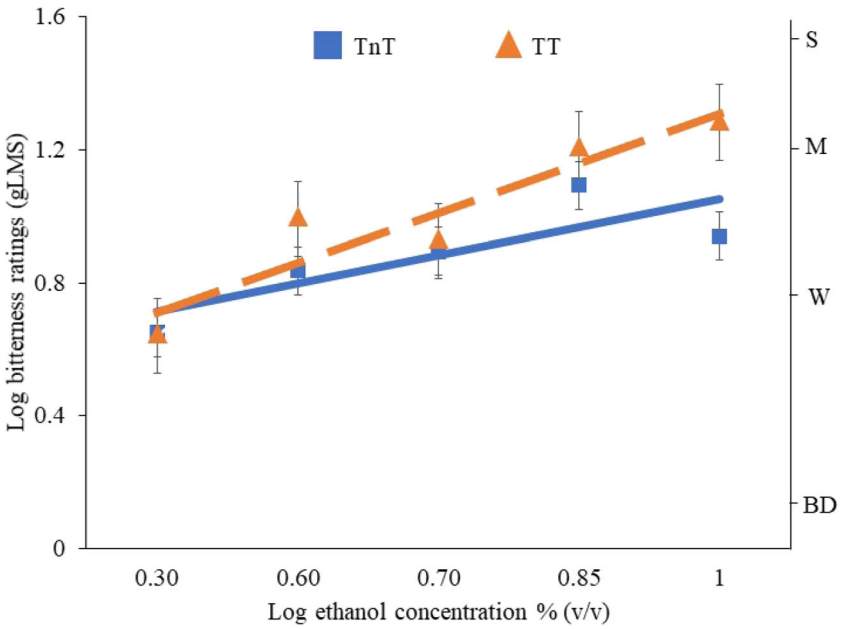

Fig. 5 Ethanol bitterness intensity ± SE mean for thermal tasters (TT) ($n = 31$) and thermal non-tasters (TnT) ($n = 29$). Log concentration represents 2, 4, 5, 7, and 10% *v/v*. Secondary scale indicates labels on the gLMS: BD—barely detectable, W—weak, M—medium, S—strong

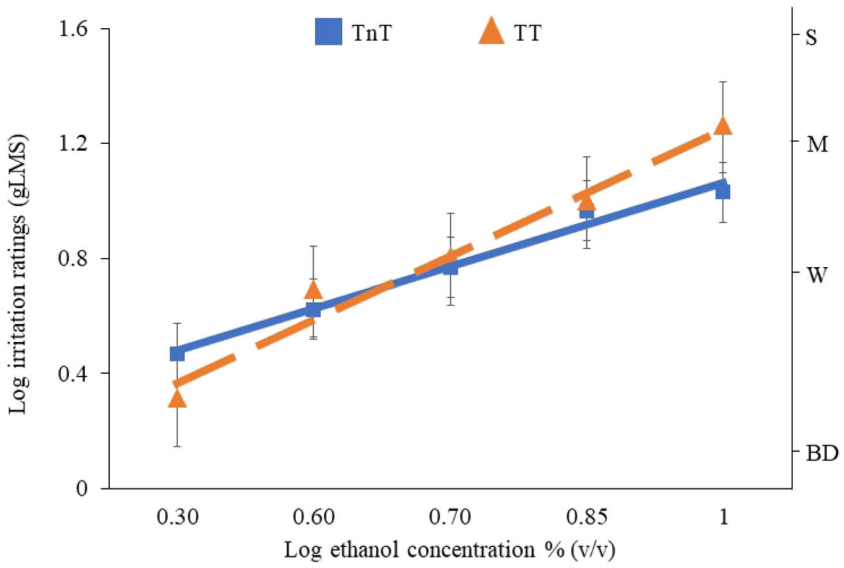

Fig. 6 Ethanol irritation intensity ± SE mean for thermal tasters (TT) ($n = 31$) and thermal non-tasters (TnT) ($n = 29$). Log concentration represents 2, 4, 5, 7, and 10% *v/v*. Secondary scale indicates labels on the gLMS: BD—barely detectable, W—weak, M—medium, S—strong

As shown in Figs. 7 and 8, TTs were more responsive than TnTs to the bitterness of ethanol ($t = 6.209$, $p = 0.013$), while the sourness of citric acid approached significance ($t = 3.864$, $p = 0.051$).

Orosensory Responsiveness and Perception of Sampled Beer and Cider

TTs rated the sourness ($t = 7.738$, $p = 0.006$), bitterness ($t = 12.009$, $p = 0.001$), and overall taste intensity ($t = 13.018$, $p = 0.00$) of sampled beer significantly higher than TnTs (Fig. 9).

TTs rated the sourness ($t = 8.078$, $p = 0.005$), astringency ($t = 5.264$, $p = 0.024$), and overall taste intensity ($t = 10.769$, $p = 0.001$) of sampled cider significantly higher than TnTs (Fig. 10).

Relationship between Orosensory Intensity of Beer- and Cider-Relevant Tastants and Sampled Beer and Cider

Tables 4 and 5 shows the Pearson correlation coefficients (r) for the intensity of sensations elicited by beer- and cider-relevant tastants and sensations elicited by sampled beer and cider. Many significant associations were found, and correlations may be interpreted as high if $|r| > 0.700$, moderate if $0.500 \leq |r| \geq 0.700$ and low if $|r| < 0.300$ (Hinkle et al. 2003; Rumsey 2013).

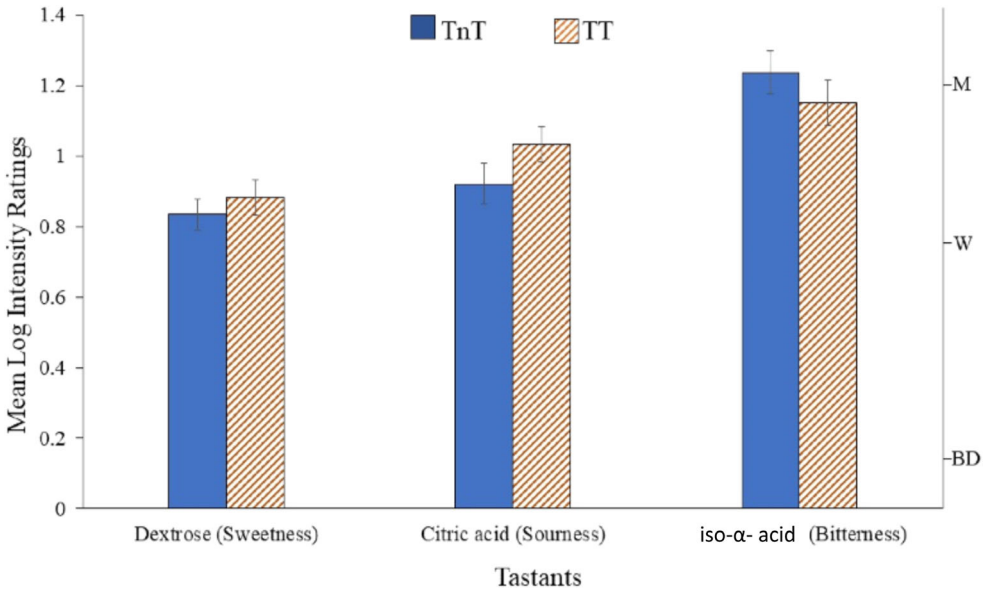

Fig. 7 Thermal taster status (TTS) effect on intensity ratings (± standard error) of beer-relevant tastants. Thermal tasters (TT) ($n = 31$); Thermal non-tasters (TnT) ($n = 29$). BD—Barely detectable, W—weak, M—medium

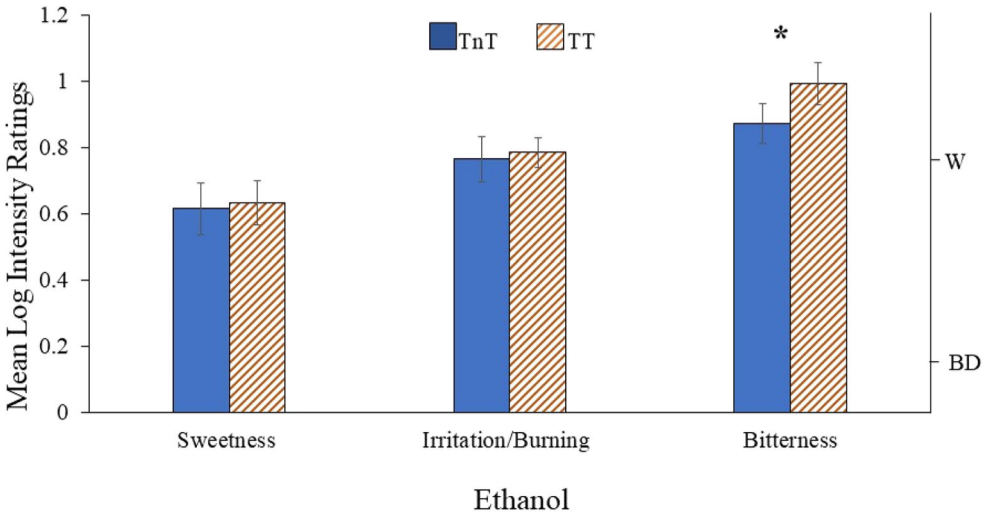

Fig. 8 Thermal taster status (TTS) effects on intensity ratings (± standard error) of beer-relevant tastants (ethanol). Thermal tasters (TT) ($n = 31$); Thermal non-tasters (TnT) ($n = 29$). * significant at $p < 0.05$. BD—Barely detectable, W—weak

Discussion

TTS and Perception of Oral Sensations—Beer- and Cider-Relevant Tastants

Extensive psychophysical studies have been conducted to investigate the relationship between physical stimuli and the sensations they evoke. However, few studies have examined the effect of TTS on the perception of oral sensation and consumption behaviors. This study introduces novelty by including both sampled products and their main orosensory constituents (at varying concentrations) in the same experimental design. Additionally, to our knowledge, this is the first study to investigate TTS effect on intensity ratings of ethanol and dextrose. As the concentration of the beer- and cider-relevant tastants increased, the intensity of the sensations elicited also tended to increase (with the exception of ethanol sweetness), but at varying rates. This is in agreement with prior psychophysical studies investigating chemosensory response to capsaicin, piperine, zingerone, and ethanol across a concentrations series (Green and Hayes 2004; Nolden and Hayes 2015).

We hypothesized that TTs would rate the intensities of oral sensations elicited by beer- and cider-relevant tastants (dextrose, citric acid, iso-α-acid, and ethanol) higher than TnTs. The results trended in the predicted direction, although this greater acuity was not seen for the bitterness of iso-α-acid. These general findings are consistent with differences reported between TTs and TnTs for intensity ratings of simple aqueous solutions, some odorants and chemesthetic stimuli (Green and George 2004; Green et al. 2005; Bajec and Pickering 2008 2010; Yang et al. 2014). Of the four beer- and cider-relevant tastants, TTs rated the bitterness of ethanol significantly higher than TnTs, while the sourness of citric acid approached significance. Interestingly, both citric acid and

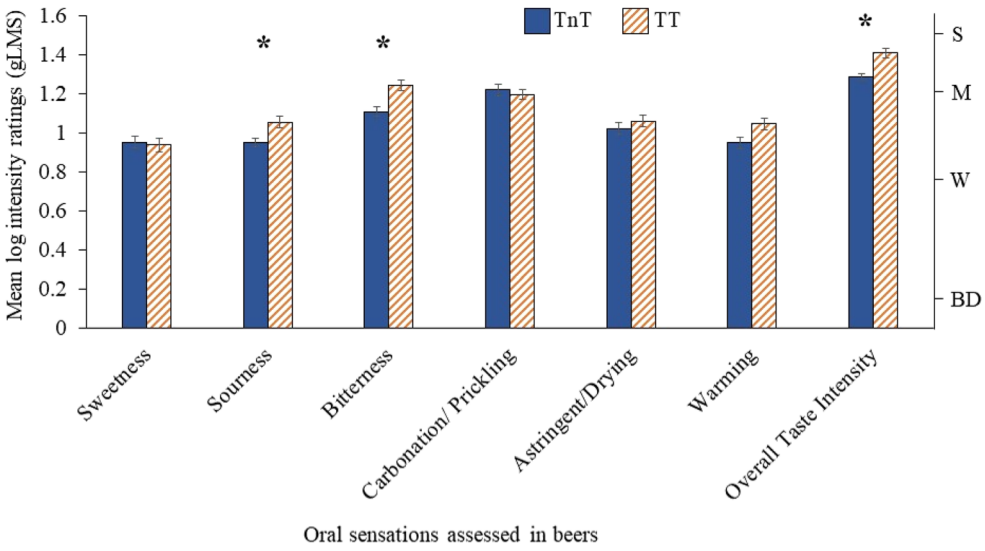

Fig. 9 Thermal taster status (TTS) effects on intensity ratings (± standard error) of beer samples ($n = 6$). Thermal tasters (TT) ($n = 31$); Thermal non-tasters (TnT) ($n = 29$). *denotes significant at $p < 0.05$. BD—Barely detectable, W—weak, M—medium, S—strong

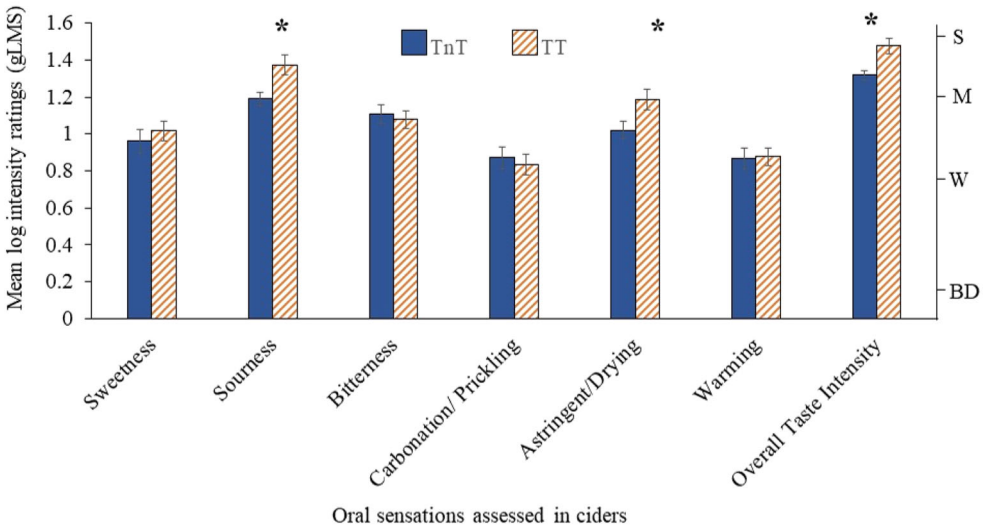

Fig. 10 Thermal taster status (TTS) effects on intensity ratings (± standard error) of cider samples ($n = 2$). Thermal tasters (TT) ($n = 31$); Thermal non-tasters (TnT) ($n = 29$). *significant at $p < 0.05$. BD—Barely detectable, W—weak, M—medium, S—strong

ethanol are trigeminal stimuli (Green 1988; Gilmore and Green 1993; Dessirier et al. 2000; Mattes and DiMeglio 2001), and Hort et al. (2016) have speculated that the trigeminal and gustatory nerves may be intertwined in TTs. It is possible that in our findings, stimulation of trigeminal receptors of TTs by ethanol and citric acid may have enhanced their gustatory response. This result adds to the evidence of a perceptual advantage among TTs with possible implications for food and beverage behavior. For instance, TTs have a lower difference threshold than TnTs for the sourness of white wine (Pickering and Kvas 2016). Thus, TTs may generally be more responsive to the orosensory properties of alcoholic beverages, which in turn, may negatively impact their liking and consequently consumption.

TTS and Perception of Oral Sensations—Beer and Cider

We also hypothesized that TTs would rate the intensity of oral sensations from sampled beer and cider higher than TnTs. TTs rated the bitterness, sourness, and overall taste intensity of beer and the sourness, astringency, and overall taste intensity of cider higher than TnTs.

These results agree with Pickering et al. (2010a), who reported that TTs tended to rate the sourness of Hoegaarden wheat beer, Molson Canadian lager, and Molson Excel low alcohol lager higher than TnTs. Additionally, in the same study TTs rated the bitterness of Molson Canadian beer higher than TnTs. These results also concur with TTS differences in

Table 4 Correlation between intensity of sensations elicited by relevant tastants and sampled beer ($n = 6$), $n = 60$ participants

Variables	Sweetness	Sourness	Bitterness	Carbonation	Astringent	Warming	Overall taste intensity
Sweetness [Dex]	0.106	0.258*	0.211	0.030	0.245	0.134	0.111
Sourness [Citric]	− 0.137	0.233	0.281*	0.364**	0.345**	0.209	0.396**
Bitterness [iso-α-acid]	− 0.138	0.069	0.362**	0.303*	0.243	0.123	0.374**
Sweetness [Eth.]	0.142	0.344**	0.231	− 0.086	0.266*	0.193	− 0.077
Bitterness [Eth.]	0.231	0.388**	0.354**	− 0.020	0.308*	0.295*	0.119
Irritation [Eth.]	− 0.022	0.190	0.335**	0.057	0.347**	0.276*	0.056
Sweetness	*1*	0.492***	0.065	− 0.223	0.207	0.174	− 0.171
Sourness		*1*	0.652***	0.154	0.657***	0.526***	0.335**
Bitterness			*1*	0.429***	0.669***	0.531***	0.672**
Carbonation				*1*	0.426***	0.605***	0.573***
Astringent					*1*	0.648***	0.420***
Warming						*1*	0.379**
Overall taste intensity							**1**

Dex Dextrose, *Eth* Ethanol, *Citric* Citric Acid

Significant associations indicated by *$p < 0.05$; **$p < 0.01$; *** $p < 0.001$

Table 5 Correlation between intensity of sensations elicited by relevant tastants and sampled cider ($n = 2$), ($n = 60$) participants

Variables	Sweetness	Sourness	Bitterness	Carbonation	Astringent	Warming	Overall taste intensity
Sweetness [Dex]	0.092	0.125	0.078	0.031	0.118	0.220	0.051
Sourness [Citric]	0.061	0.074	0.037	0.276*	0.269*	0.237	0.332**
Bitterness [iso-α-acid]	− 0.145	0.100	−0.065	0.237	0.198	0.184	0.205
Sweetness [Eth.]	0.042	0.206	0.047	0.084	0.183	0.221	− 0.149
Bitterness [Eth.]	0.206	0.303**	0.175	0.075	0.234	0.266*	0.052
Irritation [Eth.]	− 0.035	0.152	0.016	0.145	0.280*	0.233	0.002
Sweetness	*1*	0.030	0.060	0.050	0.156	0.084	− 0.053
Sourness		*1*	0.379**	0.136	0.435***	0.275*	0.526***
Bitterness			*1*	0.263	0.474***	0.423***	0.423***
Carbonation				*1*	0.496***	0.508***	0.187
Astringent					*1*	0.470***	0.411
Warming						*1*	0.284**
Overall taste intensity							*1*

Dex Dextrose; *Eth* Ethanol; *Citric* Citric Acid

Significant associations indicated by *$p < 0.05$; **$p < 0.01$, ***$p < 0.001$

the intensity ratings of orosensations elicited by white and red wines (Pickering et al. 2010b). It is interesting to note that the significant findings were for the dominant oral sensations of the beer and cider.

Association Between Tastants and Sampled Beer and Cider

Sensations elicited by the beer- and cider-relevant tastants were generally weakly to moderately associated with sensations elicited by sampled beer and cider. The beer- and cider-relevant tastants are simple aqueous solutions while beer is a complex matrix comprising a wide array of sensory active components (Bamforth 2009). Due to this compositional complexity of beer, the components likely interact with each other chemically and perceptually, leading to suppression or enhancement of some attributes. In aqueous solutions the tastant concentration directly affects which chemosensory property will dominate. The bitterness of an aqueous solution of iso-α-acid is due to the iso-α-acid itself; however, in a complex medium such as beer, ethanol, iso-α-acid and perhaps other bitterants all contribute to enhanced bitterness. Jones et al. (2008) reported enhanced bitterness of model white wine with high levels of ethanol. In contrast, sweetness from unfermented sugars may be suppressed by iso-α-acid in beer resulting in reduced sweetness perception (Clark et al. 2011).

Implications and Further Research

Flavor perception is multi-modal involving aroma, taste, and chemesthesis, with all these modalities working together to influence how we experience our food. How flavor is perceived in a simple aqueous solution may not be indicative of how it will be experienced in an actual product. From our study, we conclude that taste responsiveness to simple aqueous solutions do not map strongly to orosensory responsiveness in more complex media such as beer, in part likely due to flavor interactions. Future research could utilize binary, ternary, or quaternary mixtures to further investigate the nature and extent of mixture suppression and enhancement specifically of alcohol-relevant stimuli.

This research could be enhanced by using temporal methods such as temporal dominance of sensation or temporal check all that apply to assess beer and cider, particularly given the noted role of aftertaste in quality judgements of these products. These alternative methods offer the advantage of assessing several attributes simultaneously over time, unlike single point evaluations such as those employed in this study (Di Monaco et al. 2014).

Given the enhanced acuity of TTs to some of the nominally sensorially aversive constituents of alcohol observed here, it is possible that they may avoid or reduce intake of alcoholic beverages; thus, their phenotype may offer some protection against the misuse and abuse of alcohol. This speculation requires further research; however, some support is found in the results of Thibodeau et al. (2017), whereby reduced alcohol intake was reported among individuals with heightened responsive to sourness and astringency.

Conclusion

The effect of TTS on intensity ratings of oral sensations elicited by beer- and cider-relevant tastants and sampled beer and cider was examined. Additionally, the correlation between sensations elicited by beer- and cider-relevant tastants and

those elicited by sampled beer and cider was determined. TTs rated the bitterness of ethanol and the sourness of citric acid significantly higher than TnTs. TTs perceive sourness, bitterness, astringency, and overall flavor intensity elicited by sampled beer and cider more intensely than TnTs. This supports the view that TTs have a sensory advantage over TnTs in the context of complex food and beverages.

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Compliance with Ethical Standards

Conflict of Interest The authors declare that they have no conflict of interest.

Ethical Approval All procedures followed were in accordance with the ethical standards of the Brock University Research Ethics Board (File # 15–176) and with the Helsinki Declaration of 1975, as revised in 2008 (5).

Informed Consent Informed consent was obtained from all participants involved in the study.

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