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Exploring the Use of Verjuice for Reduced Sodium Pickle Production: Determination of Hedonic and Rejection Thresholds

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ABSTRACT

Food industry has been searching for strategies to reduce sodium in foods. Verjuice, an acidic juice made from thinned grapes, appears to enhance perceived saltiness in pickles. This study aimed to determine the affective thresholds (Consumer Rejection Threshold: CRT, Compromised Acceptance Threshold: CAT, Hedonic Rejection Threshold: HRT) of pickles produced with verjuice and vinegar, in order to assess whether salt concentration can be reduced. Consumers ($n = 103$) tasted eight pairs of samples (four per acidifier), comparing the control (14 g/L salt) with one of the treatments (either 0, 3.5, 7.0 or 10.5 g/L). Results showed that it is possible to reduce more salt by using verjuice as an acidifier compared to vinegar, without impacting preference in relation to the control. CAT values were similar for both acidifiers; however, HRT values for vinegar pickled cucumbers were lower compared to those with verjuice, suggesting that vinegar allowed for a greater salt reduction without sensory rejection. This work used hedonic and rejection thresholds to study whether salt concentration in pickle production can be reduced. This method has wide applicability in the food industry, offering a process to identify when the level of an ingredient exceeds or does not meet consumer expectations. Obtaining data on affective thresholds of pickles preserved with vinegar and verjuice (proposed herein as an acidifier alternative ingredient) is crucial for product development purposes, supporting quality control and guiding formulation development. The use of verjuice may be a first step in product innovation given its health and sustainable credentials. Data from this study show that food producers can reduce salt content in pickles down to ~4 g/L by preserving them with either vinegar or verjuice, without impacting liking compared to levels currently available in the market (14 g/L). This reduction can be implemented in the production of vinegar-based pickles, leading to healthier products without compromising consumer acceptance.

1 | Introduction

Pickling is a preserving technique where vegetables, fruits, or meats are kept under high salt and acid concentration conditions (Wilson et al. 2015). In Brazil, pickles are defined as products prepared with the edible parts of fruits and vegetables, whether or not subjected to a natural fermentation process (ANVISA 2024a). Pickle is a product consumed worldwide, and its market is estimated to grow from U$10 billion in 2023 to U$15 billion in 2032, driven mainly by consumers seeking bold and unique flavors (Market Research Future 2024).

Over a long maturation period in high-salt concentration brines, sodium naturally migrates into vegetable, fruit, and/or meat tissues. This phenomenon raises a public health concern because high sodium intake is associated with millions of deaths worldwide each year due to high blood pressure (Moore et al. 2022; Lorén et al. 2023). Some countries in Latin America have introduced front-of-pack nutrition labeling (FOPNL) on foods, for example, those high in sodium, to alert consumers about their content (Mexico. Secretaría de Economía 2020; Uruguay. Poder Ejecutivo, Consejo de Ministros del Uruguay 2018; Chile. Ministerio de Salud Chile 2015; Peru. Ministerio de Salud Peru 2018; Brasil and Ministério da Saúde 2020; Brasil and Ministério da Saúde, Agência Nacional de Vigilância Sanitária, Diretoria Colegiada 2020). In Brazil, food industries have committed to reducing sodium levels in processed foods in collaboration with the Health Ministry. However, in the biennium 2022–2023, 21.9% of the evaluated food categories failed to meet the reduction targets (ANVISA 2024b). Cucumbers/pickles are not included in the list of foods monitored by the Brazilian government (ANVISA 2024b), which may contribute to the lack of regulatory focus on sodium levels in this product category. This highlights the need for increased efforts to develop effective strategies that achieve sodium reduction in pickles without altering sensory quality.

Previous research has shown that it is possible to reduce sodium levels in foods without causing rejection or compromising their acceptance (Antúnez et al. 2016; Lima Filho et al. 2019; Lobo and Ferreira 2021). Several alternatives have emerged as promising options to help food industries reduce salt content, including the addition of garlic, potassium chloride, yeast extracts, enzymatic preparations, among others (Lima Filho et al. 2020; Araújo et al. 2022). In the pickle production scenario, some strategies have been proposed to lower sodium intake, including the utilization of other chloride salts (mainly calcium and potassium chlorides), structural modification of sodium chloride, and incorporation of flavor enhancers and spices (Lorén et al. 2023; Hu et al. 2024). Among these approaches, optimizing food formulation may be one of the most effective strategies to achieve this goal. Lima Filho et al. (2019) determined hedonic thresholds for sodium concentrations in hamburgers and observed that it is possible to reduce salt in hamburger formulation without jeopardizing product acceptance (Lobo and Ferreira 2021) studied the sensory response of consumers regarding the sodium in bread loaves and found that a 42% sodium reduction was possible based on hedonic thresholds. Nevertheless, a gap remains in understanding whether reducing salt in pickles can be achieved without compromising their sensory appeal.

A recent method called Hedonic Threshold Methodology (HTM) has been developed to evaluate acceptance and rejection thresholds by increasing the concentration of desirable substances, such as health-beneficial compounds, and reducing the concentration of unhealthy ingredients (such as sodium and sucrose) in foods (Lima Filho et al. 2015). This methodology allows for the determination of two thresholds: (i) Compromised Acceptance Threshold (CAT), in which the beginning of a significant reduction in acceptance is observed due to the increase/decrease of an ingredient in comparison to a control sample, and (ii) Hedonic Rejection Threshold (HRT), which represents the moment in which sensory rejection begins to occur (Lima Filho et al. 2015). For this aim, pairs of samples are presented to consumers, including the control (standard/market concentration of the ingredient or compound) and the treatment (reduction or increase of the ingredient or compound), and consumers then rate their acceptance using hedonic scales. Several studies have applied this methodology in foods and beverages, such as grape nectar beverage for sugar content reduction (Lima Filho et al. 2015; Gamba et al. 2021), cookies for butter reduction (Gamba et al. 2020), hamburgers for sodium chloride reduction (Lima Filho et al. 2019), and milk-based desserts for iron addition (Simiqueli et al. 2019). Prescott et al. (2005) previously proposed a Consumer Rejection Threshold (CRT) known as the point in which significant preference begins to occur. In the CRT method, consumers indicate their preference between pairs of products, where one sample is the control (traditional formulation) and the other sample has the stimulus intensity varied, for example, the concentration of some ingredient. The frequency of choice is then compared to the minimum number of agreeing judgments needed to establish significant differences in paired-preference tests. This methodology is widely known and has been successfully applied in a range of undesirable compounds found in wines (e.g., Prescott et al. 2005; Ross et al. 2014; Perry et al. 2019). Furthermore, the application of CRT has been used to find out at what point sucrose or sodium could be reduced in products without affecting consumer preference (e.g., Lima Filho et al. 2015; Lee et al. 2015; Torrico et al. 2020). In the present study, the use of Prescott's threshold is important to determine, regardless of the acceptance level of the control sample, at which sodium concentration consumers would prefer the control (with traditional sodium content) compared to the sample with reduced sodium content. Therefore, these three parameters (CAT, HRT, and CRT) can be used together to provide useful information for evaluating the reduction of unhealthy ingredients in foods and represent a powerful tool for this purpose. Additionally, they are the most well-established thresholds that allow for the calculation of the concentration at which sodium reduction begins to impact the sensory quality of the product.

Within the scenario of the growing pickle market, search for new flavors and aspiration to reduce sodium in foods, verjuice emerges as a promising alternative ingredient. Verjuice (English term), also known as 'verjus' in France, is an acidic juice usually produced from unripe grapes removed during green thinning but otherwise left to rot (Fia et al. 2022). This tart juice has several functional properties inherent to grape chemical composition, including compounds with antioxidant and antimicrobial activities (Alipour et al. 2012; Öncül and Karabiyikli 2019), presenting itself as an acidifying alternative to vinegar and lemon in marinades (Dupas de Matos et al. 2023), in salads (Dupas de Matos et al. 2018) and for pickle production (Dupas de Matos et al. 2019). Additionally, verjuice appears to enhance the perceived saltiness in pickled cucumbers (Dupas de Matos et al. 2019). To date, there is a lack of scientific evidence on how adding verjuice to the brine of cucumbers impacts consumer perception when a different range of salt content is used. Therefore, the aim of this study was to determine the affective thresholds (CAT, HRT, and CRT) of pickles produced with verjuice and vinegar in order to assess whether salt concentration can be reduced without affecting sensory acceptance.

2 | Materials and Methods

2.1 | Plant Materials and Ingredients

Cucumbers (Marinda variety) were harvested in December 2023 in Três Passos (RS, Brazil), with an average height of 7 cm and a diameter of 2 cm *Vitis labrusca* grapes from the Concord variety, one of the most cultivated varieties in Brazil (EMBRAPA 2021), were obtained from a grapegrower in Roca Sales (RS, Brazil) for the preparation of verjuice. The grapes were harvested at ripening stages between 29 and 3 according to the1 phenological classification scheme proposed by Coombe (1995), which represents the usual picking time for verjuice production (Dupas de Matos et al. 2017).

Regular iodized salt (NaCl) was purchased from Sal Sul (Imbituba, SC, Brazil), white vinegar from Rosina (Flores da Cunha, RS, Brazil), and mineral water from Água da Pedra (Lajeado, RS, Brazil).

2.2 | Verjuice Production

The verjuice was produced as described by (Dupas de Matos et al. 2019) with some modifications. Unripe grapes were manually destemmed, washed, and sanitized with a chlorinated solution (100 ppm, soaked for 15 min), followed by rinsing with running water. Grapes were then crushed and pressed using a perforated stainless-steel basket (40 cm diameter, 50 cm high, holes of 2 mm) until the juice was completely extracted (~60% yield). Potassium metabisulfite (0.5 g per liter of juice) was added to the resulting juice in order to prevent microbial growth and oxidation. After that, the juice was left at 0°C for 25 days for tartrate crystals precipitation, followed by vacuum filtration (filter paper 11 μm). The bottled verjuice was pasteurized (75°C for 1 min) and left to cool down. The final verjuice product was stored at 5°C until analysis (Table S1 shows the physicochemical parameters of both acidifiers).

2.3 | Pickles Production

For the picking process, pickles were produced as proposed by EMBRAPA (2008) and (EMBRAPA 2009), with some modifications. Brines ($n = 10$) were prepared by using two acidifying ingredients (vinegar: VIN, or verjuice: VER), which were mixed with mineral water (50:50 ratio) followed by salt addition at varied concentrations: 14 g/L, 10.5 g/L, 7 g/L, 3.5 g/L, 0 g/L of sodium chloride. A concentration of 14 g/L is commonly used in local pickles' production (EMBRAPA 2009) and is considered herein as the control sample, which was prepared with both VIN and VER as acidifiers. The other concentrations were based on a reduction of 25% (10.5 g/L), 50% (7 g/L), 75% (3.5 g/L) and 100% (0 g/L) of the ordinary salt concentration used in the pickles. Cucumbers were then placed into hot water (90°C) for 3 min, drained, and transferred to 500 mL glass jars (300 g of cucumber/jar), which were subsequently filled with 300 mL of respective brines (vinegar or verjuice), and closed with a screw cap. Jars were then subjected to low-temperature long time (LTLT) pasteurization (65°C for 30 min). Samples were stored for 3 months at room temperature (~23°C) before consumer testing.

2.4 | Consumer Study

2.4.1 | Participants

Participants ($n = 103$), recruited through posters on the University campus (Três Passos, RS, Brazil), met the following criteria: willing to consume and did not reject pickled cucumbers, aged over 18 years not allergic or intolerant to sulfites, no self-declared hypertension, not pregnant or lactating, and willing to attend one 60-min research session.

2.4.2 | Ethics Statement

This study followed procedures from the Helsinki Declaration for Research with Humans and was assessed and considered moderate risk following the UERGS Human Ethics Committee process (Certificate of Presentation of Ethical Appreciation number 75611823.2.0000.8091, protocol number: 6.571.942). Prior to study attendance, participants received an information sheet outlining study details and were asked to provide informed written consent. Participants were assigned a unique code to ensure anonymity. Upon study completion, participants were offered a snack treat to thank them for their time (no monetary incentive was provided).

2.4.3 | Session Procedure

Participants attended a central location test (individual tables in a neutral room (20 C ± 2°C)) at the UERGS campus in Três Passos, in groups of up to 15 people. Prior to beginning sample evaluation, participants were briefed on the study procedures.

Evaluation of the eight pairs was divided in two parts, balancing presentation: (1) verjuice-pickled cucumber ($n = 4$) and (2) vinegar pickled-cucumber ($n = 4$) samples, and vice-versa. Participants tasted the samples, one pair at a time, comparing the control (14 g/L of salt) with one of the concentrations (either 0, 3.5, 7, or 10.5 g/L). Firstly, they were asked to indicate the preferred sample. Secondly, participants rated overall liking followed by liking of saltiness and acidity by using a structured 9-point hedonic scale labeled as "dislike extremely" (1), "neither like nor dislike" (5), and "like extremely" (9). To further minimize carryover effects, participants were instructed to cleanse their palate before each pair of samples in a consistent manner (bite of cracker (Isabela, Pinhais, PR, Brazil) followed by filtered water).

On the day of the session, cucumbers were cut into 20 g pieces in a standardized way (removing the edges of the pickles), and were placed into 60 mL clear, odor-free plastic cups covered with a lid, labeled with 3-digit random codes and evaluated under white lighting. Pair presentation was monadic with a forced minimum 1 min-break between each pair. Acidifier (vinegar or verjuice) presentation was fully balanced across participants, where half of participants evaluated vinegar-based samples first followed by verjuice-based ones, and vice-versa. Samples (0–14 g/L salt levels) were presented in a complete and partially balanced design, where all participants evaluated every sample and concentrations were presented randomly. This approach was based on the recommendations of Gamba et al. (2021), who suggested presenting the stimulus samples in a random order, rather than a sequentially increasing or decreasing, to help minimize expectation bias.

At the end of the sample evaluation, information on participants sociodemographic and consumption habits was collected. Data was collected with participants' personal mobiles using Compusense cloud version 24.0.28086 (Guelph, Ontario, Canada).

2.5 | Data Analysis

Data were analyzed in XLSTAT version 2023.2.0 (Lumivero, New York, United States) and R software version 4.3.0 (R Core Team, 2020) in R studio version 2023.12.1 using the following packages: agricolae (de Mendiburu 2021).

Before Analysis of Variance (ANOVA), the normality of the data and the homogeneity of the variances were evaluated by Shapiro–Wilk and Hartley's maximum F tests, respectively. The α-risk was set at 0.05.

2.5.1 | Sensory Data

CRT was calculated for each sensory task by counting the number of consumers choosing the preferred sample and then plotting the portion of preference for the control sample (Y-axis) as a function of salt concentration in the brine (X-axis) (Prescott et al. 2005). The cut-point criteria for rejection as a function of sodium chloride concentration was 75% of consumers preferring the control sample. This approach was adopted because the original method's threshold criterion from Prescott et al. (2005) depends on the number of judges, which is a relatively arbitrary choice (Lawless and Heymann 2010). CRT value was then calculated by interpolation between two points of the portion of consumers preferring the control sample in the pair comparison (Lima Filho et al. 2015; Ardoin et al. 2020).

HRT and CAT values were calculated as follows. Hedonic scores for each pair evaluated were initially analyzed by a paired t-test (Cohen 1998) to check significant differences between pairs within acidifier. The acceptance averages (Y-axis) were then plotted as a function of sodium chloride concentration into the brine (X-axis). A linear regression (Lin 1989) was applied to the data and trend line added. Equations were also evaluated by the determination coefficient (R^2-values) and were considered with good adjustment when $R^2 > 0.70$ (Lima Filho et al. 2015; Simiqueli et al. 2019). HRT was the one in which the acceptance average was less than 5 ("neither liked nor disliked") (Lima Filho et al. 2015), indicating that bellow this salt concentration, consumer acceptance was rejected.

The t values (Y-axis), calculated in the paired t-test for each trial, were then plotted as a function of sodium chloride concentration (X-axis) and the linear regression was applied as previously described. The CAT of each attribute was calculated from the adjusted equations, wherein the sodium concentration corresponded to the point at which it exceeds the critical t value at 95% confidence (df = 102, $\alpha = 0.05$, $t_{critical} = 1.98$ to two-tail binomial distribution) (Roessler et al. 1978), indicating that from this concentration onwards, there are significant differences in liking between treatment and control, and thus acceptance is compromised.

Mean liking scores were evaluated by two-way ANOVA, considering participant as a random factor and sample (salt concentrations) and acidifier (vinegar and verjuice) as fixed factors, as well as their interaction (sample*acidifier), followed by Tukey's HSD test.

3 | Results

3.1 | Consumer Study

3.1.1 | Participants Characteristics

Participants ($n = 103$) were predominantly male (54%) with a mean age of 33.2 ± 14.1 years. Participants' consumption habits are summarized in Table 1. Regarding the stated consumption frequency of pickles, 53.4% of participants were regular pickle consumers (at least once a week or more often), and 46.6% consumed them more sporadically. The use occasion of pickles was mainly as a snack with cheese and ham (67.0%), followed by mixed with food in a meal (59.2%), in sandwiches (56.3%) and on their own (31.1%). In terms of pickle types, the most consumed was whole cucumbers (84.5%), followed by sliced cucumbers (49.5%), pickled onions (34.0%), pickled carrots (27.2%), Japanese pickled cucumbers (14.6%) and others (corn, capsicum, cabbage and broccoli) (2.9%).

3.1.2 | Preference

Participants firstly indicated their preference between two samples (where each pair had the control (14 g/L) versus one of the reduced sodium sample). CRT values for both VIN and VER samples are shown in Figure 1. VIN presented a CRT of 3.7 g/L, whereas the value for VER was slightly lower (2.2 g/L).

3.1.3 | Liking

In the second task, consumers rated their level of liking (overall, saltiness and acidity) for each pair of samples. Table 2 shows that the $VIN_{control}$ sample differed significantly ($p < 0.05$) from the reduced sodium samples for overall liking and liking of acidity, except for saltiness, where the control did not differ from VIN with 7 g/L of salt ($p > 0.05$). For VER samples, liking of saltiness was significantly different for most of the comparisons, but no

TABLE 1 | Information about stated consumption frequency of pickles, use occasions and pickle types consumed among the 103 consumers in the study.

Consumption frequency	Percentage (%)
Daily	8.7
More than once a week	26.2
Once a week	18.4
Once a fortnight	25.2
Once a month	9.7
Less than once a month	11.7
Use occasions	**Percentage (%)[a]**
As a snack (with cheese and ham)	67.0
In a meal mixed with food	59.2
In the sandwich	56.3
On its own	31.1
Type of pickles consumed	**Percentage (%)[a]**
Whole cucumber	84.5
Sliced cucumber	49.5
Onion	34.0
Carrot	27.2
Japanese cucumber	14.6
Other types	2.9

[a]Participants could select multiple options.

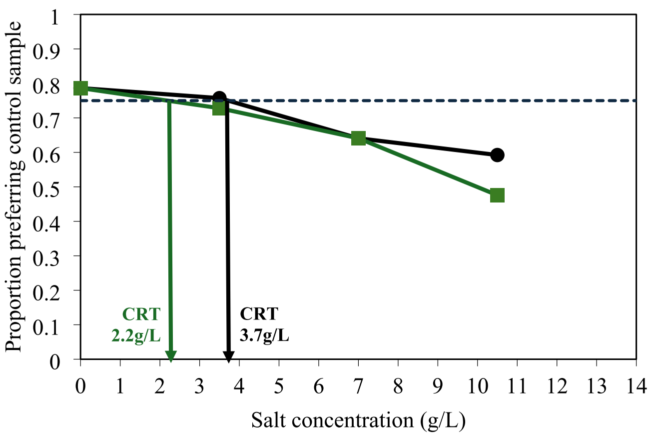

FIGURE 1 | Proportion of consumers choosing pickles using verjuice (□, in green) and vinegar (o, in black), produced with different salt concentrations added to the brine. Dotted line represents the cut-off point (0.75) to indicate significant differences on preference. CRT: Consumer Rejection Threshold.

differences were found between 14 g/L and 10.5 g/L for overall liking and liking of acidity (Table 2).

Differences within acidifiers and between acidifiers were also investigated. ANOVA showed that sample (salt concentration) and acidifier were statistically significant ($p < 0.05$) for liking, but not

TABLE 2 | Paired t-test comparison of pickled cucumber samples in the Hedonic Threshold Methodology (HTM).

	Vinegar (VIN)		
Liking	**Pair comparison**	**Mean ± Std. Dev**	***p***
Overall	14 g/L vs. 0 g/L	6.7 ± 1.8 vs. 4.7 ± 2.2	0.0000[a]
	14 g/L vs. 3.5 g/L	6.4 ± 1.8 vs. 5.3 ± 2.2	0.0000[a]
	14 g/L vs. 7.0 g/L	6.4 ± 1.9 vs. 5.6 ± 2.2	0.0067[a]
	14 g/L vs. 10.5 g/L	6.5 ± 1.9 vs. 5.9 ± 2.0	0.0217[b]
Saltiness	14 g/L vs. 0 g/L	6.1 ± 2.0 vs. 4.6 ± 2.2	0.0000[a]
	14 g/L vs. 3.5 g/L	5.9 ± 1.9 vs. 5.1 ± 2.1	0.0014[b]
	14 g/L vs. 7.0 g/L	5.9 ± 1.8 vs. 5.6 ± 1.9	0.1511[c]
	14 g/L vs. 10.5 g/L	5.9 ± 1.9 vs. 5.5 ± 1.8	0.0359[b]
Acidity	14 g/L vs. 0 g/L	6.1 ± 2.1 vs. 4.2 ± 2.0	0.0000[a]
	14 g/L vs. 3.5 g/L	6.1 ± 2.1 vs. 5.2 ± 2.2	0.0003[a]
	14 g/L vs. 7.0 g/L	5.9 ± 2.0 vs. 5.3 ± 2.3	0.0291[b]
	14 g/L vs. 10.5 g/L	6.1 ± 2.1 vs. 5.5 ± 2.1	0.0252[b]
	Verjuice (VER)		
Liking	**Pair comparison**	**Mean ± Std. Dev.**	***p***
Overall	14 g/L vs. 0 g/L	5.3 ± 2.2 vs. 3.6 ± 2.2	0.0000[a]
	14 g/L vs. 3.5 g/L	5.3 ± 2.3 vs. 4.0 ± 2.1	0.0000[a]
	14 g/L vs. 7.0 g/L	5.0 ± 2.2 vs. 4.3 ± 2.1	0.0046[a]
	14 g/L vs. 10.5 g/L	5.2 ± 2.1 vs. 4.7 ± 2.0	0.0800[c]
Saltiness	14 g/L vs. 0 g/L	5.4 ± 2.0 vs. 3.7 ± 2.0	0.0000[a]
	14 g/L vs. 3.5 g/L	5.2 ± 2.1 vs. 4.1 ± 2.2	0.0000[a]
	14 g/L vs. 7.0 g/L	5.1 ± 2.1 vs. 4.4 ± 2.1	0.0035[a]
	14 g/L vs. 10.5 g/L	5.0 ± 2.1 vs. 4.5 ± 2.1	0.0358[b]

(Continues)

TABLE 2 | (Continued)

	Verjuice (VER)		
Liking	**Pair comparison**	**Mean ± Std. Dev.**	***p***
Acidity	14 g/L vs. 0 g/L	5.1 ± 2.2 vs. 4.1 ± 2.2	0.0002[a]
	14 g/L vs. 3.5 g/L	5.0 ± 2.0 vs. 4.2 ± 2.2	0.0015[a]
	14 g/L vs. 7.0 g/L	5.1 ± 2.2 vs. 4.3 ± 2.0	0.0059[b]
	14 g/L vs. 10.5 g/L	5.0 ± 2.0 vs. 4.5 ± 2.0	0.0564[c]

[a]1% of significance.
[b]5% of significance.
[c]Not significant at 5%.

TABLE 3 | Associated p-values with the effect of sample (salt concentrations), acidifier (verjuice and vinegar), and their interaction from ANOVA by liking for sensory attributes. **Bold** *p*-values indicate significance at the 95% confidence level.

Liking	Sample	Acidifier	Sample*acidifier
Overall	**< 0.0001**	**< 0.0001**	0.932
Saltiness	**< 0.0001**	**< 0.0001**	0.732
Acidity	**< 0.0001**	**< 0.0001**	0.686

significant for interaction (sample*acidifier) (Table 3). Comparing the acidifiers for each sample, the mean overall liking score for VIN was higher ($p < 0.05$) compared to VER, except for saltiness at 14 g/L (control) and acidity at 0 g/L ($p > 0.05$) (Figure S1).

3.1.4 | Hedonic Thresholds

Mean liking scores were plotted against salt concentration to calculate HRT values (Figure 2) and results show that VIN samples consistently had higher liking scores than VER samples (detailed information about linear regression is shown in Table S2).

Linear regression of means for all attributes evaluated (Y_1) as a function of salt concentration (X) was significant ($p < 0.05$) and presented good adjustment to the data ($R^2 > 0.70$). For overall liking, the HRT of VIN was 2.0 g/L, whereas the HRT of VER was 12.7 g/L (Figure 2A). For saltiness, the HRT of VIN and VER was 3.1 g/L and 13.4 g/L, respectively (Figure 2B). For acidity, the HRT for VIN was 2.9 g/L, whereas it was higher than 14 g/L for VER samples (Figure 2C).

Based on t_{calc} of *t* tests (Y_2) as a function of salt concentration (X), CAT was calculated, and results are shown in Figure 3 (detailed information about linear regression are shown in Table S3). For overall liking, CAT was 10.0 g/L for VIN and 9.9 g/L for VER (Figure 3A). For saltiness, CAT for VIN and VER was 8.5 g/L and 9.9 g/L, respectively (Figure 3B). For acidity, CAT was 9.1 g/L for VIN and 8.5 g/L for VER (Figure 3C).

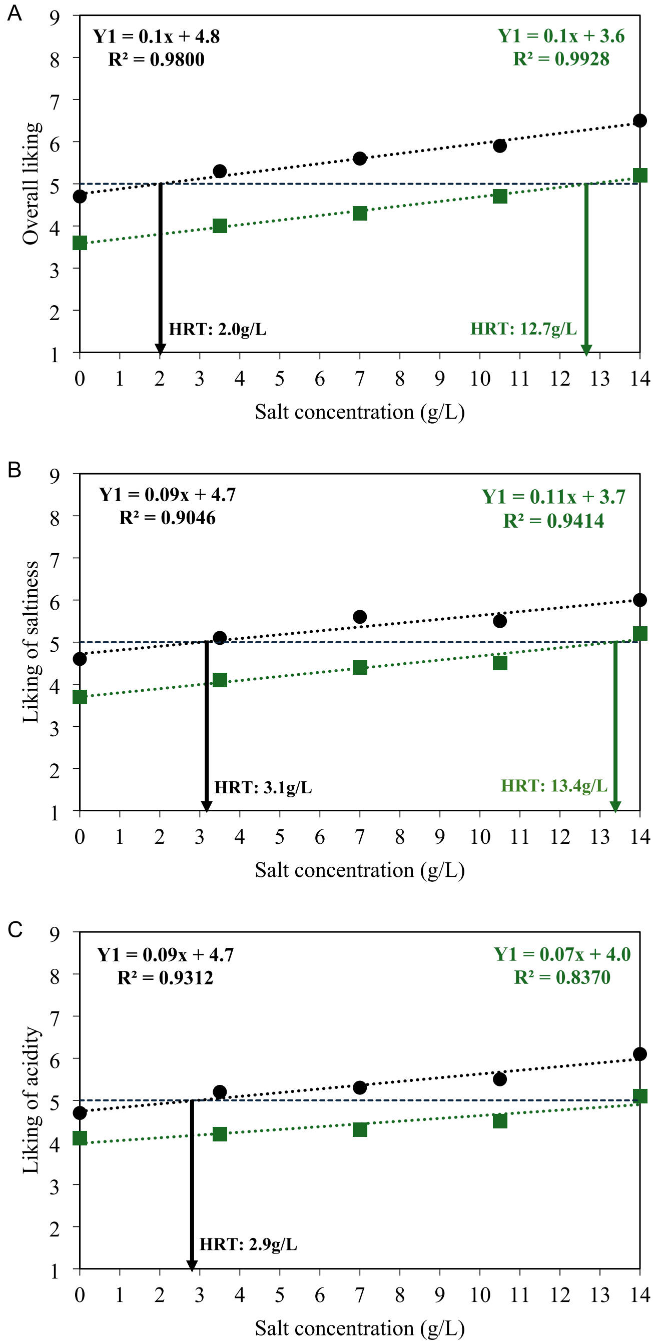

FIGURE 2 | Mean liking scores as function of the sodium concentration for verjuice (□, in green) and vinegar-based samples (o, in black) for overall liking (A), liking of saltiness (B) and acidity (C). Dotted lines represent the trend lines for the experimental data and dashed line shows the cut-off point (5.0, referring to "neither like nor dislike") to calculate HRT values.

4 | Discussion

4.1 | CRT, HRT, and CAT

In the present work, verjuice was used as an acidifier alternative to try to reduce salt content in pickled cucumber, utilizing vinegar (traditional acidifier for pickling) as the traditional comparison. Results showed that it is possible to reduce down to 3.8 g/L

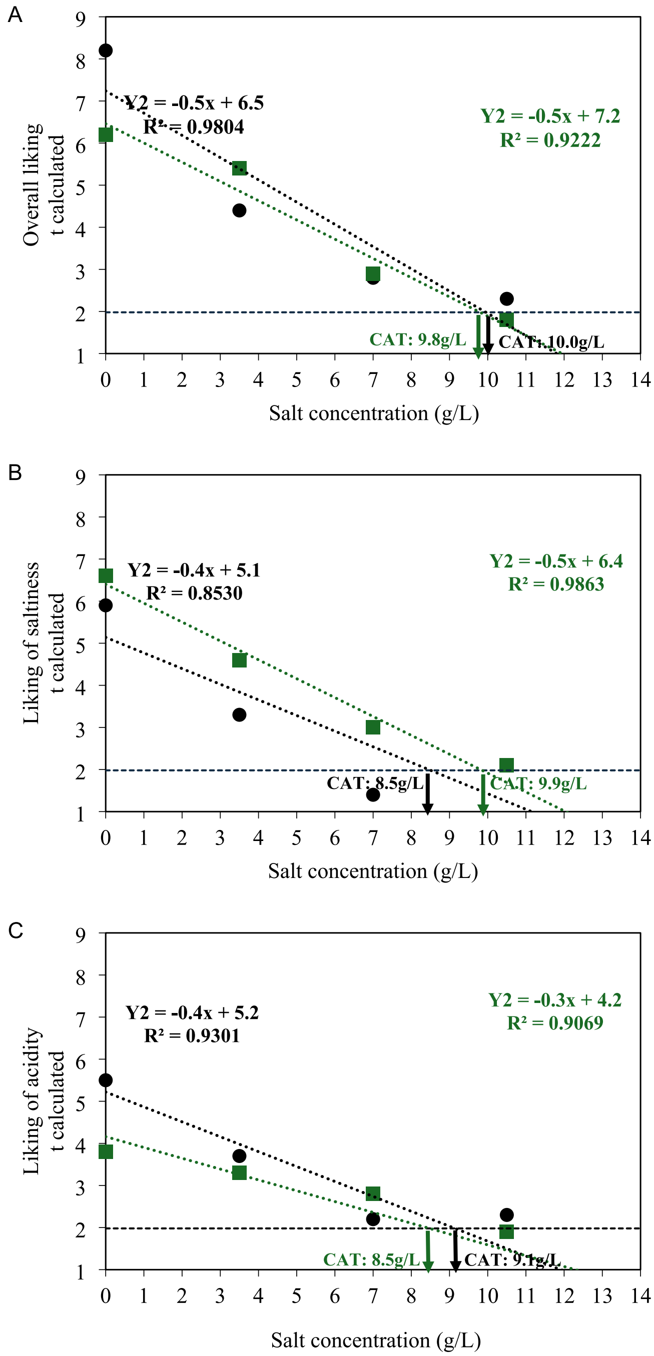

FIGURE 3 | Calculated *t* values as function of the sodium concentration for verjuice (□, in green) and vinegar-based samples (o, in black) for overall liking (A), liking of saltiness (B) and acidity (C). Dotted lines represent the trend lines for the experimental data and dashed line shows the cut-off point (1.98) to calculate CAT-values.

(CRT_{VIN}: 3.7 g/L; 72.8% reduction) of salt in vinegar without changing consumer preference in relation to the control (14 g/L), whereas in verjuice it is possible to reduce down to 2.3 g/L (CRT_{VER}: 2.2 g/L; 83.6% reduction) showing that verjuice allowed for a higher salt reduction, presenting itself as a valid acidifying ingredient for pickle production. Although CRT determines the point at which significant preference begins to occur, it only indicates which sample is preferred compared to the control and not when reduced acceptance and sensory rejection occur, highlighting the importance of using CAT and HRT as well (Lima Filho et al. 2015).

Interestingly, results showed that it is possible to reduce 27.9% of salt in the current production processes when using vinegar as an acidifier. Specifically, it is possible to reduce to 10.1 g/L of salt (at 10.0 g/L ($CAT_{VIN\ overall}$) rejection happens) when using vinegar without significant changes in acceptance compared to the control (14 g/L) (Figure 3). The possibility of reducing salt in verjuice-based brines was similar: it is possible to reduce 29.3% of salt ($CAT_{VER\ overall}$: 9.9 g/L) without significant changes in overall acceptance compared to the control. Previous research has studied the use of verjuice in different food matrices. (Dupas de Matos et al. 2019) have used verjuice as a salad dressing ingredient compared to other traditional seasoning ingredients. The authors did not report significant differences in consumer perceived saltiness of salads seasoned with verjuice, lemon juice, and vinegar. Later, (Dupas de Matos et al. 2019) found that pickles acidified with verjuice were perceived as saltier by consumers compared to vinegar pickled cucumbers. The methodology for determining hedonic thresholds (CAT and HRT) has been used to study sodium reduction in complex matrices, such as hamburgers (Lima Filho et al. 2019). The authors found that reducing sodium initially impacted the acceptance of flavor, followed by aroma, overall impression, and texture. However, the sodium reduction did not result in sensory rejection of aroma or texture. In the present study, salty and overall liking were impacted first, followed by acceptance of acidity. While this product differs significantly from the one used in the present study, it demonstrates that CAT and HRT provide valuable insights that can be beneficial to the food industry. Depending on the specific food matrix, such as pickles in the present study or hamburgers in the referenced work, this methodology can help identify optimal sensory thresholds for salt reduction, ultimately contributing to healthier product formulations without compromising consumer acceptance.

Considering the current scenario in Brazil where local pickles producers commonly use 14 g/L of salt, this study showed that salt reduction firstly impacted overall liking ($CAT_{VIN\ overall}$: 10 g/L), followed by the liking of acidity ($CAT_{VIN\ acidity}$: 9.1 g/L) and saltiness ($CAT_{VIN\ saltiness}$: 8.5 g/L). In contrast, with verjuice, the liking of saltiness was significantly affected when salt reached 9.9 g/L, followed by overall liking at 9.8 g/L and liking of acidity at 8.5 g/L, showing that changes in saltiness and overall acceptance occurred simultaneously. The similar CAT values for overall liking and liking of saltiness in verjuice samples, compared to a wider range of CAT values observed when vinegar was used as an acidifier, could be due to verjuice's smoother and more delicate flavor profile (Dupas de Matos et al. 2023). This factor may have enhanced the perception of saltiness in the cucumber samples, however the mechanisms behind this remain unknown. Results of present study align with findings from (Dupas de Matos et al. 2019) in which pickled cucumbers preserved in verjuice-based brines showed higher perceived intensity of saltiness than those produced with vinegar, which may be related to verjuice's lower pungency (Dupas de Matos et al. 2019). Additionally, Hatae et al. (2009) reported that the detection and recognition thresholds of salt decreased with the addition of vinegar in model systems. Therefore, further research is needed to explore the sensory characteristics that may influence the perception of saltiness in verjuice-based pickles.

In the present study, changes observed in acceptance are likely related to salt migration from the brine to cucumbers, influenced by differences in osmotic pressure (Damodaran and Parkin 2019). Previous literature has shown that sodium levels affect the perception of different sensory attributes, such as saltiness and acidity (Breslin 1996; Hatae et al. 2009), as well as some off-notes, as sodium migration during the pickling process acts as bitterness inhibitors (Breslin and Beauchamp 1997; Liem et al. 2011; Lima Filho et al. 2019). Moreover, variation in sodium chloride content modifies the structure of the food matrix, influencing the release kinetics of flavor compounds through physicochemical interactions between components of the food matrix and their perception (Thomas-Danguin et al. 2019).

Regarding HRT values, results showed that it is possible to reduce down to 2.1 g/L of salt (85.0% reduction) when using vinegar without overall rejection of pickles (liking ≤ 5.0). It is important to highlight that although it was not the main objective of this study, these findings indicate relevant information to the food industry. In contrast, with verjuice, it is possible to have an 8.6% reduction of salt without sensory rejection. However, in vinegar samples, salt reduction initially led to the rejection of liking of saltiness when the salt level dropped to 3.1 g/L, followed by a rejection of acidity at 2.9 g/L, before reaching the overall rejection ($HRT_{VIN\ overall} = 2.0$ g/L). For verjuice, no reduction of salt concentration is possible without causing rejection of acidity, as the HRT was estimated at higher concentrations than 14 g/L. In terms of saltiness, consumers rejected samples when the salt concentration reached 13.4 g/L, indicating that only a 3.6% reduction is feasible. It is important to note that the liking of acidity for the control sample (14 g/L of salt) was 5.1 ± 1.5 (Table 2), which is very close to the cut-off point (5.0) established for a sensory rejection, placing it near the rejection zone, leading to an estimated HRT > 14 g/L.

Comparing vinegar and verjuice, it is evident that acceptance scores of vinegar samples were higher compared to those of verjuice on average, except for the 14 g/L for saltiness and 0 g/L for acidity (Figure S1). This can explain why HRT values of vinegar were much lower compared to those of verjuice samples. For example, $VIN_{control}$ presented an overall mean liking score of 6.5 ± 1.9, while $VER_{control}$ presented an overall mean liking score of 5.2 ± 2.2. This indicates that vinegar samples had a wider range of acceptance before reaching the mean score of 5.0, whereas the verjuice samples were already close to the cut-off point at 14 g/L. Consequently, even a small reduction in salt led to a decrease in acceptance, affecting the HRT values for verjuice samples. This helps explain the discrepancies observed between HRT and CAT of vinegar and verjuice samples. Additionally, familiarity plays a critical role in consumer responses to sensory stimuli (Tuorila and Hartmann 2020), suggesting that the relatively low acceptance of verjuice-pickled samples could be due to the lack of consumer familiarity with this acidifier. The importance of situational or meal context in product acceptance has been previously studied (e.g., Meiselman 2008; Piqueras-Fiszman and Jaeger 2015). Given that the majority of participants reported eating pickles with other foods, and only 31% consumed them on their own, future studies could explore how the context in which pickles are consumed influences their overall acceptance.

5 | Limitations

Considering that cucumber variety, type of vinegar, and verjuice as well as the time of pickle maturation may influence the results obtained, further research is needed to investigate a wider range of processing conditions to better evaluate the feasibility of using verjuice as an acidifier ingredient in a large-scale production.

6 | Conclusion

For both acidifiers, results indicated that it is possible to reduce salt at similar levels (~4 g/L) without impacting overall liking, liking of saltiness, and acidity of pickles in relation to the control (14 g/L). Regarding the preference, it is possible to use slightly less salt by replacing verjuice (≤ 2.3 g/L) over traditional acidifier ($CRT_{vinegar}$: 3.7 g/L) without impacting preference in relation to the control. However, looking at the rejection threshold, vinegar allowed for a higher salt reduction compared to verjuice. As verjuice is still unknown in Brazil, this may explain higher rejection thresholds compared to vinegar-based samples. On the other hand, food industries could reduce more salt by using verjuice (down to 11.7 g/L vs. 10.2 g/L for verjuice and vinegar, respectively) without changing consumer preference for pickles in relation to commercially available pickles. Nevertheless, verjuice has shown to be a promising acidifier to reduce salt levels in pickles. By utilizing a juice made from discarded grapes as an acidifying ingredient, this study enhances verjuice's health and sustainability credentials while also positioning its incorporation as a potential first step in product innovation. Furthermore, the methodology for determining sensory thresholds has a wide range of applications, such as supporting quality control, guiding formulation development, monitoring shelf-life, lowering production costs, and improving the healthiness of foods without compromising product sensory appeal or leading to rejection. This methodology extends beyond the food industry and can also be applied in other sectors; however, further research is needed to confirm and expand on these potential applications.

Author Contributions

Rubia Selmira Lassen: investigation, writing – reviewing and editing. **Voltaire Sant'Anna:** conceptualization, data curation, formal analysis, funding acquisition, methodology, project administration, visualization, writing original draft. **Fernanda Leal Leães:** investigation, supervision, writing – reviewing and editing. **Tarcísio Lima Filho:** formal analysis, writing – reviewing and editing. **Amanda Dupas de Matos:** conceptualization, data curation, formal analysis, methodology, project administration, resources, supervision, visualization, writing original draft, writing – reviewing and editing.

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Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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Supporting Information

Additional supporting information can be found online in the Supporting Information section.