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Sensory Evaluation of Sodium Chloride-Containing Water-in-Oil Emulsions

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ABSTRACT: The sensory perception of water-in-oil emulsions containing a saline-dispersed aqueous phase was investigated. Manipulating saltiness perception was achieved by varying the mass fraction aqueous phase (MFAP), initial salt load, and surfactant concentration [(polyglycerol polyricinoleate (PgPr)] of the emulsions, with formulations based on a central composite design. Saltiness and emulsion thickness were evaluated using a trained sensory panel, and collected data were analyzed using response surface analysis. Emulsion MFAP was the most important factor correlated with increased salt taste intensity. Emulsifier concentration and interactions between NaCl and PgPr had only minor effects. Emulsions more prone to destabilization were perceived as saltier irrespective of their initial salt load. The knowledge gained from this study provides a powerful tool for the development of novel sodium-reduced liquid-processed foods.

KEYWORDS: *water-in-oil emulsion, salt, stability, sensory evaluation, rheology*

INTRODUCTION

In 2003, in response to excessive salt intake worldwide and research correlating dietary sodium levels and cardiovascular disease, the World Health Organization set a target upper intake of ≤5 g of NaCl (≤2000 mg of Na) per person per day. Studies have shown that although consumers consider sodium intake an important health issue, their purchasing habits do not reflect this.[1] Consumers have adapted to the high salt levels present in processed foods and often find low-sodium products to be less palatable.[2] The ongoing challenge for food manufacturers is thus to generate products with reduced sodium levels while maintaining their sensory acceptability to the consumer.

One proposed strategy for sodium reduction in liquid foods is the use of multiple emulsions containing NaCl,[3] which consist of a water-in-oil (w/o) emulsion incorporated as the dispersed phase within an oil-in-water emulsion (o/w), thereby yielding a water-in-oil-in-water double emulsion ($w_1/o/w_2$). In this regard, there is a dearth of information available on the sensory perception of multiple emulsions and significantly less on the perception of nonvolatiles in w/o emulsions.[4] Barylko et al.,[4] citing the research of Ohta et al.,[5] stated that, in general, taste intensity is lower in w/o emulsions compared to o/w emulsions, and the ability to discriminate tastes is reduced in oily compared to aqueous media. This group also found that the taste intensity of sucrose in w/o and o/w emulsions of equal volume fraction ratios did not differ, suggesting phase inversion upon oral processing as the mechanism responsible for sensory perception.

The key compositional parameters that will affect sensory perception of salt incorporated in emulsions include the choice of surfactant, NaCl load, and the emulsion's mass fraction aqueous phase (MFAP). Formulating w/o emulsions requires the use of low-HLB emulsifying agents that provide sufficient stability prior to the emulsion being consumed. One such surfactant is polyglycerol polyricinoleate (PgPr), an oligomeric molecule prepared by the esterification of condensed castor oil fatty acids with polyglycerol[6] (Figure 1). It enhances emulsion stability by reducing interfacial tension (maximum reduction at ~1−1.5 wt % of the oil phase[7]) and via polymer strand steric stabilization that prevents aqueous phase droplet−droplet coalescence.[8] The initial salt present in an emulsion will understandably affect the perception of salt intensity. Yet, when used in combination with PgPr, NaCl also increases emulsion stability against coalescence by modifying surfactant efficacy through interaction with the oligomeric ricinoleic acid esters in PgPr present at the oil−water interface.[9,10] Thus, NaCl can function as the primary taste component as well as an emulsion stabilizer. Finally, an emulsion's MFAP may also influence stability given its relationship with an increased probability of droplet collision and coalescence.[11] This in turn is likely to affect the oral perception of saltiness; however, no studies on the importance of emulsion composition and rheology on salt taste perception are available to date.

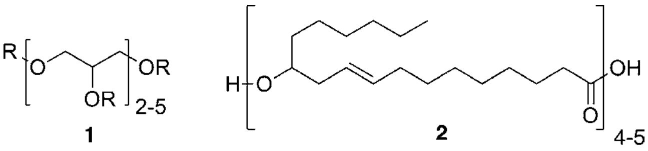

Figure 1. Molecular structure of PgPr (**1**) in which at least one R is polyricinoleic acid (**2**) and the others are either hydrogen or fatty acid residues (adapted from Dedinaite et al.[8]).

This study aimed to understand how formulation affects the stability and ultimately the taste intensity of salt present in w/o emulsions. Our hypothesis was that "less stable" emulsions

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Table 1. Emulsion Properties and Sensory Analysis of the Experimental Salt-Containing Water-in-Oil Emulsions[a]

						saltiness response[b]		thickness response[c]	
sample code	MFAP[d]	PgPr[e] (%oil)	NaCl (%aq)	PgPr (%ttl)	NaCl (%ttl)	mean[f]	SD	mean[f]	SD
14	0.48	1.0	3.9	0.52	1.87	**8.5 a**	1.3	**7.5 a**	1.3
5	0.40	0.80	1.8	0.48	0.72	5.9 b	2.1	6 ij	2.1
6	0.40	1.2	1.8	0.72	0.72	7.6 a	2.3	6.9 ab	1.1
7	0.40	0.80	6.0	0.48	2.4	8.1 a	1.3	6.9 ab	1.2
8	0.40	1.2	6.0	0.72	2.4	4.3 cdef	2.9	5 cdef	1.8
9	0.29	0.66	3.9	0.47	1.1	3.0 fg	2.0	5.3 cde	1.8
10	0.29	1.3	3.9	0.95	1.1	4.7 bcd	1.9	5.6 cd	1.7
11	0.29	1.0	0.34	0.71	0.10	5.6 bc	2.6	5.7 cd	1.3
12	0.29	1.0	7.4	0.71	2.2	3.1 efg	1.7	5.4 cde	1.7
15	0.29	1.0	3.9	0.71	1.1	4.2 de	2.0	5.4 cd	1.6
1	0.18	0.80	1.8	0.66	0.32	**2.1 g**	1.4	4.0 fg	1.9
2	0.18	1.2	1.8	0.99	0.32	5.2 bcd	3.0	6.0 bc	1.7
3	0.18	0.8	6.0	0.66	1.1	2.6 g	1.3	4.4 efg	1.9
4	0.18	1.2	6.0	0.99	1.1	2.7 g	1.5	4.7 defg	1.9
13	0.10	1.0	3.9	0.90	0.39	**2.1 g**	1.1	**3.8 g**	2.0

[a] The left-hand grouping represents the emulsion compositions as per the central composite design. Variables are reported as percent of respective phases (%aq, %oil) and as percent of total sample mass (%ttl). Sensory response for attributes "thickness" and "saltiness" were obtained by sensory panel ($n = 9$). Extreme values are in bold. [b] Values input by panelists on a 10 cm line scale with references of 1 = 0.05 wt % NaCl in water, 9 = 0.2 wt % NaCl in water. [c] Values input by panelists on a 10 cm line scale with references of 1 = sample 13, 9 = sample14. [d] MFAP , mass fraction aqueous phase, the fraction of the sample by mass made of the aqueous phase. [e] PgPr, polyglycerol polyricinoleate. [f] Means with same letter are not significantly different. Tukey's allocation letters correspond to their columns only.

would be perceived as saltier than "more stable" emulsions, given that "less stable" droplets would rupture and release their saline cargo upon oral processing when compared to "more stable" droplets. As a result, more NaCl would be released near the oral mucosa, where the taste receptors and oral shear are most prevalent.[12]

MATERIALS AND METHODS

Materials. Additive-free canola oil was provided by Bunge Foods (Hamilton, ON, Canada). Crystalline NaCl, ACS certified (Fisher Scientific, Ottawa, ON, Canada) and PgPr (Admul Wol 1403K, Kerry Ingredients, Tralee, Co. Kerry, Ireland) were used without further purification. The water used for sensory evaluation and emulsion production was tap water filtered through an in-line water filtration system, known to remove chlorine, pesticides, and other small organic compounds as well as 98% of lead, 88% of copper, and 91% of mercury (Brita, Oakland, CA, USA).[13]

Experimental Design and Preparation. Twenty formulations were prepared according to a central composite experimental design containing PgPr (0.66−1.34 wt % of the oil phase), NaCl (0.34−7.4 wt % of the aqueous phase), and filtered water (10−48 wt % of the emulsion) (Table 1). The design included a range of these factors so that a statistically robust response surface model could be developed from the collected data. Each factor had five levels in the design: two axial points outside the range of interest, high and low factorial points, and a center point.

Previous research has shown that the sensory intensity of water-soluble, nonvolatile taste compounds in emulsions is dependent on the concentration of the tastant in the aqueous phase rather than in the system as a whole.[14] Thus, NaCl concentrations were calculated on the basis of concentration in the aqueous phase. Likewise, the concentration of PgPr was calculated on the basis of the mass of the oil phase. Canola oil and PgPr were weighed and mixed together in a stainless steel double boiler at 70 °C; NaCl and filtered water were weighed and mixed in a separate container at 70 °C. The aqueous components were added and stirred as the mixture was brought again to 70 °C. Prehomogenization was performed using a Silverson L4RT laboratory scale rotor/stator (Silverson Machines, East Longmeadow, MA, USA) at 7500 rpm for 30 s. Immediately after, the samples were passed twice through a preheated APV Gaulin 15MR two-stage high-pressure valve homogenizer (APV, Concord, ON, Canada). The pressures were set at 3000 and 500 psi for the first and second stages, respectively. Samples were cooled uncovered at 4 °C and stored covered until testing.

Stability Study. Emulsion stability was quantified over time on the basis of dispersed phase sedimentation and coalescence. Immediately following production, 10 g of each sample was weighed into a test tube and stored at 3 °C covered with Parafilm. Measurements of phase separation were taken for 14 days following production, beginning 1 day after production (day 1). The degree of phase separation was based on where a clear distinction could be made between a clear sedimented aqueous phase and an intact upper emulsion phase. Separation values were reported as a fraction of the total sample height. To compare results, an adjustment was performed by dividing the height fraction of the aqueous phase separated by the volume fraction of aqueous phase in the sample, giving an effective "fraction separated" value.

Light Microscopy. Samples were imaged ~2 h after production on an Olympus BX60F5 light microscope (Olympus America Inc., Center Valley, PA, USA). The high number of droplets in the field of view caused overlap and prevented counting, requiring dilution. Samples (50 μL) were pipetted into 1 mL of canola oil, covered with Parafilm, and repeatedly inverted until homogeneous; 2 μL of this diluted sample was pipetted onto a glass microscopy slide and covered with a coverslip. Samples were imaged with a 100× objective lens (Olympus UPlanFI) using Image-Pro Plus 6.0 software (Media Cybernetics, Bethesda, MD, USA), captured with an Olympus DP71 digital camera at a resolution of 1360 × 1024 dpi (Olympus Canada Inc., Markham, ON, Canada). Two slides per sample were prepared, and three images per slide were taken.

Image Analysis. Image processing was performed with Adobe Photoshop CS4 (Adobe Systems Inc., San Jose, CA, USA) and Image-Pro Plus 6.0 (Media Cybernetics). Images were cropped centrally to 300 × 300 dpi to reduce the number of counts per image. A high-pass filter was applied to emphasize droplet edges. A median filter was then applied to reduce noise in the image, and a further sharpening filter was applied to again enhance droplet edges. Following thresholding, the droplet Feret length was determined with measurements restricted to values between 0.2 and 5 μm. The lower boundary was selected to eliminate any particles smaller than the limit of resolution of the light microscope. Visual inspection revealed no droplets larger than 5 μm.

Rheology. Rheological measurements were conducted with a cone-and-plate geometry on a TA AR 1000 rheometer (TA Instruments, New Castle, DE, USA) using a 2° stainless steel cone geometry ($d = 4$ cm). Rheological measurements were taken ~4 h after production, concurrent with sensory evaluation. Samples were loaded onto the Peltier baseplate of the rheometer at 25 °C, and the geometry was lowered to 52 μm, followed by a 2 min temperature equilibration. The treatment consisted of a 5 min sample relaxation followed by a 3 min shear stress sweep from 10 to 200 s^{-1}, with a 5 s measuring delay to ensure that readings were stable. Each sample was evaluated in triplicate, and viscosity values were determined from these readings.

Sensory Evaluation. Concurrent with the rheological measurements, sensory evaluation was conducted using a trained panel. Data were recorded using Compusense 5 software (Compusense, Guelph, ON, Canada). Ethics approval was obtained from the Research Ethics Board of the University of Guelph (REB 09MY020). Nine individuals were trained for the evaluation of saltiness and emulsion thickness as well as in the use of a 10 cm line scale for this evaluation. As reference for sensory evaluation and scale calibration, emulsions were compared to two salt solutions (0.05 and 0.2 wt % NaCl). The attributes were selected in an attempt to separate the possibly cognitively related properties of saltiness and sample thickness.[15] Saltiness was defined as "salt taste" as understood from aqueous solutions of NaCl presented to the panelists as references. Thickness was defined as resistance to movement perceived immediately after the sample was placed in the mouth and manipulated with the tongue. Samples were prepared the same day as the evaluation and equilibrated at 21 °C prior to evaluation. Samples were presented in 10 mL servings in 30 mL plastic cups labeled with a random three-digit blinding code. Panelists were told to take each sample into their mouths, evaluate for thickness, swish for 10 s, and evaluate for saltiness. Panelists were instructed to spit out the sample and rinse according to the following procedure: rinse with a 0.06 wt % citric acid solution (citric acid, 99.5+% FFC, SAFC Supply Solutions, Oakville, ON, Canada) to clear the mouth of oily residue, take a bite of apple to clear the palate, and rinse with water to clear the palate and empty the mouth of apple pieces. Panelists were given 60 s between sample evaluations and 120 s after four consecutive evaluations. The 20 samples were presented to panelists in a random order over three sessions of testing. Three replicates of testing were conducted, requiring a total of nine sessions to complete the testing. Blocking was selected as per Cochran and Cox.[16]

Statistics. Statistical analysis of the sensory data was performed using SAS v9.2 statistical analytical software (SAS Institute Inc., Toronto, ON, Canada). For data quality, a general linear model was performed examining replication, treatment, and judge effects. In addition, skewness, kurtosis, and residuals analysis were performed. Response surface analysis was used to develop a model integrating the influence of the experimental factors on the ratings of saltiness and thickness. Triplicates of all emulsions were prepared, giving three complete replicates for all sensory, rheology, stability, and light microscopy data. All results are expressed as the mean ± standard deviation, and statistical differences were deemed to be significant when $P < 0.05$.

■ RESULTS

Light Microscopy. Image analysis of emulsion droplet size revealed little difference between formulations, with the average aqueous droplet diameters (Feret particle length) between 0.34 and 0.43 μm, with relatively large standard deviations (Figure 2; Table 2). This narrow range suggested that differences in droplet size would not affect the sensory perception of these emulsions, as has been noted by other groups.[12,17] The various formulations yielded comparable unimodal droplet size distributions. Hence, the possibility of larger droplets altering the sensory perception of salt was discounted. Finally, there was no obvious dispersed phase droplet flocculation or coalescence during the time between emulsion preparation and sensory evaluation.

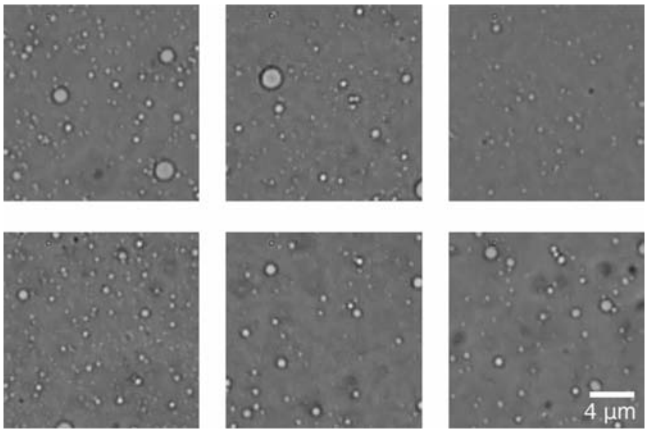

Figure 2. Emulsion droplet sizes imaged with light microscopy. Samples with extreme levels for each factor are shown. Sample codes 9, 10, 11, 12, 13, and 14 are shown from top left to bottom right. Refer to Table 1 for corresponding formulations (sample code). Scale bar = 4 μm.

Emulsion Viscosity. Figure 3 shows the emulsion viscosity shear rate dependence as a function of MFAP. Higher MFAPs were associated with higher viscosity at all shear rates and a stronger tendency toward shear-thinning. The most dramatic decrease in apparent viscosity was seen in the sample with MFAP = 0.48, showing a decrease of ~22% in the shear rate range studied. The exponential relationship between MFAP and emulsion viscosity indicated that at higher MFAPs, there was a stronger influence of the dispersed phase on viscosity (Figure 4). In dilute w/o emulsions, viscosity will be largely dependent on the properties of the continuous oil phase as the emulsion droplets are unlikely to interact given their sparseness. As the concentration of the dispersed phase increases, greater resistance to flow is seen and greater droplet−droplet friction occurs, leading to increased viscosity. The shear-thinning observed likely occurred as a result of droplets aligning in the shear field at higher shear rates, providing gradually reduced flow resistance.[18]

Emulsion Stability. Emulsion stability results demonstrated formulation groupings based on dispersed phase sedimentation. The emulsion with the smallest sedimentation consisted of the lowest MFAP (sample 13), whereas samples 5, 9, and 2 exhibited significantly more phase separation. These samples consisted of low PgPr, low NaCl, or high MFAP, implying an effect of these factors on stability. When samples with similar NaCl concentrations as a percent of the aqueous phase (such as samples 9 and 13) were compared, greater stability was observed in the samples with higher levels of PgPr and lower aqueous phase fractions.

Sensory Evaluation. Sensory response for attributes "saltiness" and "thickness", sorted by MFAP in descending order (Table 1), indicated a strong influence of sample MFAP on both salt taste intensity and thickness rating. There was a significant increase in perceived salt taste intensity with increasing MFAP ($P < 0.0001$), as well as interaction between NaCl and PgPr content ($P = 0.08$). Relating saltiness to sample formulation yielded clear trends. Notably, an inverse saltiness perception was noted in emulsion groups with identical PgPr concentrations and MFAPs. For example, samples 2 and 4 showed a decrease in salt taste intensity with an increase in

Table 2. Emulsion Properties and Sensory Analysis of the Experimental Salt-Containing Water-in-Oil Emulsions[a]

						Feret particle length (μm)		fraction separated (adjusted)	
sample code	MFAP[b]	PgPr[c] (%oil)	NaCl (%aq)	PgPr (%ttl)	NaCl (%ttl)	mean[d]	SD	mean[d]	SD
14	0.48	1.0	3.9	0.52	1.87	0.38 abc	0.21	0.46 ab	0.04
5	0.40	0.80	1.8	0.48	0.72	0.39 abc	0.18	0.53 a	0.02
6	0.40	1.2	1.8	0.72	0.72	0.37 b	0.19	0.48 ab	0.05
7	0.40	0.80	6.0	0.48	2.4	0.43 ac	0.23	0.47 ab	0.04
8	0.40	1.2	6.0	0.72	2.4	0.39 abc	0.20	0.28 ab	0.15
9	0.29	0.66	3.9	0.47	1.1	0.37 b	0.15	0.53 a	0.04
10	0.29	1.3	3.9	0.95	1.1	0.38 bc	0.18	0.33 ab	0.11
11	0.29	1.0	0.34	0.71	0.10	0.35 b	0.18	0.34 ab	0.06
12	0.29	1.0	7.4	0.71	2.2	0.36 b	0.14	0.38 ab	0.03
15	0.29	1.0	3.9	0.71	1.1	0.42 a	0.71	0.34 ab	0.09
1	0.18	0.80	1.8	0.66	0.32	0.38 bc	0.20	0.30 ab	0.08
2	0.18	1.2	1.8	0.99	0.32	0.36 b	0.15	0.68 a	0.52
3	0.18	0.8	6.0	0.66	1.1	0.35 b	0.13	0.27 ab	0.12
4	0.18	1.2	6.0	0.99	1.1	0.35 b	0.16	0.20 ab	0.18
13	0.10	1.0	3.9	0.90	0.39	0.34 b	0.15	0.03 b	0.05

[a] The left-hand grouping represents the emulsion compositions as per the central composite design. Variables reported as percent of respective phases (%aq, %oil) and as percent of total sample mass (%ttl). The Feret particle length was determined by light microscopy and image analysis (n = 3). The emulsion-separated fraction was determined by sedimentation testing and adjusted to account for sample water content (n = 3). [b] MFAP, mass fraction aqueous phase, the fraction of the sample by mass made of the aqueous phase. [c] PgPr, polyglycerol polyricinoleate. [d] Means with the same letter are not significantly different. Tukey's allocation letters correspond to their columns only.

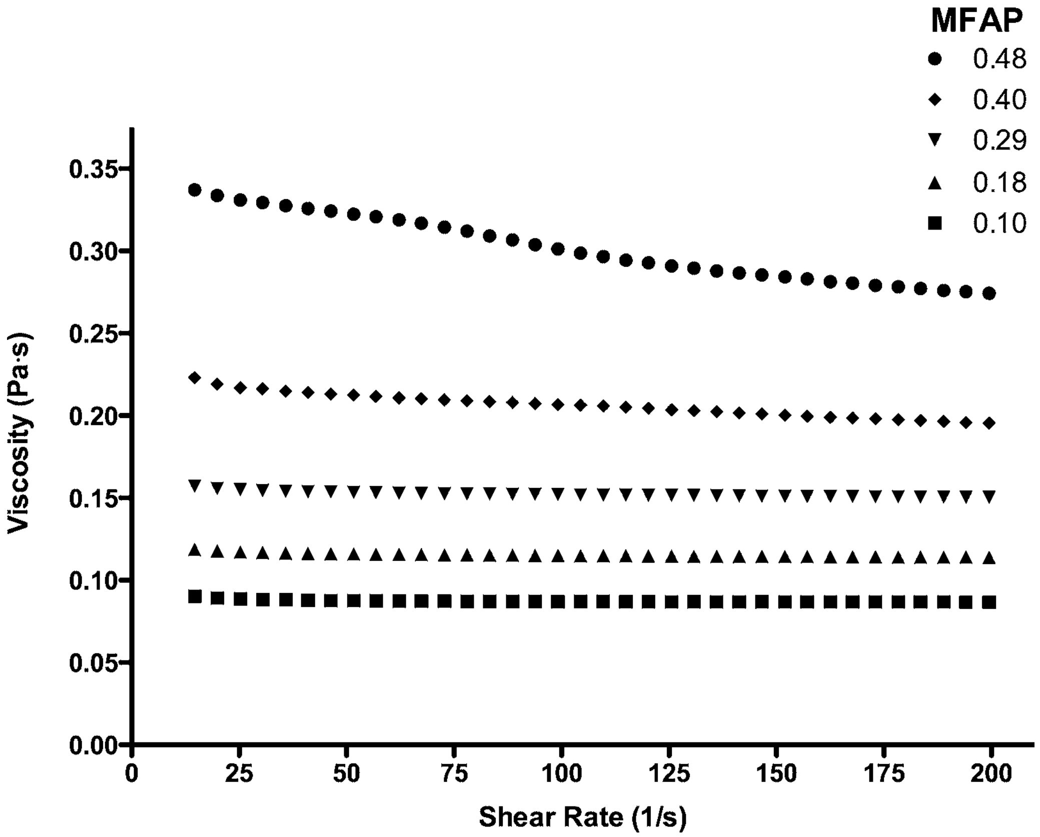

Figure 3. Emulsion viscosity shear rate dependence as a function of mass fraction aqueous phase (MFAP) (n = 3). Error bars removed for clarity.

NaCl (Figure 5A3). This was mirrored when samples 11 and 12 (with a 20-fold increase in salt content, Figure 5B3) and samples 6 and 8 (Figure 5C3) were compared, indicating that interaction between NaCl and PgPr likely increased emulsion stability, thus reducing salt taste intensity. However, samples 5 and 7 did not show this trend (Figure 5C3), as an increase in salt taste intensity with an increase in NaCl load was observed. This suggested that this inverse relationship held only below a threshold MFAP.

Response surface analysis for saltiness indicated that the most robust model included no quadratic terms (eq 1; R^2 = 0.57). The P values for MFAP, PgPr, PgPr × NaCl were <0.0001,

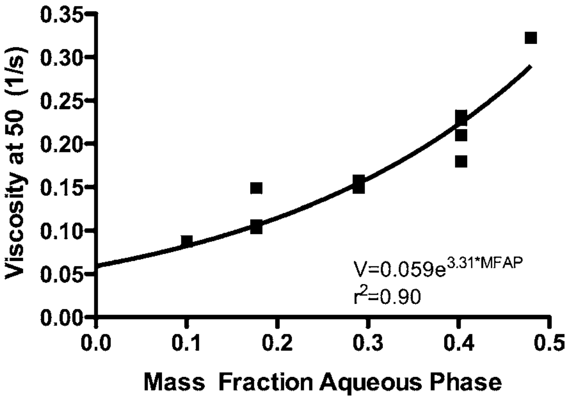

Figure 4. Relationship between emulsion viscosity and MFAP at 50 s^{-1} ($n = 3$).

0.02, and 0.08, respectively. For the attribute "thickness", the only factor having a significant influence was MFAP, and so it was the only one included in the model ($P < 0.0001$). These equations indicated that MFAP was the most significant factor influencing salt taste intensity (R_S) (eq 1, $R^2 = 0.57$) and the only significant factor influencing the perception of thickness (R_T) (eq 2, $R^2 = 0.55$).

$$R_S = 1.67 + 15.7\text{MFAP} + 0.087(\text{NaCl} \times \text{PgPr}) - 0.51\text{PgPr} \qquad (1)$$

$$R_T = 3.51 + 7.65\text{MFAP} \qquad (2)$$

■ DISCUSSION

All emulsions were stable for the duration of all sensory trials, with no change in droplet size observed during the experimental time frame. Although the particle size analysis showed significant differences among the various compositions ($P < 0.05$), the range of particle size averages was narrow, varying by no more than 0.09 μm. As a result, the differences in droplet size were not likely to affect sensory perception. Akhtar et al.[17] and Dresselhuis et al.[12] indicated that in o/w systems, there was no impact of droplet size on sensory perception of compounds dispersed in oil-in-water emulsions, especially with droplets below 5 μm, at which humans cannot distinguish differences.

Emulsion Composition and Sensory Perception. The results of the response surface analysis indicated that the main factor influencing saltiness was MFAP. The hypothesis of emulsion stability dictating sensory perception should have predicted PgPr concentration as the principal factor, but its

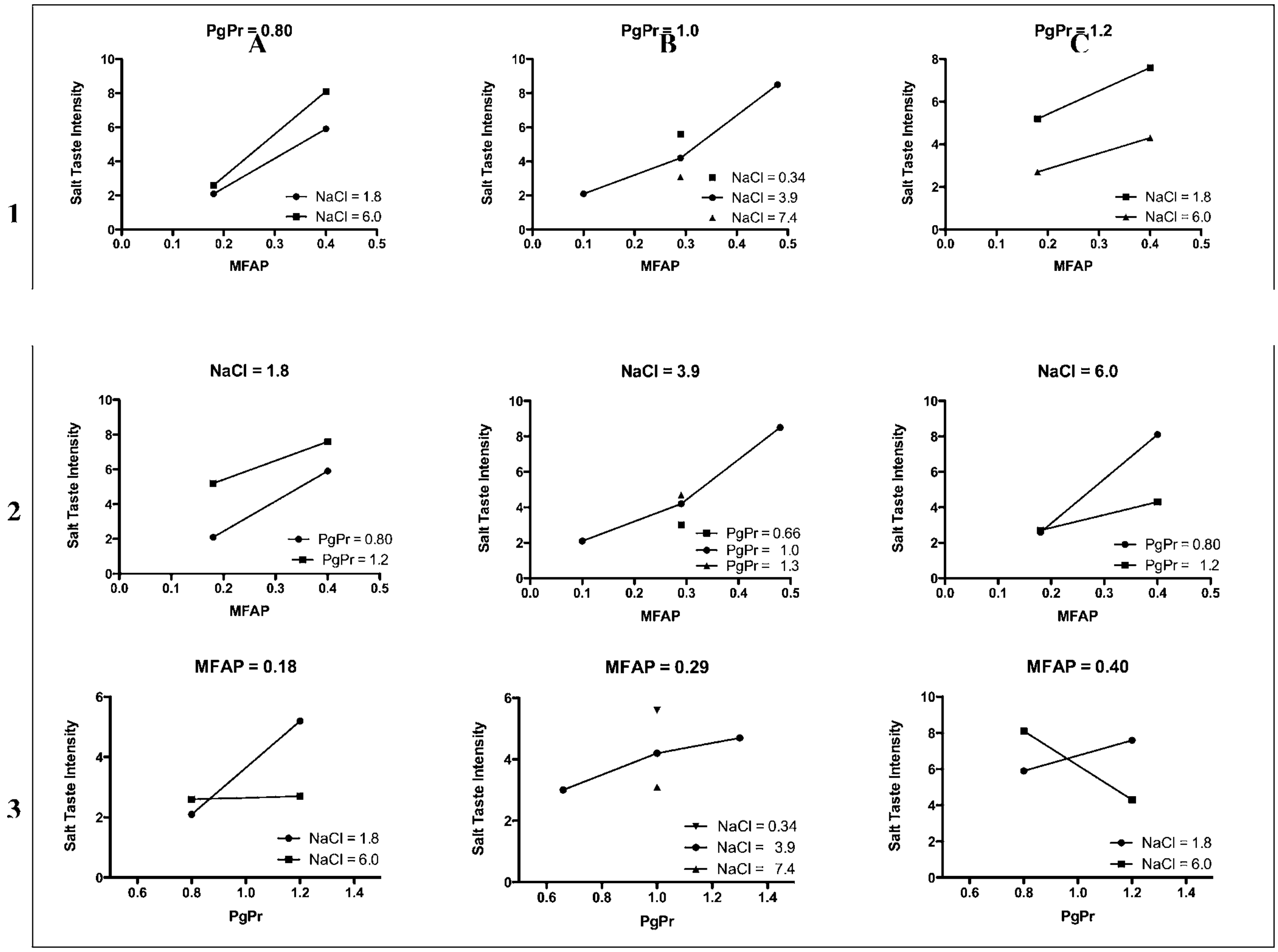

Figure 5. Scatter plots of salt taste intensity holding each variable constant at three different levels. PgPr and NaCl reported as percentages of their respective phases.

influence was not as significant as MFAP ($P < 0.02$ vs $P < 0.0001$ for PgPr and MFAP, respectively). MFAP was the dominant factor for several reasons. First, with a greater MFAP (and assuming similar droplet sizes in all emulsions), there was a greater number of salt-containing droplets subjected to droplet−droplet collisions and coalescence during oral processing. With more droplets destabilizing and releasing their saline payload, more salt was freely available for perception in the oral cavity. Second, greater MFAPs implied that there would be less oil in the emulsion to coat the oral mucosa during consumption. As noted by Lynch et al.,[19] a more thorough oil coating in the mouth often diminishes sensory perception and intensity. Similarly, Malone and Appelqvist[14] stated that the sensory perception of saline oil-in-water emulsions was dependent on the salt concentration and volume fraction of the aqueous phase (and, by default, the volume fraction of the oil phase). This assertion would also apply to oil-continuous systems, when one considers the mouth-coating effect. Finally, PgPr concentration affected emulsion stability and thus breakdown, with lower surfactant levels resulting in less stable emulsions more prone to coalescence. From a sensory perspective, this increased the likelihood of droplets breaking down in the mouth and releasing their content, likely explaining the PgPr term in eq 1.

It has been reported that salt destabilizes o/w emulsions due to an electrostatic screening effect, by which repulsion between two charged droplets (where an ionic surfactant is used) is shielded by the NaCl counterions, leading to droplet flocculation and coalescence.[9] In the present oil-continuous systems, salt had a stabilizing effect, notably by increasing emulsifier absorption density at the interface, increasing interfacial film strength and reducing interfacial tension.[9,10] Furthermore, changing the hydration conditions of the absorbed emulsifiers via depletion of the hydration shell around the surfactant polar headgroup may have significantly affected solubility and hence emulsion stability.[21] Together, these effects created conditions that favorably reduced coalescence.

The interplay between NaCl and PgPr significantly influenced salt taste intensity. At a low MFAP (0.18), there was no clear-cut relationship between these two parameters. For example, with formulations 2 and 4, even though the NaCl concentration was lower in the former (1.78 vs 6%), its saltiness was perceived as significantly higher than that of the latter formulation (saltiness rating of 5.2 vs 2.6) ($P < 0.05$). Yet, formulations 1 and 3 (MFAP = 0.18) did not show this unexpected behavior (ratings of 2.1 vs 2.6), with no differences in salt taste perception even though sodium levels were divergent (1.78% vs 6%). In formulations 2 and 4, the PgPr concentration was 1.2% as opposed to 0.8% in formulations 1 and 3. At high MFAP (0.40), emulsions with more PgPr (samples 6 and 8) showed greater salt taste intensity with less NaCl present compared to equivalent formulations with less PgPr (samples 5 and 7), for which higher taste intensity was seen with greater NaCl concentration. It appears that there is some threshold at or near this high MFAP at which, with a lower PgPr concentration, the stabilizing influence of NaCl is no longer enough to reduce sensory intensity. This stabilizing effect was most dramatic with samples 11 and 12 (MFAP = 0.29), with the former deemed saltier despite the fact it contained 20 times less salt. Although the separation assay did not indicate an observable difference between samples 11 and 12, the significant difference in sensory perception suggests a difference in stability in these emulsions under oral processing, perhaps an enhanced resistance to shear with higher sodium chloride levels. These results confirmed that emulsions with less PgPr and NaCl were more prone to oral destabilization, leading to a more intense saltiness response.

In line with MFAP-dependent viscosity ratings, thickness sensory ratings were also directly related to MFAP (Table 1), with higher sensory thickness ratings dependent on MFAP. Whether saltiness was influenced by sample thickness was not determined. However, the effect of MFAP clearly influenced more than simply thickness, as it was directly tied to NaCl present and thus saltiness. This interconnectedness between viscosity and NaCl sensory perception was not studied, as it was difficult to modify either thickness or saltiness without modifying the other, presenting a significant challenge in clarifying this relationship. The apparent shear-thinning behavior observed in samples with MFAP above 0.29 may have had an influence on the sensory perception of thickness in these samples. Koliandris et al.[20] reported that the sensory perception of thickness, but not taste, was dependent on the pseudoplasticity of aqueous hydrocolloid systems, but further study would be required to investigate this in an emulsion system. Of note, the relationship between emulsion viscosity at both 50 and 100 s^{-1} and sensory ratings of thickness yielded Pearson product-moment correlation coefficients of 0.91 and 0.92, respectively ($P < 0.0001$), suggesting a strong relationship between instrumental and sensory measures of viscosity.

Overall, this study demonstrated that limited emulsion stability is the key factor dictating saltiness perception, with the interplay between salt load, PgPr concentration, and MFAP responsible for providing an appropriate saltiness response. These findings have clear implications for the development of salt-reduced foods and highlight the delicate balance between ensuring adequate emulsion stability during the lifetime of a processed food and the requisite oral destabilization to ensure appropriate saltiness perception. If this balance is not found in a formulation, poor shelf stability and/or suboptimal salt taste perception will be the result.

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Notes

The authors declare no competing financial interest.

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