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Short Communication

The sensory optimum of chicken broths supplemented with calcium di-glutamate: A possibility for reducing sodium while maintaining taste ☆

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ABSTRACT

This study examined the effects of calcium di-glutamate (CDG) supplementation on the sensory and hedonic characteristics of chicken broth. Thirty-four normal weight men and women aged 20–35 years tasted 12 soups containing 4 different concentrations of sodium chloride (.16%, .53%, .85%, and 1.7% w/w) and three concentrations of CDG (0%, .17%, and .33% w/w). Participants tasted all the soups twice over 2 days and used computer-administered visual analog scales to record taste intensity and hedonic ratings. Soups were presented in random order, at least 3 min apart to allow for taste ratings and mouth rinsing. Data were analyzed using repeated measures analysis of variance. Response surface methodology (RSM) was used to determine the hedonic optima for sodium chloride and CDG. Results indicated that CDG could partly replace sodium chloride at constant levels of liking and pleasantness. These data provide evidence that lower sodium broths can be made more palatable with CDG supplementation.

1. Introduction

Dietary recommendations urge consumers to reduce their sodium intakes (USDA/DHHS, 2010). However, foods that are low in salt (sodium chloride) may be less preferred (Breslin & Beauchamp, 1997). The inclusion of other tastes or flavors may allow manufacturers to reduce the sodium content of foods, without sacrificing palatability (Kremer, Mojet, & Shimojo, 2009). Based on its sensory profile, the amino acid glutamate, in particular, may provide an effective way to enhance the palatability of reduced-sodium soups (Ball, Woodward, Beard, Shoobridge, & Ferrier, 2002; Roininen, Lähteenmäki, & Tuorilla, 1996; Yamaguchi & Takahashi, 1984).

The ability of glutamate to enhance the sensory quality of certain savory foods is well established (Bellisle, 1998) and discovery of a taste receptor pathway (Nelson et al., 2002), indicates that the umami sensation provided by glutamate is a distinct taste in its own right. Laboratory-based sensory studies have shown that monosodium glutamate (MSG) can potentiate the perceived savoriness of broths and improve hedonic response overall (Daget & Guion, 1989; Okiyama & Beauchamp, 1998; Roininen et al., 1996; Yamaguchi & Takahashi, 1984).

However, MSG may not be the best vector for sodium reduction since lowering the content of sodium chloride would be partly offset by the higher content of MSG. While sodium-free salts of glutamate would be preferable, their sensory qualities have not been extensively studied.

Calcium di-glutamate (CDG) provides a sodium-free alternative. CDG is one of the 5 glutamate salts internationally accepted as food flavor enhancers (Jinap & Hajeb, 2010). In one study, the addition of CDG to lower-sodium soups helped to maintain hedonic value (Ball et al., 2002). However, that study did not identify the optimum sensory combination of sodium chloride and CDG. Sensory qualities of the taste mixtures with respect to the 5 taste sensations (i.e. sweet, sour, salty, bitter, and umami or savory) were also not measured. This study was designed to assess the sensory optimum as well as those attributes.

This study examined the sensory characteristics of a range of values of sodium chloride and CDG added to a low sodium chicken broth. The sodium values included those that the US Food and Drug Administration uses to classify soups as "reduced sodium" and "low sodium"(Kurtzweil, 1994).

2. Materials and methods

2.1. Participants

Thirty-four men and women aged 20 and 35 participated in the study. Participants were normal weight (body mass index 18.5–24.9). Participants were recruited on campus and the surrounding neighborhood through fliers, campus newspapers, and online postings.

Candidates were invited to attend one preliminary screening session in the lab where they completed a written consent form.

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After the consent, each candidate's weight and height were measured to verify BMI. Potential subjects were also screened to verify the eligibility criteria and to determine whether they were willing to consume the soups given in the study. Potential participants were excluded if they were taking medication, were smokers, had food allergies or restrictions, disliked chicken soups or broths, or if their personal schedule did not permit regular scheduled attendance. All aspects of the study were approved by the Institutional Review Board of the University of Washington.

2.2. Protocol

The study followed a within-subject, repeated measures design, with each participant serving as his or her own control. Participants were required to refrain from eating at least 2 h prior to their testing session.

Participants arrived at 1420 h on the first testing session and sat in separate cubicles in the sensory evaluation room. They were briefed on study protocols and asked to remain seated for the length of the study. During the first laboratory visits, participants tasted and rated four sodium chloride (NaCl) solutions in deionized water (10 ml approx.), ranging in concentration from .16% to 1.7% w/w and served in 15 ml sample cups at room temperature (22–25 °C). Participants were asked to hold the sample in their mouths for 5 s and to complete computer-based visual analog scale (VAS) ratings.

Beginning at 1500 h, 12 NaCl/CDG concentration combinations of chicken broth were tested at 3-min intervals to allow for mouth rinsing between samples. Each 10–12 ml serving broth was served in 15 ml sample cups served warm (50–60 °C). After all 12 combinations were evaluated, participants were allowed to leave. The sequence of NaCl/CDG concentrations was randomized for each participant. Each participant was exposed to the 12 combinations of NaCl and CDG twice over 2 days, separated by at least 1 week.

2.3. Test broth characteristics

All broths were prepared in the laboratory using ''Kitchen Basics Unsalted Chicken Stock'' (Kitchen Basics Inc. Brecksville, OH). Chicken stock was purchased from a single lot at a local supermarket to assure consistency and contained .16% w/w NaCl (150 mg sodium per 240 ml serving). This base chicken stock allowed for upward adjustment of the total sodium concentration by the addition of CDG and NaCl. This product also allowed this study to examine a product that meets the FDA standards for a ''reduced sodium'' product (i.e. at least 25% less sodium than the original product) and that is close to the standard for the product label ''low sodium'' (i.e. 140 mg or less sodium per serving). The range of CDG concentration for the test broths was 0–.33% w/w and the range for NaCl concentration was .16–1.7% (see Table 1). CDG was obtained from Ajinomoto Co., Inc. and added to the chicken stock to achieve the desired concentrations. Diamond Crystal® Pure Natural Kosher Salt (Cargill Inc., Minneapolis, MN) was added to each condition to achieve the desired sodium concentrations.

The energy density (ED) was .1 kcal/g for all broth vehicles. Samples of the plain broth were sent to Sillicker Inc. (Sillicker Food Safety and Quality Solutions Inc., Chicago Heights, Illinois) for laboratory ascertainment of sodium and glutamic acid concentrations. Analyses were conducted using the AOAC 984.27 method (AOAC, 2002). Analyses showed that the base broth contained no glutamic acid (<.05% w/w) (detection limit = .01% w/w) and very little sodium (68 mg/100 g), consistent with the amount listed on the label.

2.4. Taste and hedonic evaluations

Taste intensity and hedonic ratings were assessed using a semi-anchored VAS presented on the computer screen. Each scale had opposing extremes, i.e. ''not at all savory'' versus ''extremely savory.'' Participants used a computer mouse to position a cursor along a 100 mm line that best described their sensation at that time. The questions were:

Please rate the intensity of the following characteristics for this broth: ''sour'', ''bitter'', ''salty'', ''savory'', ''sweet'', and ''pleasant''. The term savory was used to describe the ''umami'' taste because the ''umami'' flavor is often interpreted in western cultures to be ''savory'' (Ninomiya, 2002). Participants were also asked to rate how much they liked each broth using the same 100 mm scale.

2.5. Data analyses and sensory optimization modeling

Data analysis used the statistical package for the social sciences (SPSS) version 17.0. Saltiness intensity ratings of NaCl solutions were analyzed using repeated measures analyses of variance (ANOVA) with NaCl concentration as the repeated measure and gender as the between subjects factor. Sensory and hedonic ratings for chicken broths were analyzed using repeated measures ANOVA, with NaCl-glutamate combinations as a within-subjects factors and gender as between-subjects factors. For the sensory and hedonic responses where ANOVA's indicated a significant effect of condition, Bonferroni correction was applied. Given that no main effects of gender were observed for any taste variables, data were pooled across men and women.

Sensory and hedonic ratings were then used to construct three-dimensional response surfaces for estimating sensory optima. Response surface methodology (RSM) is an approach to analyzing flavor or tastant interactions that can reveal optimal combinations beyond those that were tested directly (Drewnowski & Moskowitz, 1985; Soukoulis & Tzia, 2009). The method relies on quadratic algorithms and is well established in sensory analysis (Drewnowski, Brunzell, Sande, Iverius, & Greenwood, 1985; Yamaguchi & Takahashi, 1984). For the present study, the quadratic equations took the form of:

$$Y = b_0 + b_1X_1 + b_2X_2 + b_{11}X_1^2 + b_{22}X_2^2 + b_{12}X_1X_2$$

where Y = sensory rating, X_1 = % NaCl and X_2 = % CDG.

The RSM models were run using Design-Expert version 8.0 for Windows (Stat-Ease Inc., Minneapolis, MN).

2.6. Sample size

Sample size calculations were based on expected largest difference in liking ratings (mm VAS) between any two conditions. The sample size was 34 adults and was based on a mean (±SD) effect size of 8 (±23) mm and a power level of 80% and $\alpha = .05$ using a standard formula for cross-over study designs (Rosner, 2000).

3. Results

3.1. Participant characteristics

The mean BMI was 23.0 (±1.7) kg/m^2 for the 17 males and 21.6 (±1.9) kg/m^2 for the 17 females. Mean age was 24.2 (±3.8) years for males and 22.8 (±3.5) years for females.

3.2. Aqueous solutions

Analyses of taste responses for NaCl solutions showed a significant main effect of NaCl concentration, $F(3,30) = 103.48$ ($p < .001$).

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Table 1
Mean (SE) taste intensity and hedonic ratings for the 12 broths.

% w/w CDG	.16% w/w NaCl	.53% w/w NaCl	.85% w/w NaCl	1.70% w/w NaCl
Sour (100 mm VAS)				
0	20.9(4.1)	23.7(3.7)	20.00(3.1)	30.8(4.3)
0.17	23.9(4.2)	21.4(3.4)	23.07(3.3)	27.4(4.4)
0.33	24.7(4.5)	21.1(3.5)	21.20(3.6)	25.8(4.1)
Bitter (100 mm VAS)				
0	21.7(4.2)	22.0(3.9)	17.8(3.4)	22.5(4.1)
0.17	23.7(3.8)	20.6(3.6)	17.8(3.2)	22.5(4.0)
0.33	28.7(4.6)	18.5(3.3)	17.9(3.4)	19.8(3.9)
Salty (100 mm VAS)				
0	14.5(2.3)	37.7(3.5)	55.8(3.1)	82.9(1.7)
0.17	16.5(2.3)	42.9(3.1)	54.8(2.7)	80.9(2.1)
0.33	22.4(2.8)	40.8(3.1)	56.6(3.2)	75.4(2.7)
Sweet (100 mm VAS)				
0	12.3(2.3)	19.4(3.2)	20.5(3.4)	15.7(3.4)
0.17	16.4(2.5)	24.4(3.5)	22.4(3.3)	17.7(2.7)
0.33	14.1(2.6)	21.9(2.9)	24.5(3.8)	19.1(3.5)
Savory (100 mm VAS)				
0	17.8(2.5)^{a}	39.6(2.8)^{b}	50.7(3.1)^{b,c,e}	46.3(4.3)^{b,d,e}
0.17	23.2(2.7)^{a}	46.2(3.1)^{b}	56.9(3.1)^{e}	51.7(4.1)^{b,e}
0.33	27.0(3.1)^{a}	46.9(2.6)^{b}	57.2(3.1)^{c,d,e}	52.2(4.5)^{b,e}
Pleasant (100 mm VAS)				
0	25.7(2.6)^{a}	42.4(2.9)^{b,h}	54.6(3.1)^{b,e}	35.9(3.5)^{a}
0.17	27.3(3.1)^{a}	50.5(2.4)^{b,f}	57.8(3.1)^{e,f,g,i}	41.8(3.8)^{a,b,g}
0.33	31.1(2.1)^{a,h}	51.4(2.9)^{b,i}	56.1(2.9)^{f,g,i}	41.8(4.4)^{a,b,i}
Liking (100 mm VAS)				
0	26.4(2.6)^{a}	46.3(2.5)^{b}	56.8(2.8)^{c,d}	37.0(3.6)^{a,b}
0.17	27.7(2.8)^{a}	51.9(2.0)^{b,c,d}	58.6(2.6)^{d}	43.2(3.7)^{a,b,c}
0.33	29.4(3.0)^{a}	53.1(2.3)^{b,c,d}	55.9(2.8)^{b,c,d}	42.3(2.3)^{a,b,c}

Within each rating scale, means with no common superscript differ ($p < .05$). For sour, bitter, and salty ratings, no superscripts are present due to a lack of a significant effect of CDG and NaCl concentration.

Pairwise comparisons revealed that all solutions were different from one another (all p's < .001). There were no significant interactions.

3.3. Sensory responses to broth conditions

Sensory and hedonic ratings for the 12 stimuli are shown in Table 1. The sensory ratings for sour and bitter were centralized around 20 mm VAS, thus none of the ratings were very high. The ANOVAs for the sensory characteristics of ‘‘sour’’ and ‘‘bitter’’ did not reveal any significant effects of NaCl concentration or CDG concentration for the chicken broths, thus they were not included in any further analysis.

The broths with the lowest NaCl concentrations (.16%) were rated as the least ‘‘salty’’, and ratings increased monotonically toward the highest concentration of NaCl (1.7%). The means and standard errors for all 12 conditions for participants' responses to ‘‘salty’’, ‘‘sweet’’, ‘‘savory’’, ‘‘pleasant’’, and ‘‘liking’’ are contained in Table 1. The ANOVAs for the ‘‘salty’’ rating indicated a significant effect of NaCl concentration, F (3, 30) = 253.89, $p < .001$, but no effect of CDG concentration was observed. Analysis of the pair-wise comparisons between the sodium concentrations indicated that all concentrations were significantly different than one another (all p's < .001). There were no effects of gender or any gender related interactions.

Sweetness ratings centered around 15–20 mm for most of the broths with no large deviations. However, the ratings in terms of ‘‘sweet’’ appear to be more parabolic where the highest ratings were at the moderate concentrations of saltiness and higher concentrations of CDG (see Table 1). The ANOVA for ‘‘sweet’’ indicated there was a significant effect of CDG concentration F (2, 31) = 3.83, $p = .03$, and a significant effect of NaCl concentration F (3, 30) = 5.94, $p < .001$. There was no effect of gender or any interactions between broths. The broth that was rated as the most ‘‘sweet’’ was the broth that contained .33% CDG and .85% NaCl. The broth rated as the least ‘‘sweet’’ was that containing 0% CDG and .16% NaCl. Although there were significant effects of NaCl and CDG concentration, the analysis of the Bonferroni corrected pairwise comparisons did not reveal any significant differences among the conditions (see Table 1).

The ratings for the sense of ‘‘savory’’ ranged from approximately 18–57 mm with the broth rated as the least savory containing 0% CDG and .16% NaCl and that rated highest being the one containing .17% CDG and .85% NaCl. These ratings also appeared parabolic where the savory ratings at the highest concentration of NaCl decrease relative to those at the moderate levels of NaCl and higher concentrations of CDG. The ANOVA for ‘‘savory’’ indicated that there was a significant effect of CDG concentration F (2, 31) = 16.13, $p < .001$. There was also a significant effect of NaCl concentration F (3, 30) = 41.27, $p < .001$. There was no effect of gender or any interactions between broths. The broth that was rated as the most ‘‘savory’’ was the broth that contained .33% CDG and .85% NaCl w/w. The analysis of the Bonferroni corrected comparisons for all conditions did indicate that there were some significant differences among the different conditions (see Table 1).

The ratings for the ‘‘pleasant’’ ratings ranged from approximately 26–58 mm. The broth that was rated as the most ‘‘pleasant’’ was the broth that contained .17% CDG and .85% NaCl w/w. The broth rated as the least ‘‘pleasant’’ was that containing 0% CDG and .16% NaCl. These ratings were quadratic in nature, as the high concentrations of NaCl decreased the pleasant ratings to similar levels as the very low NaCl concentration, an effect somewhat modified by the CDG concentration. The ANOVA for ‘‘pleasant’’ indicated there was a significant effect of CDG concentration F (2, 31) = 7.14, $p = .002$. There was also a significant effect of NaCl concentration F (3, 30) = 27.33, $p < .001$. There was no effect of gender or any interactions among broths.

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The ratings for "liking" were very similar to those for "pleasant." The broth that was rated as the most liked was the broth that contained .17% CDG and .85% NaCl w/w. The broth rated as the least liked was that containing 0% CDG and .16% NaCl. The ANOVA for "liking" also indicated there was a significant effect of CDG concentration $F(2, 31) = 3.51$, $p = .04$. In addition, there was a significant effect of NaCl concentration $F(3, 30) = 38.26$, $p < .001$. There was no effect of gender or any interactions among broths.

3.4. Modeling of sensory optima

Data were used to estimate sensory optima using the RSM. Only the sensory variables that showed significant differences across sodium and CDG concentrations were modeled. The resulting contour plots for sweet, savory, liking, and pleasant are shown in Fig. 1. There were significant correlations among these dependent variables. The highest of these correlations was between the "liking" and "pleasant" ratings ($r = .92$, $p < .001$), followed by the pleasant and savory ratings ($r = .63$, $p < .001$), the liking and savory ($r = .60$, $p < .001$), savory and sweet ratings ($r = .34$, $p < .001$), pleasant and sweet ratings ($r = .31$, $p < .001$), and sweet and liking ($r = .30$, $p < .001$). For all surfaces the optimum appeared at the middle levels of NaCl (i.e. from .54% to 1.30% w/w) and the higher levels of CDG (i.e. from .17% to .33% w/w). In terms of "liking" and "pleasant" ratings of the broth stimuli, the contour plots indicate that moderate liking (between 45 and 60 mm on the VAS) was maintained for the lower NaCl concentrations (e.g. .54–.93% w/w) only when CDG was present.

For the "sweet" model the regressions model terms are as follows; where Y = "sweet" ratings, X_1 = % NaCl and X_2 = % CDG. The resulting equation determined by RSM for sweetness is:

$$Y = 9.35 + 24.65X_1 + 27.63X_2 - 12.59X_1^2 - 64.97X_2^2 + 3.23X_1X_2 \quad (R^2 = .91).$$

The same RSM model applied to sweetness was also used to solve for Y = "savory" ratings. The resulting equation is:

$$Y = 5.44 + 82.28X_1 + 52.69X_2 - 34.18X_1^2 - 79.10X_2^2 - 5.75X_1X_2 \quad (R^2 = .99)$$

The same RSM model was also used to solve for Y = "pleasant" ratings resulting in:

$$Y = 12.62 + 80.80X_1 + 41.08X_2 - 39.22X_1^2 - 70.50X_2^2 - 1.66X_1X_2 \quad (R^2 = .98)$$

The RSM model was then used to solve for Y = "liking" ratings resulting in:

$$Y = 13.62 + 84.48X_1 + 32.35X_2 - 41.25X_1^2 - 70.22X_2^2 + 1.96X_1X_2 \quad (R^2 = .98)$$

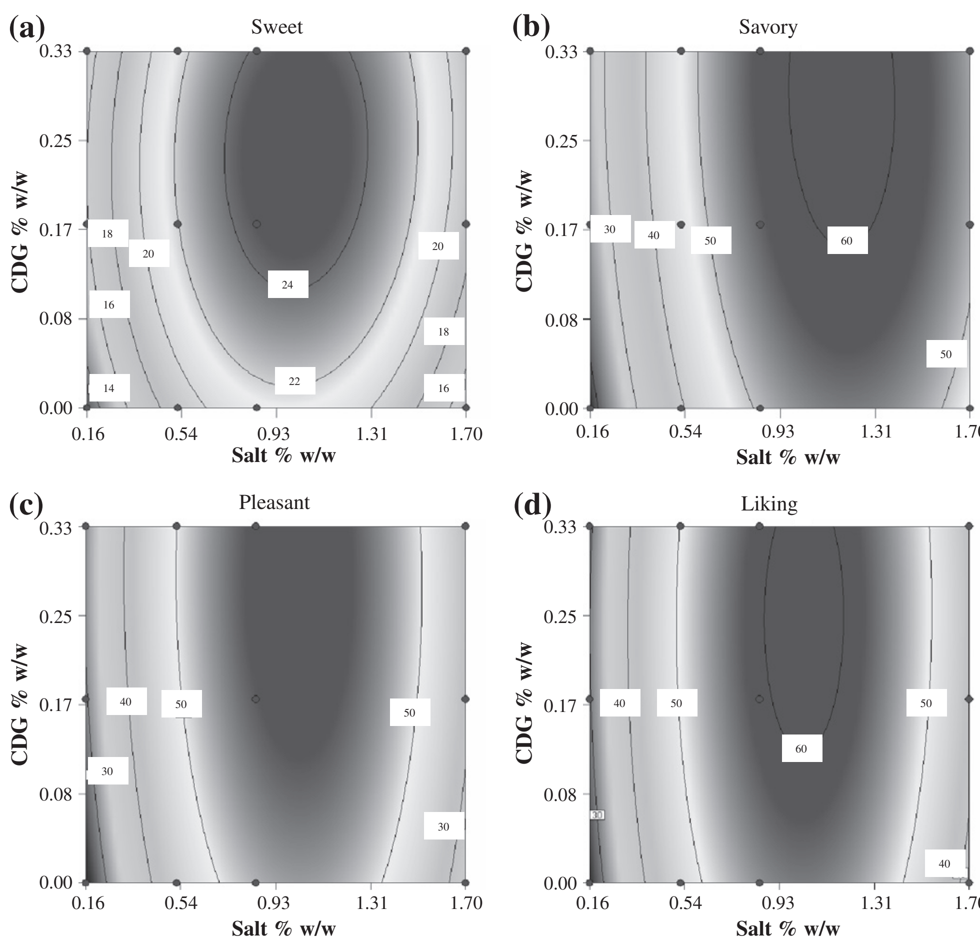

Fig. 1. Contour plots derived using response surface methodology showing (a) "sweet" ratings (b) "savory" ratings (c) "pleasant" ratings and (d) and degree of liking. Darker areas indicate higher ratings and numbers represent participant ratings for each variable.

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Table 2
Response surface quadratic regression model for sensory and hedonic attributes.

Rating type	df	*F* value	*p* Value
Sweet	5	12.43	.004
Savory	5	815.66	<.001
Pleasant	5	70.13	<.001
Liking	5	58.06	<.001

The significance and terms of all quadratic regression models are listed in Table 2. All models were significant and the model coefficients for NaCl concentration were higher than those for CDG concentration in each case.

4. Discussion

Taste is one of the most important factors influencing consumers food purchasing decisions (Drewnowski & Darmon, 2005; Glanz, Basil, Maibach, Goldberg, & Snyder, 1998). Sodium improves the taste of food products and also contributes to other sensory characteristics but intake of sodium by Americans is far in excess of current dietary guidelines, contributing to chronic disease (Smith-Spangler, Juusola, Enns, Owens, & Garber, 2010; USDA/DHHS, 2010). The Dietary Guidelines for Americans have stressed the need to reduce the sodium content in the food supply (USDA/DHHS, 2010). However, reaching that goal, while maintaining the palatability of food, will require reformulation and possibly the use of flavor enhancing ingredients.

The present findings indicate that calcium di-glutamate (CDG) can improve the sensory and hedonic characteristics of lower-sodium foods. These results are also supported by previous studies investigating the sensory characteristics of soups containing CDG and other glutamate based compounds (Ball et al., 2002; Yamaguchi & Takahashi, 1984). However, these previous studies used much more complex soups that contained ingredients such as pumpkin and Japanese bonito. The current study used a basic chicken broth and added differing levels of NaCl and CDG, thus our results help to generalize previous findings.

This study used varying concentrations of CDG and sodium to establish sensory profiles of a chicken broth and a sensory optimum for that sensory profile was established using RSM. One limitation of the current findings is that a CDG concentration which could cause lower hedonic ratings was not established. While sodium chloride concentrations in excess of .85% w/w were found to be associated with lower hedonic ratings, such a hedonic breakpoint was not well established with regard to CDG. Future studies should be conducted to establish a concentration of CDG that decreases the sensory pleasure of chicken broth to assure that the hedonic optimum from CDG concentration is achieved. However, as the hedonic ratings for the chicken broths did not differ substantially between those broths supplemented with .33% CDG and the broths containing .17% CDG, this is not a major limitation. Another limitation is that this study exclusively used naïve tasters rather than a mix of naïve and trained tasters. The reason for this was that this study was designed to build on previous similar designs (Ball et al., 2002). This feature may have led to the finding that the "savory" and "sweet" ratings were correlated with the "liking" and "pleasant" ratings because the naïve panelists may not have been able to distinguish these specific sensations without training (Sinesio, Comendador, Peparaio, & Moneta, 2009). Future studies could include trained tasters to ascertain better sensory characteristic data for each condition (Sinesio, Peparaio, Moneta, & Comendador, 2010). However, this previous study also indicated that naïve participants could distinguish between soups with increasing umami flavor, even though they could not identify the specific attribute "umami" (Sinesio et al., 2010). Future studies should also be directed toward the different types of food products, where CDG supplementation might allow for reduced the sodium concentration without loss of palatability.

5. Conclusions

Supplementing chicken broth with calcium di-glutamate can improve the taste profile of lower sodium soups and might be useful in reducing the sodium content of the food supply.

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