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The effect of Zinc on Human Taste Perception

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Abstract

Zinc salts are added as a nutritional or functional ingredient in food and oral care products. The first experiment in this study investigated the taste and somatosensory effect of zinc salts (chloride, iodide, sulfate, bromide, acetate). The zinc salts had very little taste (bitter, salty, savory, sour, sweet), and the taste that was present was easily washed away with water rinses. The major oral quality of zinc was astringency, and the astringency lingered beyond expectoration. The second experiment combined zinc salts with prototypical stimuli eliciting basic tastes. Zinc was a potent inhibitor of sweetness and bitterness (>70% reduction in taste), but did not affect salt, savory or sour taste. The implications of zinc’s influence on flavor are discussed in this paper.

Keywords: zinc salts, taste inhibition, human psychophysics, sweet, bitter
The Taste of Zinc

Introduction

Zinc is an essential micronutrient for humans that is required as a co-factor for numerous enzymic reactions. As such, zinc is essential for the healthy growth and development of the population (for review see Brandao-Neto and others (1995)). Zinc deficiency is one of the leading risk factors for morbidity and mortality (ranked 11th by the WHO) in developing regions of the world, with infants and children at particular risk (Ezzati and others 2002). Given zinc’s importance for healthy growth and development, zinc salts are added to a number of foods as nutritional supplements. In addition, zinc salts are added to foods and oral care products for antimicrobial and anti-halotosis effects (Loesche and Kazor 2000), for functionality within a matrix (Ng and MacKnight 1996), and for binding in dental-cements to support tooth structures (Pawlig and Trettin 2000).

When zinc is added to a food or oral care product, it will likely contact the taste tissue when placed in the mouth. It is therefore important to understand the influence of zinc in products on taste perception. The aim of this paper is to describe how zinc influences taste perception.

Zinc readily complexes with amino acids and proteins, and has a high affinity for both thiol and hydroxy groups. Because of the chemical and physical properties of zinc, it has the ability to influence oral perception by: 1/ eliciting taste itself, 2/ interfering with the normal functioning of a taste system, and 3/ eliciting astringency. What follows is a brief background on taste receptor processes and mechanisms of astringency that are relevant to this research.

Zinc as a taste stimulus. The oral cavity contains the taste receptors that are responsible for detection of a wide variety of chemicals, including cations such as zinc.
The taste system presumably evolved in part to distinguish nutritive food from toxins, thereby increasing the likelihood of survival and reproduction of individuals who have these gustatory capabilities (Glendinning 1994). Stimuli interact with taste transduction mechanisms in the oral cavity (ionotropic and metabotropic receptors) and afferent signals are sent to the nucleus of the solitary tract, the first gustatory relay, and to upstream taste processing regions of the brain where the signal is decoded and a taste sensations are perceived (sweet, sour, salty, bitter and savory). Taste will be perceived if zinc activates taste transduction mechanisms.

**Zinc as a taste modifier.** Taste receptors are composed of amino acids making them susceptible to protein-zinc complexes. Any binding of zinc to taste receptor proteins could change the 3-dimensional structure of the receptor, thereby altering the active site of the receptor, rendering it unavailable for normal function. If this hypothetical situation occurs, zinc may inhibit or alter the taste of foods or oral care products to which it is added.

**Zinc as an astringent.** Astringency is a tactile sensation rather than a taste (Breslin and others 1993) and is defined as “the complex sensations due to shrinking, drawing or puckering of the epithelium as a result of exposure to substances such as alums or tannins” (ASTM 1989). Zinc may bind to salivary protein responsible for oral lubrication resulting in a change in the 3-D structure of the protein that causes reduced salivary lubrication (an astringent sensation). In addition, zinc may cross-link epithelial proteins causing a constriction of the oral surface that results in astringency.

This is the first comprehensive investigation of zinc’s influence on taste. The first experiment investigates the taste of five zinc salts and their lingering effect in the oral
cavity after a brief adaptation. The second experiment investigates the influence zinc sulfate has when mixed with exemplars of the five basic tastes (bitter, salty, savory, sour, sweet).
Materials and Methods

Stimuli

Zinc chloride (ZnCl₂), zinc bromide (ZnBr₂), zinc iodide (ZnI₂), zinc acetate (Zn(C₂H₃O₂)₂), zinc sulfate (ZnSO₄), magnesium sulfate (MgSO₄), sodium chloride (NaCl), monosodium glutamate (MSG), tannic acid, sucrose, ammonium chloride (NH₄Cl), urea, and glucose were purchased from Sigma (St. Louis). Quinine-HCl (QHCl) was purchased from Fluka Chemika (Buchs, Switzerland). Carbonated water (Seltzer) was purchased from a local store. Aqueous solutions were freshly prepared every 2-3 days, using deionized (di) Millipore™ filtered water, prior to the initialization of the experiments. The solutions were stored in amber glass bottles and refrigerated. Millipore™ filtered di water was used as the blank stimulus and the rinsing agent in all experiments.

Subject training

Twenty-eight non-smoking volunteers (eighteen females) between 18 and 52 years old (mean 30 years) were paid to participate in the study. Subjects were generally employees of Monell Chemical Senses Center (primarily Caucasian and African-American). They provided their informed consent on an Institutional Review Board approved form. The subjects were asked to refrain from eating, drinking or chewing gum for at least one hour prior to testing. Not all subjects participated in all experiments. All tests were carried out in a facility specifically designed for group testing at the Monell Chemical Senses Center. Subjects were initially trained to use the general Labeled Magnitude Scale (gLMS) following standard published procedures (Green and
others 1993; Green and others 1996) except the top of the scale was labeled as “strongest imaginable’ sensation of any kind (Bartoshuk 2000). The gLMS is a psychophysical tool that requires subjects to rate the perceived intensity along a vertical axis lined with adjectives: barely detectable=1, weak=5, moderate=16, strong=33, very strong=51, strongest imaginable=96; the adjectives are spaced semi-logarithmically, based upon experimentally determined intervals to yield ratio quality data. The scale only shows adjectives not numbers to the subjects, but the experimenter receives numerical data from the computer program. Subjects were trained to identify each of the five taste qualities and the oral sensation of astringency and tingle/sting by presenting them with 10ml of prototypical stimuli: salty, 150mM NaCl; bitter, 0.05mM QHCl; sweet, 300mM sucrose; sour, 3mM citric acid; savory, 100mM MSG; astringency 0.5mM tannic acid; and tingle/sting from carbonated water. To help subjects understand a stimulus could elicit multiple taste qualities, 300mM urea (bitter and slightly sour) and 50mM NH₄Cl (salty, bitter, and slightly sour) were employed as training stimuli.

A computerized data-collection program was used in all sessions with either 5 gLMSs corresponding to: SWEET, SALTY, SOUR, SAVORY, and BITTER, or 3 gLMSs corresponding to TINGLE/STING, ASTRINGENT, and BITTER, were presented simultaneously. The order of the scales on the monitor was randomised from session to session but remained constant within each session.

Standardization of gLMS ratings.

The gLMS standardization methodology followed previously published methodology used in our laboratory (Delwiche and others 2001). A brief description
follows. Subjects rated the loudness of six tones (generated by a Maico Hearing Instruments tone generator, presented via headphones at 4000 Hz for 2 sec at levels 0, 20, 35, 50, 65, and 80 dB) and the heaviness of six visually identical weights (opaque, sand-filled jars at levels 225, 380, 558, 713, 870, and 999 g). All ratings were made on a computerized gLMS. Subjects were asked to rate the intensity of loudness or heaviness respectively, and all judgments were made within the context of the full range of sensations experienced in life. All stimuli were presented twice in blocks of ascending order. Subjects first rated the intensity of weights, then tones.

There was a significant correlation loudness and heaviness ($r^2=0.62$, $p<0.01$). Since these variables should be unrelated, the correlation indicated that the LMS ratings were subject to individual scale-use bias and required standardization across subjects.

To determine a standardization factor, each subject’s average intensity for loudness was divided by the grand mean for loudness across decibel levels and subjects. This procedure for determining correction factors was repeated with heaviness ratings (averaging across weight levels). The two correction factors were averaged (weights and tones), and each individual’s intensity ratings were multiplied by his or her personal standardization factor for scale-use bias.

Data normalization

The intensity ratings for the salts tended to follow a log-normal distribution. Taking the log of the ratings approximated a normal distribution. Before taking the log, all zero values were converted to 0.24, the lowest possible value above zero that can be measured on the computerized general LMS.
Statistical analysis

Numerical results are expressed as geometric means ± standard error. Statistical variation was determined by one or two-way analysis of variance (ANOVA) using Statistica 6.0 software package. Post-hoc analysis was performed using Tukey HSD. P values <0.05 were considered statistically significant.

Experiment 1A. Descriptive analysis of the taste of zinc salts

The aim of this experiment was to establish the oro-sensory profile of five zinc salts at multiple concentrations (5mM, 25mM, 50mM). Metallic taste was not a descriptor in this research, primarily due a lack of: 1/ an established scientific validity as to whether ‘metallic’ is a taste quality, and 2/ a defined prototypical stimuli that could be used during subject training.

Stimuli

The salts used in this experiment were: ZnCl₂, Zn(C₂H₃O₂)₂, ZnBr₂, ZnI₂, ZnSO₄. Three concentrations were used: 5mM (327ppm Zn), 25mM (1635ppm Zn), and 50mM (3270ppm Zn). Deionized water (dH₂O) was included as a blank as well as a diluent for the salts.
Methodology

During any session, subjects (n=14, 28±4 years old, 8 female) rated either the five taste qualities (sweet, sour, salty, bitter, savory) or two somatosensations (astringency, tingle/sting) and bitterness. Bitterness was included with the somatosensations to minimize any “halo-dumping” effects that may occur, particularly between astringency and bitterness (Lawless and Clark 1992; Frank and others 1993; Clark and Lawless 1994). Subjects were placed into one of two counter-balanced groups, with one group of subjects rating taste qualities first, while the second group began rating somatosensations and bitterness. There was a maximum of 12 solutions per session and each subject participated in 12 sessions. In any one session, subjects tasted solutions of the same molarity to avoid potential carryover effects of tasting a 50mM solution followed by the same solution at 5mM. For example, 50mM ZnSO₄ was tasted in the same session with other 50mM solutions. As a measure of reliability of ratings, each subject tasted and rated all salts at all concentration on three separate occasions. The testing protocol was as follows: subjects wearing nose-clips to avoid olfactory input, were given numerically labeled trays containing solutions (10ml presented in 30ml plastic medicine cups) of the zinc salts in random order. A di water control was also included in each session. Subjects rinsed with di water at least four times prior to testing and at least 4 times during the interstimulus interval of 180 sec. In addition, subjects were given water crackers (Best Yet) between samples to help reduce any lingering oral astringency from the salts. Each subject tasted, and then rated each solution prior to expectorating. Subjects rated on the gLMS.
Experiment 1B. The lingering effects of zinc in the oral cavity

During Experiment 1A, subjects reported that the effects of zinc linger in the mouth after expectoration. This experiment assessed what the lingering effects of zinc were, and if two water rinses were sufficient to wash away any residual tastes and/or somatosensations.

Methodology

Subjects (n=17, 30±4 years old, 10 female), wearing noseclips, were given a series of three solutions (10ml in 30ml medicine cups): solution one was a 50mM zinc solution, two and three were \( \text{di} \) water. Subjects were naïve to the contents of the cups. The rating procedure, scale, and counterbalanced order were the same as above. Subjects were required to place the first solution (50mM zinc salt) in their mouth, hold the solution in their mouth for 5 sec, then rate the intensities of the qualities (either tastes or somatosensations) shown on the computer screen. After an interstimulus interval of 10sec, subjects repeated this procedure with the second solution (\( \text{di} \) water). There was a second interstimulus interval of 10sec and the procedure was repeated with the third solution (\( \text{di} \) water). Subjects were unaware that solutions two and three were \( \text{di} \) water. Subjects did not rinse with water or eat crackers during the experiment. Each session took approximately 1 min to complete and to avoid any potential carry-over effects, subjects had to wait at least an hour between sessions and complete no more than 3 sessions per day. Intensity ratings for each salt at each concentration were made in triplicate.
Experiment 2. The effect of zinc sulfate on sweet, salty, bitter, and savory taste

As well as stimulating taste, zinc salts may alter taste perception of other compounds. The aim of this experiment was to determine whether zinc alters the taste perception of prototypical stimuli (QHCl-bitter, NaCl-salty, MSG-savory, citric acid-sour, and glucose-sweet) at multiple concentrations (therefore multiple intensities).

Stimuli

Only one zinc salt was used in this experiment, ZnSO$_4$. ZnSO$_4$ was chosen because it’s astringency was generally perceived as the weakest in comparison with the other zinc salts. MgSO$_4$ was selected as a control salt to compare the effects of zinc with another divalent cation with the same anion. Prototypical taste stimuli were glucose (sweet), QHCl (bitter), NaCl (salty), citric acid (sour), and MSG (savory).

Methodology

Subjects (n=14, 29±5 years old, 7 female), wearing nose-clips, assessed the influence 25mM ZnSO$_4$ and 25mM MgSO$_4$ had on the sweetness of varying concentrations of glucose (0.4, 0.8, 1.2, 1.6, 2.0, 2.4M), bitterness of QHCl (0.04, 0.11, 0.18, 0.25, 0.33, 0.4mM), savoriness of MSG (30, 60, 90, 120, 200, 300mM), saltiness of NaCl (50, 100, 150, 250, 350, 500mM), and sourness of citric acid (1, 1.6, 2.2, 2.8, 3.4, 4mM). A computerized data-collection program was used in all sessions with 6 gLMSs
corresponding to the basic tastes (SWEET, SALTY, SOUR, SAVORY, BITTER) on one screen, followed by ASTRINGENCY on a second screen. Solutions were prototypical taste stimuli alone and the prototypical taste stimuli with either 25mM ZnSO₄ or MgSO₄. For example, subjects would rate the tastes and astringency of 1.2M glucose followed by rating the tastes and astringency for 1.2M glucose mixed with 25mM ZnSO₄. The prototypical stimulus was always rated first, followed by the stimulus mixed with the salt to avoid any carryover effects of the salt on taste. Between the samples there was an interstimulus interval of 30 sec during which subjects rinsed with di water at least four times. Subjects rated one stimulus pair in any one session with a maximum of 3 sessions a day. Ratings were performed in triplicate for each concentration as a measure of reliability of rating.
Results and Discussion

Experiment 1A and 1B:

Experiment 1A  The taste and somatosensations of zinc salts

A two-way ANOVA (anion x concentration) was performed on the taste and somatosensory intensities of the zinc salts (Figure 1A-F). The anion attached to zinc significantly influenced bitterness [F(4,108) = 3.6, p<0.05], sourness [F(4,52) = 30.1, p<0.001], saltiness [F(4,52) = 5.7, p<0.001], tingle/sting [F(2,26) = 14.11, p<0.05], and astringency [F(4,52) = 8.3, p<0.001]. Increasing the concentration of zinc salts from 5mM to 50mM significantly increased bitterness [F(2,54) = 27.5, p<0.001], sourness [F(2,26) = 7.0, p<0.05], saltiness [F(2,26) = 3.8, p<0.05], tingle/sting [F(2,26) = 4.35, p<0.05], and astringency [F(2,26) = 12.36, p<0.001]. The anion and concentration had no influence on the savory taste of zinc salts. Zinc salts were not described as having sweetness.

The perceived taste of zinc salts was generally below weak (verbal descriptor corresponding to 5.76) on the gLMS (Figure1A-D). An exception to this was zinc iodide, which was reported as having a predominant sour taste. However, there was no difference in pH among the zinc solutions (pH6.5±2). The reporting of increased sourness of zinc iodide may be due to subject confusion between sour and astringent. In general, as the pH of a solution becomes more acidic (more sour), the astringency will increase (Rubico and McDaniel 1992; Lawless and others 1994; Lawless and others 1996; Sowalsky and Noble 1998). Therefore, if a compound is astringent, like the zinc salts, subjects may rate the solutions more sour. In support of this statement, ZnCl₂ was
The next most astringent and sour zinc salt behind ZnI₂. Tukey HSD found no significant difference between the astringency or sourness of ZnI₂ and ZnCl₂.

Tingle/sting is a quality elicited by carbonated water. During pre-testing for this research, tingle/sting was determined to be an attribute associated with the zinc salts. Tukey HSD revealed the chloride and acetate anions significantly reduced the tingle/sting attribute (Figure 1E). Alternatively, the iodide, sulfate, and bromide anions enhance tingle/sting. The physiological mechanisms for tingle/sting are unknown as are the reasons why certain anions would have differential effects on it.

Astringency was the major oral sensation associated with the salts (Figure 1F).

The probable causes of the astringency of zinc solutions are: 1/ the ability of zinc to bind salivary proteins, which in turn causes a decrease in oral lubrication, and/or 2/ cross-linking epithelial bound proteins causing a puckering sensation. Zinc iodide was significantly more astringent than zinc acetate, sulfate, and bromide (p<0.05), indicating that the associated anion can reduce the influence of astringency. Further research is needed to determine how the anions differentially affect astringency.

Experiment 1B Lingering oral effects of zinc salts

Water rinses after tasting NaCl are perceived as faintly sweet (Bartoshuk and others 1971; Bartoshuk 1974). However, in this study, no new tastes were perceived in response to water rinses following a brief adaptation to 50mM zinc salts. Rinsing with water significantly decreased taste intensity: bitterness [F(2,32)=4.6, p<0.05], sourness [F(2,32)=3.7, p<0.05], and savoriness [F(2,32)=6.1, p<0.05] (results not shown). The taste qualities saltiness and sweetness were not reported as being elicited during the water
rinses. Tukey HSD showed the second water rinse significantly decreased the taste intensity compared to the 50mM brief adaptation and first water rinse. Overall the taste of the salts, which was negligible, was easily washed away.

Tingle/sting was not an attribute associated with the water rinses suggesting it is only perceived when the zinc solutions are in the mouth.

Astringency was the most dominant oral sensation associated with zinc salts (Figure 1F). Unlike the tastes, which were washed away with the water rinses, the astringency of the zinc salts was not significantly reduced after two water rinses (Figure 2). There was no effect of anion on the ability of water to rinse away the perceived astringency. Zinc may be binding to epithelial proteins causing the astringent sensation and the binding affinity of zinc to certain epithelial proteins was strong enough to persist during the water rinses.

**Discussion of Experiment 1A&B**

At the concentrations used in this study, the addition of zinc to food and oral care products should not unduly add to the taste profile (bitter, salty, savory, sour, sweet).

However, the addition of zinc adds astringency that lingers once the product is removed from the mouth, and rinsing with water does not diminish the effect. The astringency of zinc and its lingering effects could be a potential problem for manufacturers wanting to incorporate zinc salts into either food or oral care products. However, the choice of anion associated with zinc affects the intensity of the astringent sensation (for example the sulfate anion reduces astringency in comparison to the iodide anion).
Experiment 2

The influence of zinc on sweetness

ZnSO$_4$ altered the sweetness of glucose [F(1,13) = 22.7, p<0.001] and there was a significant interaction between zinc and the concentration of glucose [F(5,65) = 8.0, p<0.001]. Tukey HSD revealed that ZnSO$_4$ significantly inhibited the sweetness (p<0.001) of glucose at all concentrations (Figure 3A). The mean sweetness inhibition by ZnSO$_4$ was 75%, and the mean sweetness intensity of the glucose-ZnSO$_4$ solutions was below weak (gLMS 4.05±0.88). Overall the results show that zinc is a potent inhibitor of sweetness and that increasing the concentration of glucose does not increase the sweetness of the solution containing zinc. This suggests that the mode of suppression is non-competitive. This should be a concern for the food industry (see Discussion below) and further research is needed to assess the influence of a variety of concentrations of zinc on sweetness. The control salt MgSO$_4$ did not inhibit the sweetness of glucose [F(1,13) = 1.9, p=0.2]. This is the first report that zinc is a potent inhibitor of the sweetness in humans.

The influence of zinc on bitterness

ZnSO$_4$ altered the bitterness of QHCl [F(1,13) = 16.1, p<0.001] and there was a significant interaction between ZnSO$_4$ and the concentration of QHCl [F(5,65) = 5.66, p<0.001]. Tukey HSD revealed that ZnSO$_4$ significantly inhibited the bitterness (p<0.001) of QHCl at all concentrations (Figure 3B). The mean bitterness inhibition by ZnSO$_4$ was 70%, and the mean bitterness intensity of the QHCl-ZnSO$_4$ solutions was below weak (gLMS 4.09±0.26). Overall the results show that ZnSO$_4$ is a potent inhibitor
of the bitterness of QHCl. MgSO$_4$ also inhibited the bitterness of QHCl [F(1,13) = 10.2, p<0.05], but there was no interaction between MgSO$_4$ and concentration of QHCl [F(5,65) = 0.4, p=0.85]. A two-way ANOVA between the bitterness of QHCl-MgSO$_4$ and QHCl-ZnSO$_4$ revealed a difference between the salts [F(1,13) = 7.7, p<0.05] and an interaction between the salts and concentration of QHCl [F(5,65) = 4.3, p<0.05]. Tukey HSD revealed that QHCl-ZnSO$_4$ was significantly less bitter than a mixture of QHCl-MgSO$_4$ at all, except the lowest, concentration of QHCl (p<0.001).

This is the first report that zinc is a potent inhibitor of the bitterness in humans.

Influence on salty, savory, and sour

ZnSO$_4$ and MgSO$_4$ did not significantly alter salty, savory, or sour taste qualities. (Figure 3C,D,&E).

Discussion of Experiment 2

Zinc is a potent inhibitor of the sweetness of glucose and the bitterness of QHCl but did not affect sour, salty, or savory taste. The suppression of taste is likely to be an oral peripheral phenomenon due the physio-chemical properties of the zinc ion rather than a cognitive effect of any perceived taste of zinc. In support of this statement, zinc differentially affected taste qualities, both sweetness and bitterness intensity was inhibited, while salty, sour and savory intensity was unaffected. If the inhibition were a central cognitive effect of the perceived taste of zinc, inhibition of taste qualities would be common.
Possible mechanisms for zincs effect on sweet and bitter taste

The taste transduction mechanisms for sweet and bitter have not been fully elucidated (for a review on taste transduction mechanisms see (Lindemann 2001)). It is known that there are multiple transduction mechanisms for bitter taste (Spielman and others 1992; Adler and others 2000; Chandrashekar and others 2000; Delwiche and others 2001; Keast and Breslin 2002a). It must be noted that zinc may only interfere with the mechanism/s responsible for bitter taste transduction of QHCl, or a subset of bitter compounds (of which there are thousands), rather than all bitter compounds. In other words, the observation that ZnSO₄ inhibits the bitterness of QHCl does not predict that ZnSO₄ will globally inhibit bitterness. The same argument is more difficult to make for sweetness. There is one reported putative receptor for sweetness (Nelson and others 2001; Li and others 2002) (as opposed to numerous for bitter), and if ZnSO₄ is altering the binding site of the one receptor (and there are no other sweet taste receptors), then ZnSO₄ may inhibit the sweetness of all sweeteners.

Zinc’s suppression of bitterness

The inhibition of bitterness by ZnSO₄ should be considered a positive effect for the food industry, especially as new foods often are supplemented with nutraceuticals, many of which are bitter. The addition of zinc would potentially inhibit the added bitterness and make the product more palatable. The pharmaceutical industry is very interested in compounds that inhibit bitterness (Keast and Breslin 2002b), and ZnSO₄’s ability to inhibit the bitterness of QHCl is dramatic.
How does a reduction in taste influence flavor?

Model-aqueous-binary-mixtures of taste eliciting compounds can be predictive of taste interactions in complex food matrices (Keast and Breslin 2003). In a food, the addition of zinc has the potential to reduce the appetitive taste ‘sweet’. The inhibition of sweetness is a direct result of adding zinc, but also there will be indirect effects of sweetness loss that need to be considered. An appetitive taste such as sweetness can be used to mask tastes that are aversive (the phenomenon of mixture suppression). If the sweetness of a product is inhibited by the addition of zinc, aversive tastes will be enhanced as they are released from the mixture suppression (as shown by Breslin and Beauchamp (1997)). In essence, the appeal of the food suffers twice as the appetitive taste is diminished and the aversive tastes are thereby enhanced.

As well as the effect on other tastes, flavor, which incorporates taste, aroma, and somatosensations, will be affected. The inhibition of sweetness will have a major influence on how the overall flavor is perceived. What follows is a hypothetical example outlining how flavor and liking of a product may be affected by the inhibition of a taste.

The sweetness of a strawberry is linked to the strawberry’s aroma and vice versa (Schifferstein and Verlegh 1996). Both sweetness and strawberry aroma are congruent and enhance pleasantness beyond additivity. In addition, the strawberry odor has been shown to enhance sweetness (Schifferstein and Verlegh 1996). If zinc was added to a ripe strawberry flavor, the reduction in sweetness of the strawberry will release sourness from mixture suppression. The strawberry will be perceived as less sweet and more sour. The increased sourness in combination with the strawberry odor is a partially incongruent combination and the pleasantness of the strawberry will be reduced. Also, the odor-
induced taste enhancement of sweetness would not exist. The reduction in sweetness of the strawberry set off a chain of events that resulted in an enhancement of less desirable attributes of the strawberry (sourness), and an incongruent combination of sour taste and strawberry aroma that resulted in a further decrease in pleasantness. Overall, a reduction in one taste quality may have far reaching effects in a complex flavor.

Conclusions

Zinc salts will continue to be added to food and oral care products for nutritional as well as functional reasons. This paper has demonstrated that zinc can influence taste perception and thereby influence the flavor of a food or oral care product. If manufacturers are adding zinc to a new or existing product, it would be beneficial to assess the influence the added zinc is having on the taste profile.
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List of Figures

Figure 1A-F  The taste and somatosensation of zinc salts at three concentrations (5, 25, 50mM). Each figure represents a taste quality or somatosensation: 1A bitterness, 1B salty, 1C savory, 1D sour, 1E tingle/sting, and 1F astringency. On all figures, the y-axis lists the salts used in the experiment, the x-axis plots the three concentrations (5mM, 25mM, 50mM), and the Z-axis represents the intensity rating on the general Labeled Magnitude Scale (gLMS). The secondary z-axis has the adjective ‘weak’ that corresponds to the descriptor position on the gLMS. Bars represent geometric means of intensity. Abbreviations for salts are ZnBr₂ = zinc bromide, ZnSO₄ = zinc sulfate, ZnI₂ = zinc iodide, ZnAc = zinc acetate, and ZnCl₂ = zinc chloride. Different letters represent significant differences (p<0.05) in intensity between either the salts (a,b) or concentration (z,y) used.

Figure 2  The effect of two water rinses on astringency of zinc salts. The x-axis lists the trial, either the adaptation of the zinc salt or the two water rinses, the y-axis lists the salts used in the experiment, and the Z-axis represents the astringency intensity rating on the general Labeled Magnitude Scale (gLMS). The secondary z-axis has the adjective ‘weak’ that corresponds to the descriptor on the gLMS. Bars represent geometric mean of the intensity of astringency. Abbreviations for salts are the same as in Figure 1. Different letters represent significant differences (p<0.001) in intensity between either the salts (a,b).
**Figure 3A-E** The influence of zinc on the five basic tastes elicited by prototypical stimuli. Each Figure represents the influence of ZnSO₄ and MgSO₄ on one taste quality: 3A sweetness of glucose, 3B bitterness of QHCl, 3C saltiness of NaCl, 3D savory of MSG, and 3E sourness of citric acid. On all Figures the x-axis lists concentration of the prototypical stimuli and the prototypical stimuli with 25mM ZnSO₄ and MgSO₄. Each pair set shows the prototypical stimuli at one concentration both with and without ZnSO₄ or MgSO₄. Bars represent geometric means of the taste intensity (sweet, salty, sour, bitter, or savory) ± standard error. An ** indicates a significant difference (p<0.001) in taste intensity between a pair of stimuli at one concentration. A is directly above the stimuli that statistically differ.
The Taste of Zinc

Figures

Figure 1A

![3D bar chart showing the intensity of bitterness for different zinc salts at varying concentrations. The chart indicates significant differences between the salts at p<0.05 and p<0.001 levels.]
Figure 1B

The Taste of Zinc

The bar chart shows the intensity of taste for different zinc salts at various concentrations. The salts are labeled as ZnBr₂, ZnSO₄, ZnCl₂, ZnAc, ZnI₂. The chart indicates significant differences between the salts and concentrations, with some showing p<0.001 and others p<0.05. The chart also highlights weak taste at certain concentrations.
The Taste of Zinc

Figure 1C

![Graph showing the intensity of savory taste for different zinc salts at various concentrations.]

Zinc Salts: ZnBr₂, ZnSO₄, ZnI₂, ZnAc, ZnCl₂

Concentration: 5mM, 25mM, 50mM, 100mM

Intensity Scale: 0, 2, 4, 6

Legend: weak
Figure 1D

The Taste of Zinc

Intensity vs. Concentration of Zinc Salts

- ZnBr2
- ZnSO4
- ZnI2
- ZnAc
- ZnCl2

Intensity

Zinc Salts

Sour

5mM
25mM
50mM

p<0.001
p<0.05
The Taste of Zinc

Figure 1E

Intensity

Concentration

Zinc Salts

ZnBr2  ZnSO4  ZnI2  ZnAc  ZnCl2

weak

p<0.05

p<0.05
The Taste of Zinc

Figure 1F

![Bar graph showing intensity of astringency for different zinc salts at various concentrations.](image)

Zinc Salts: ZnCl₂, ZnAc, ZnI₂, ZnSO₄, ZnBr₂

Intensity vs. Concentration (5mM, 25mM, 50mM)

- p<0.001
- Significance levels: a, b, a, b, z, y

Weak astringency indicated by "weak."
The Taste of Zinc

Figure 2

Astringency

Intensity

50mM

1st rinse

2nd rinse

weak

p<0.001

Zinc salts

ZnI₂
ZnSO₄
ZnBr₂
ZnAc
ZnCl₂

weak

577

578

579
Figure 3A

Zinc and magnesium influence on sweet taste

- Glucose
- Glucose + 25mM ZnSO4
- Glucose + 25mM MgSO4

Sweet Intensity vs. Glucose [M]
Figure 3B  

Zinc and magnesium influence on bitter taste

![Graph showing the effect of zinc and magnesium on bitter taste](image)

- Quinine-HCl
- Quinine-HCl + 25mM ZnSO4
- Quinine-HCl + 25mM MgSO4

Bitter Intensity

Quinine-HCl [mM]

0.04 0.11 0.18 0.25 0.33 0.40

---

The Taste of Zinc
Figure 3C

Zinc and magnesium influence on salt taste

![Graph showing the effect of zinc and magnesium on salt taste intensity. The x-axis represents NaCl concentration in mM, ranging from 50 to 500, and the y-axis represents salt intensity ranging from 0 to 30. The graph compares NaCl alone, NaCl + 25mM ZnSO4, and NaCl + 25mM MgSO4 at various concentrations. The data suggests that zinc and magnesium affect the taste intensity at different NaCl concentrations.]
Figure 3D

Zinc and magnesium influence on savory taste

- **MSG**
- **MSG + 25mM ZnSO4**
- **MSG + 25mM MgSO4**

<table>
<thead>
<tr>
<th>MSG [mM]</th>
<th>Savory Intensity</th>
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<tbody>
<tr>
<td>30</td>
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<tr>
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<td>25</td>
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<tr>
<td>400</td>
<td>30</td>
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Figure 3E

Zinc and magnesium influence on sour taste