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Time–intensity characteristics of iron compounds

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Abstract

Discrete-interval time–intensity scaling was used to measure the sensory characteristics of three iron compounds, 0.05 M ferrous sulfate, 0.03 M ferrous chloride and 0.05 M ferrous gluconate. All three compounds exhibited strong and persistent metallic flavors. Ferrous chloride was highest in bitter taste and ferrous gluconate highest in initial sourness and astringency. Evidence of anionic inhibition was seen in that ferrous gluconate was lower in bitterness relative to ferrous chloride. Taste properties decayed rapidly over the 2-min test period but astringency had slower onset, reached a maximum at 60 s and remained at or near the maximum level during the test period. These common iron fortifying agents show complex and different sensory profiles. The sensations that are predominant change over time, with a lingering astringency and metallic taste that may lessen their suitability for use in food fortification.

Keywords: Time–intensity; Iron compounds; Sensory properties; Metallic taste

1. Introduction

Iron salts are characterized by a metallic retronasal smell in addition to basic tastes and astringency (Hettinger, Myers, & Frank, 1990; Lawless et al., 2004). Studies of divalent salts show that they differ in the predominance of metallic, bitter and astringent sensations they evoke. For example, iron salts tend to give the highest metallic sensations, while copper is more predominantly bitter, and zinc both bitter and astringent (Keast, 2003; Lawless et al., 2004). Ferrous sulfate is generally recommended as a metallic standard in applied sensory evaluation (Civille & Lyon, 1996), but clearly other iron compounds as well as other divalent salts can evoke this problem flavor (Borocz-Szabo, 1980).

The complex pattern of sensory qualities from divalent salts may not be fully captured by descriptive methods or psychophysical scaling that address only the peak or overall sensory intensity through a single response. Tastes and oral tactile sensations differ in their time courses. Perception of components of taste mixtures may depend upon their appearance time (Marshall, Laing, Jinks, Effendy, & Hutchinson, 2005). In contrast to most tastes, astringency has slow onset and persists (Drobna, Wismer, & Goonewardene, 2004; Fischer, Boulton, & Noble, 1994; Guinard, Pangborn, & Lewis, 1986; Lee & Lawless, 1991). Thus the sensory experience of astringency can be more completely measured by time–intensity scaling procedures. Given the slower onset of astringency, as opposed to tastes, one could expect the sensory profile of complex salts to change over time, with tastes being predominant early and astringency being predominant later. To our knowledge, the time course of metallic retronasal sensations has not been published, although qualitative observations with iron salts indicate that the metallic and astringent sensation have remarkable persistence (Borocz-Szabo, 1980).

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The sensory and chemical properties of iron salts have interest to the food science and nutrition communities. Iron deficiency has high prevalence in developing countries, with over one billion people worldwide suffering from deficiency or chronic anemia (Yip, 2001). In the US, iron deficiency is estimated to affect 11% of females of childbearing age and 9% of children below the age of 2, for whom anemia can impair cognitive development (Looker, Dallman, & Carroll, 1997). One difficulty in iron fortification is that iron salts with high bioavailability such as ferrous sulfate are also catalysts for oxidative changes in foods leading to off-flavors and color changes. To alleviate this problem, food scientists have tried various strategies such as the use of chelated iron (Bovell-Benjamin, Allen, Frankel, & Guinard, 1999), encapsulation (Jackson & Lee, 1991), or use of iron salts with organic anions (such as ferrous fumarate, lactate, or malate, found in common mineral nutrition supplements). Anions may invoke some inhibitory effects that reduce undesirable sensory properties. For example, calcium salts are often used in foods in the form of calcium gluconate or gylcerophosphate, which are less bitter than calcium chloride (Lawless, Rapacki, Horne, & Hayes, 2003).

Ionizable tastants such as salts dissociate in solution to produce two effective stimuli (as well as shells of organized water molecules), the anion and cation. With partially dissociated organic acids, there are three—the anion, the H^+ or hydronium ion, and the undissociated acid in solution. Although it is widely accepted that the positively charged cation is primarily responsible for the taste properties of salts, clearly there is modification by the anions present. In an early demonstration of anionic inhibition, Miller (1971) showed that surrounding a salt stimulus with an annular stimulation pattern with potassium benzoate would suppress the neural response to sodium chloride. This followed a suggestion by Beidler that benzoate was often seen in electrophysiological studies to have an inhibitory effect. Among the monovalent halides, salty taste responses are weakened as the anion is changed from chloride to bromide to iodide (Murphy, Cardello, & Brand, 1981). The diffusion of larger anions across tight junctions and into basolateral areas of taste receptor cell channels is limited, therefore salts with larger anions are less effective stimuli than chlorides in which both anion and cation can cross into the paracellular regions for stimulation (Delwiche, Halpern, & DeSimone, 1999; Ye, Heck, & DeSimone, 1991, 1993). The bitterness of calcium is suppressed when comparing the response to chloride to the response to organic anions such as lactate, glycerophosphate and gluconate (Lawless et al., 2003; Tordoff, 1996). Whether anionic effects would be seen in the temporal profile of iron salts has not been studied. To examine this we chose a small anion, chloride (molecular weight (M_W) = 35.45), a larger inorganic ion but one with a double negative charge that would more strongly associate a shell of water molecules (sulfate, M_W = 96.1) and a larger organic ion, gluconate (M_W = 195.18).

The main purpose of this study was to explore the temporal properties of iron salts, using two common salts, ferrous sulfate and ferrous chloride and an iron salt with a large organic anion, ferrous gluconate which has good bioavailability (Jackson & Lee, 1991). A second question of interest was whether the anionic suppression of bitterness, as seen in calcium salts, would also occur with iron salts, and whether anionic suppression would extend to other taste properties.

2. Materials and methods

2.1. Subjects

Twelve healthy subjects (five male, ages 21–58, mean 34) were recruited from the Cornell University Community by advertisement. All subjects were non-smokers and free from any self-reported deficits of taste and smell. Subjects gave informed consent and were paid a token incentive at the completion of the study. The protocol was approved by the Cornell University Committee on Human Subjects.

2.2. Stimuli

Test solutions consisted of ferrous sulfate (0.05 M $FeSO_4 \cdot 7H_2O$, F.W. 277.9, Aldrich Chemical Co.), ferrous chloride (0.03 M $FeCl_2 \cdot 4H_2O$, F.W. 198.7, Mallinckrodt Baker) and ferrous gluconate (0.05 M $Fe[HOCH_2(CHOH)_4CO_2]_2 \cdot 2H_2O$, F.W. 482.19, Johnson Matthey Co.), all reagent grade and prepared in deionized water (Barnstead D3750, 16.5–18 MΩ resistance, with 0.2 μm hollow fiber filter). Concentrations were chosen on the basis of informal pretesting to represent moderate and approximately equal overall sensory impact. Solutions were prepared daily to prevent development of odorous by-products from oxidation. Test solutions were presented as 20 ml samples in 60 ml odorless plastic cups (Fabri-Kal 2 oz.) at room temperature (22 °C). Stimuli were sipped and expectorated. The three salts were chosen to represent a large organic anion (gluconate, about the size of a glucose molecule), a small anion (chloride) and one of intermediate size (sulfate, having a −2 charge and an associated shell of hydration).

2.3. Procedure

2.3.1. Training

Subjects attended one training session prior to testing. The purpose of training was to demonstrate the physical and mental tasks associated with a temporal