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Effect of iron on taste perception and emotional response of sweetened beverage under different water conditions

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ABSTRACT

Although sweeteners are widely used additives in beverages, taste interaction between sweeteners and minerals in water is rarely reported. The objective was to investigate the influence of different concentrations of iron and water hardness on taste perception of sweetened beverages and characterize the corresponding emotional profiles. Taste interaction was developed by dissolving five natural and artificial sweeteners [sucrose, honey, sucralose, saccharin, and acesulfame potassium (ace-K)] into four synthetic waters [soft water (0 mg Fe/L), moderate hard water (0.3 mg Fe/L), hard water (1 mg Fe/L) and very hard water (3 mg Fe/L)], respectively. Sweet and metallic taste intensity of different combinations were compared by pairwise ranking tests. Acceptability and emotional response on sucrose sweetened beverage with and without the addition of iron was evaluated by 9-point hedonic score test and check-all-that-apply emotional term ballot. Iron (Fe^{2+}) created metallic flavor in drinking water and produced *bored* and *disgusted* feelings for consumers. Other minerals such as Ca^{2+}, Mg^{2+} and Na^{+} at subthresholds impacted taste perception of water. Sweetness of sweeteners was varied with different concentrations of minerals in water and with different types of sweeteners. High concentration of iron and water hardness significantly increased ($p < 0.05$) the sweetness of sucrose, honey and ace-K. Sweet-metallic taste interaction between sucrose and ferrous ions significantly ($p < 0.05$) increased the acceptance of very hard water (3 mg Fe/L), and created a unique emotional profile- "mild". Distribution of emotional profiles could be different between samples with the same hedonic scores and provide more in-depth information than acceptance test.

1. Introduction

Water is critical to beverage production and its quality directly influences the taste and acceptability of the corresponding beverage products. Water quality is classified by the composition and concentration of the containing minerals, which can add salty, bitter, sweet or metallic flavor to water (Burlingame, Dietrich, & Whelton, 2007; Dietrich & Burlingame, 2015). When minerals reach certain concentrations, they may deeply impact taste perception of final products by interacting with each other or reacting with other food constituents. In the food industry, water used for beverage production has to meet drinking water standards established by US Environmental Protection Agency. However, minerals without toxic effects but influencing taste perception of water are regulated by Secondary Drinking Water Regulations (USEPA, 2016), which are guidelines for public water systems followed on a voluntary basis for most states in United States. Corrosion of metal piping is an additional source of excess metal ions in tap water (Dietrich et al., 2004; Duranceau, Wilder, & Douglas, 2012; Lauer, 2004).

Many companies provide additional water filtration and treatment steps to standardize their water supply. However, such processes are expensive and may not be feasible for small companies. Consumers may also have filters at the tap to reduce minerals in their drinking water. However, their home made beverages (such as coffee, tea, beer, wine) may be affected by residual minerals. Therefore, high concentration of mineral ions found in the supplied water may greatly impact taste perception if used in beverage production.

Humans are sensitive to many minerals; some thresholds are below the maximum amount set by Secondary Drinking Water Regulations (USEPA, 2016). Copper can be detected at very low concentration ranging from 0.5 to 13 mg/L (Cuppett, Duncan, &

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Dietrich, 2006; Jesse, Cohen, Kamphake, & Richard, 1960); the Secondary Drinking Water Standards for copper is 1.0 mg/L (USEPA, 2016). Iron is one of the most noticeable minerals since it can impart metallic flavor in drinking water as low as 0.17 mg/L (Mirlohi, Dietrich, & Duncan, 2011), which is below the secondary drinking water standard for iron set at 0.3 mg/L. Furthermore, iron is found most frequently in water supplies since it is the fourth most common element found in the Earth's crust and widely spread in the natural environment. Effects of iron and other minerals on metallic flavor of drinking water have been reported. Iron (II) sulfate is represented as a metallic sensation in deionized water and the metallic sensitivity could be weakened with the existence of other minerals (Hoehl, Schoenberger, & Busch-Stockfisch, 2010). However, a commercial food product is a comprehensive flavor system with many interactions; a single taste never exists. Thus, how minerals influence taste perception of beverages through interaction with other taste stimuli still needs further study.

Taste interactions are important to the development and modification of food products and have been widely studied for decades. Taste interaction between same taste stimuli including sweet (Ayya & Lawless, 1992; Schiffman, 1995), umami (Yamaguchi, 1967), salt (Breslin & Beauchamp, 1995), sour (Bartoshuk & Cleveland, 1977) and bitter (Keast & Breslin, 2002b), and between multiple taste stimuli such as umami/salt (Keast & Breslin, 2002a; Woskow, 1969), salt/sour (Breslin, 1996), bitter/salt (Breslin & Beauchamp, 1995, 1997), bitter/sour (Keast & Breslin, 2002a; Pangborn, 1960), sweet/salt (Beebe-Center, Rogers, Atkinson, & O'Connell, 1959; Breslin, 1996), sweet/sour (Curtis, Stevens, & Lawless, 1984), and bitter/sweet (Calvino, Garcia-Medina, & Cometto-Muniz, 1990; Schiffman et al., 1994) were reported in previous studies. However, binary taste interaction between sweet and metallic flavor have not been previously reported.

Different from other taste perception, metallic sensation is a combination of metallic taste and retronasally perceived odor (Mirlohi et al., 2011). Metallic taste is characterized as bitter and salty taste as well as astringent mouthfeel (Ömür-Özbek & Dietrich, 2011) and often carries a lingering aftertaste (Hong, Duncan, & Dietrich, 2009). Metallic flavor is widely observed as an undesirable sensory side effect. It has been associated with polyphenols in cloudy raw fruit juices, some meat products, and metal ions found in drinking water (Sarin, Snoeyink, Lytle, & Kriven, 2004), and attributed to metal from containers during production, storage and transportation. Some alternative sweeteners, such as acesulfame potassium (ace-K) and saccharin, may also contribute low levels of bitter, astringent and metallic characteristics at higher concentrations (Horne, Lawless, Speirs, & Sposato, 2002). It is recognized that metallic flavor is a negative attribute and can reduce product acceptability.

Consumer acceptability of a food product is the traditional approach for estimating potential purchase/consumption behavior; however, product success does not always follow this measure. Correlation between consumer emotional response and sensory experience during food consumption has been explored in recent years to provide additional information on prediction of product success (Leitch, Duncan, O'Keefe, Rudd, & Gallagher, 2015; Walsh, Duncan, Potts, & Gallagher, 2015). Emotional response can help describe the impact of sensory quality on consumer hedonic response (King & Meiselman, 2010). However, no study has related emotional response to perception of taste interactions to our knowledge.

Our study objective was to document the influence of different concentrations of iron and water hardness on taste perception of sweetened water beverages. Taste interaction was investigated by detecting sweet and metallic intensity generated from combinations of four synthetic waters and five commercial sweeteners. In addition, emotional response in combination with acceptance tests was applied to study sweet-metallic interaction between sucrose and ferrous sulfate.

2. Materials and methods

2.1. Materials

Food-grade chemicals including iron (II) sulfate heptahydrate ($FeSO_4{\cdot}7H_2O$), sodium bicarbonate ($NaHCO_3$), calcium sulfate dihydrate ($CaSO_4{\cdot}2H_2O$), magnesium sulfate heptahydrate ($MgSO_4{\cdot}7H_2O$), and potassium chloride (KCl) were purchased from Spectrum Chemical (New Brunswick, NJ). Acesulfame potassium (ace-K) was received from Wego Chemical & Mineral Co. (Great Neck, NY) and sucralose was received from Sucral (Tate & Lyle; London). Saccharin, honey (clover) and sucrose (Kroger; Cincinnati, OH) were purchased at the local supermarket. Distilled water, drinking water and unsalted soda crackers were purchased from Kroger (Kroger brand, Cincinnati, OH).

2.2. Preparation of iron-containing sweetened beverage

2.2.1. Preparation of synthetic water

The preparation of synthetic soft water followed the formulation of minerals for hard and soft natural waters in 100 large cities in the United States as described by Burlingame et al. (2007) and Smith, Davison, and Hamilton-Taylor (2002) with slight modification. To prepare synthetic water with appropriate hardness (DES, 2008), mineral concentration in moderate hard, hard and very hard water was determined through multiplying mineral ions concentration in soft water by 2.5, 5, and 7.5, respectively (Table 1). Synthetic very hard water (4 L) was prepared daily with food grade chemicals following the compositions in Table 1. Distilled water (3.8 L) (The Kroger Co., Cincinnati, OH, 45202) was purchased in a clean glass bottle, to which was added 461.9 mg $MgSO_4{\cdot}7H_2O$, 635.5 mg $NaHCO_3$ and 114.7 mg KCl. The solution was aerated with magnetic stirrer overnight. The next day, 1367.4 mg of $CaSO_4{\cdot}2H_2O$ was added to 200 mL distilled water in a separate glass beaker with stirring. After the calcium sulfate was totally dissolved, the solution was added to the 3.8 L solution and mixed well. The combined solution was aerated vigorously with magnetic stirrer for an additional 24 h to dissolve the added chemicals and stabilize the medium. Then the prepared very hard water was diluted by distilled water at the ratio 1:6.5 for soft water, 1:4 for moderate hard water and 1:1.5 for hard water (Table 1). Right before sensory testing, 1.5 mg of $FeSO_4{\cdot}7H_2O$ was dissolved in 1 L synthetic moderately hard water, 5.0 mg was dissolved in 1 L synthetic hard water, and 14.9 mg was dissolved in 1 L synthetic very hard water. The pH and hardness of each type of synthetic water are listed in Table 1.

2.2.2. Preparation of sweetened beverage

All samples were prepared daily to prevent degradation or precipitation of compounds. Clean glassware was rinsed thoroughly beforehand to remove any residual minerals. Iron-containing sweetened beverages were obtained by adding five sweeteners respectively into each iron-containing solution in Table 1 to form ace-K beverage (2.64×10^{-4} g/mL), honey beverage (0.0624 g/mL), saccharin beverage (0.0037 g/mL), sucralose beverage (9.5×10^{-5} g/mL) and sucrose beverage (0.05 g/mL). The concentrations of above five sweeteners were established based on our previous study (Leitch et al., 2015), which identified sweet equivalence of different sweeteners to a 5% sucrose in water solution (w/w).