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The effect of food additives in fruit drinks on the nosespace using Selected Ion Flow Tube Mass Spectrometry (SIFT-MS)

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The effect of additives on the volatile concentrations of three fruit drinks was measured in the nosespace in real-time and compared to the effect on the mouthspace and static headspace. Oil, whey protein, milk protein, collagen, pectin, sucrose, glucose, or NaCl were added to orange juice, strawberry drink, and tomato puree, and the nosespace, mouthspace, and headspace were measured. The addition of oil produced the most significant decrease in volatile compound concentrations in the nosespace of orange juice followed by proteins, pectin, sucrose, glucose, and NaCl. The nosespace was more sensitive to changes due to additives than the mouth or headspace measurements. The order of effectiveness of the additives for the strawberry drink and tomato puree was similar to orange juice. However, there were some differences due to food matrix, such as NaCl produced no significant effect on the nosespace concentration while producing a significant increase in some volatiles in the mouthspace and headspace of strawberry drink and tomato puree. The effect of the additives was not the same for nosespace, headspace, mouthspace, and the type of fruit drink, thus the food matrix, composition, and static versus dynamic conditions affected the way volatile compounds were released into the air.

Key words: Food additives, mouthspace, nosespace, fruit drink, SIFT-MS.

INTRODUCTION

The release of volatile compounds from the food matrix is necessary in order to allow humans to perceive the odor of food (Linforth and Taylor, 2006). During eating, volatile compounds in the food are introduced into the mouthspace or bolus and consequently transferred though the seal or velum, which opens with the movement of the mouth and jaw. After leaving the bolus, volatiles enter the pharynx and then transfer to the olfactory epithelium in the nose where the signal is transferred to the brain. Therefore, the effect of food additives on release of volatile compounds from the food matrix should be measured in the nose but is more commonly measured in the headspace of static containers, or less commonly, in the mouth. The effect of additives may be different under the static conditions in the headspace than the dynamic conditions in the nosespace.

The difference between headspace and nosespace conditions may play an important role in how additives

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change volatile concentrations. Static headspace conditions, which are most commonly measured, allow the volatile compounds to reach equilibrium (Boland et al., 2004, 2006). This measurement can be predicted by the partition coefficient, which is the maximum volatility of volatile compounds. However, in the dynamic system of the mouth and nose, the concentrations are continually diluted by air flow across the surface and the behavior of volatile compounds are affected by both partition coefficient and kinetics, which determine the rate of release of volatile compounds (Boland et al., 2004). The diffusion of volatile compounds under static conditions allows the steady release of volatile compounds including bound volatile compounds but in dynamic conditions, the release of volatile compounds changes over time as the concentration of volatile compounds in the bulk phase attempts to remain constant (De Roos, 2006).

Volatile compounds are released from foods, reaching the gustatory and olfactory receptors in the mouth and the nose by a three phase process (Friel and Taylor, 2001). First, volatiles initially release from the food into the saliva phase in the mouth. Second, volatiles partition from the saliva to the air phase in the mouth. Finally, dilution and transportation of volatiles occurs from the air phase in the mouth to the airways of the nose. Therefore, food-saliva interaction may occur during phase two.

The addition of oil, proteins, pectin, sugar and salt should have a significant effect on the headspace concentration of volatile compounds in food. Oil (Chung et al., 2003; Rosett et al., 1997; Ventanas et al., 2010b) and proteins (Kuhn et al., 2006; Macleod et al., 1988, Thanh et al., 1992) reduce the volatility of volatile compounds due to their hydrophobic characteristics. Pectin decreases volatile concentrations due to its three-dimensional cross-linked network (Chinachoti, 1995). Sucrose decreases volatile compound concentrations by sucrose-sucrose interaction, presence of additional hydroxyl groups, and sucrose-water interactions (Richardson et al., 1987; Roberts et al., 1996; Starzak et al., 2000). NaCl increases volatile compound concentrations due to the salting-out phenomenon (Bakierowska and Trzeszczynski, 2004; Martínez et al., 2012; Ventanas et al., 2010a). Although, the headspace concentration of volatile compounds in foods are affected by different additives, consumer consumption is done in the mouth, which involves mastication and food-saliva interactions (Friel and Taylor, 2001; Van Ruth and Roozen, 2000; Van Ruth et al., 2001).

The flavor-solute interactions in the nosespace, the headspace, and the mouthspace may be different because of human saliva, mastication, and differences in static and dynamic conditions. Different additives were added to three fruit drinks to compare volatile concentrations in the nosespace, headspace and mouthspace.

MATERIALS AND METHODS

Sample preparation

Orange, strawberry, and tomato were chosen as the fruit drinks due to the fact that many confections, sauces, and beverages contain orange, strawberry or tomato. For orange, five different brands of orange juice (Kroger, Columbus, OH, U.S.A; Simply Orange Juice Company, Apopka, FL, U.S.A; Minute Maid, The Coca-Cola Company, Atlanta, GA, U.S.A.; Citrus World, Inc., North Lake Wales, Florida, U.S.A.; Tropicana Drink, Inc., Chicago, IL, U.S.A.) were chosen for each replicate and used immediately. For strawberry drink, 12.5% of strawberry jam-type flavor (Givaudan Flavors Corporation, Cincinnati, OH, U.S.A.) was mixed in deionized water. Five different brands of grape tomatoes (Chubby Cheek, Four Season Produce Inc., PA, U.S.A.; Fresh Selection, The Kroger Co., OH, U.S.A.; Sunripe, Pacific Tomato Grower Ltd., FL, U.S.A.; Simple Truth Organic, The Kroger Co., OH, U.S.A.; NatureSweet, NatureSweet Tomatoes, TX, U.S.A.), were used to produce the different replicas of tomato puree. Tomatoes (1698 g) were blended for 30 s (Magic Bullet juicer, Homeland Housewares, LLC, Los Angeles, CA, U.S.A.) and 450 ml each were put into four 946 ml Ziploc bags. Puree was held for 15 mins from the start of pureeing to maximize volatile formation and then microwaved on high for 2 mins (KOR-6115 Daewoo, Daewoo Electronics Sales U.K. Limited, Berkshire, England) to a minimum of 70°C to inactivate the enzymes.

Sodium chloride, pectin, protein, sugar, and oil

To 100 ml of orange juice, strawberry drink or tomato puree, were added one of the following additives: 5% or 10% of olive oil (Kroger Co., Cincinnati, OH, USA) plus 1% mono and diglycerides (Continental Custom Ingredient, Inc., West Chicago, IL, USA); 1% (w/v) of whey protein isolate (Industrial Food Ingredients, Minneapolis, MN, USA), milk protein (Protient INC., Norfolk, NE), or collagen (Arnhem Group, Cranford, NJ, USA); 1% (w/v) low-methoxyl pectin (TIC Gums, Inc., Belcamp, MD, USA), 5% and 10% D-(+)-glucose (Sigma-Aldrich, Co., St. Louis, MO, USA), 5% or 10% (w/v) of sucrose (Domino Food, Inc., Yonkers, NY, USA), or 5% or 10% (w/v) of NaCl (Sigma-Aldrich, Co., St. Louis, MO, USA).

Headspace, mouthspace, and nosespace volatiles analysis

Headspace samples (3 or 24 ml) were filled in 500 ml Pyrex bottles containing 1 ml artificial saliva (Van Ruth et al., 1997) or 1 ml deionized water. The stock artificial saliva was made by dissolving 2.160g mucin (Sigma-Aldrich, Co., St. Louis, MO, USA), 1.369g K_2HPO_4 $3H_20$ (Sigma-Aldrich, Co., St. Louis, MO, USA), 0.877g NaCl (Sigma-Aldrich, Co., St. Louis, MO, USA), 0.477 KCl (Sigma-Aldrich, Co., St. Louis, MO, USA), 0.441g $CaCl_2$ $2H_20$ (Sigma-Aldrich, Co., St. Louis, MO, USA), and 0.500g NaN_3 (Sigma-Aldrich, Co., St. Louis, MO, USA) in 100 g deionized water, and purged with nitrogen gas (50ml/min) for 15 h (Van Ruth et al., 1997). Next, 0.521g $NaHCO_3$ (Sigma-Aldrich, Co., St. Louis, MO, USA) and 0.667g (20,000 unit) of porcine alpha amylase (Sigma-Aldrich, Co., St. Louis, MO, USA) were added to 10 ml stock saliva and the stock saliva was diluted with 90 ml deionized water (Van Ruth et al., 1997). The volume of artificial saliva needed was determined experimentally by the total volume after the subject held 3 ml water in his mouth for 110 s. The values reported in the tables as headspace are for 3 ml of sample plus 1 ml saliva. For headspace, the bottles, containing water or artificial saliva, were closed with a silicon septum cap and equilibrated in a water bath at 37 °C (mouth temperature) for 30 mins. The samples were added to the equilibrated bottles and shaken for 10 s before the measurement. The static headspace of volatile compounds were sampled directly by piercing the septum on 500 ml Pyrex bottles with a passivated needle connected to a Selected Ion-Flow Tube Mass Spectrometer (SIFT-MS) (SYFT Voice 200, Syft LTD, Christchurch, New Zealand). Water (37°C) was used as a blank between each sample and all samples were measured for 110 s. The flow tube pressure during the machine run was 0.060±0.002 torr. The temperature of the capillary and arm was automatically maintained at 120°C. Each sample was measured using five replicates.

The volatile compounds in the mouthspace were sampled by exhaling though the breath inlet connected to the SIFT-MS. A portion of the sample (3 ml) was placed into the mouth and gargled for 10 s without exhaling. Ten sec mouth exhales were measured for the mouthspace during a test and the samples were not swallowed during the test. The mouthspace and the nosespace were measured separately on different samples.

The volatile compounds in the nosespace were sampled by exhaling through a 12.7 cm flexible straw directly into the passivated needle on the headspace inlet. A 3 ml sample was placed in the mouth, held for 10 s, swallowed and the breath exhaled through the left nostril for 10 s. The average concentrations of the mouthspace and the nosespace samples were calculated using acetone as a breath marker to indicate when the exhale began and ended (Smith et al., 2011; Sturney et al., 2013). Each replicate was the average of three exhales. Each sample was measured using five replicates.

A method was created and used for the measurement of volatiles in the headspace, mouthspace, and nosespace, thus timescale, precursor ion and the calculation method were the same for all measurements. The method used a selected ion mode with H_3O^+, O_2^+, and NO^+ as precursor ions to determine the concentrations of each volatile compound. The method was developed based on the volatile compounds which are important to the flavor of each fruit drink (Buttery, 1993; Ozcan and Barringer, 2011; Perez-Cacho and Rouseff, 2008). The concentration (M) of selected volatiles was calculated using the product count rate (Ip), reaction rate constant (k), precursor ions count rate (I), and reaction time (t) as shown in the equation: (M)=Ip/Ikt (Spanel and Smith, 1999). The constants in the calculation are compiled in the SYFT library thus the calculation was done automatically by Lab SYFT software during the measurement (Syft Technology, Middleton Christchurch, New Zealand) (Table 1).

Statistical analysis

One-way analysis of variance (ANOVA) was performed on volatile data by Minitab (Minitab Inc., PA, USA) and Tukey's test was carried out to determine significant differences among mean values of volatile concentrations. A significance level of 0.05 was applied throughout the study. Normalization was used for the tomato puree and the orange juice data.

RESULTS AND DISCUSSION

Orange Juice

In orange juice, all of the additives tested except NaCl, produced a decrease in volatile concentrations in the nosespace (Table 2). However in the mouthspace, only half of the volatiles showed a significant percent decrease in volatile concentration. In the headspace there were even fewer differences. Thus, even though absolute concentrations were lowest in the nose, the differences were more significant and there was a greater percent change from the control when additives are added to the food matrix, than expected on the basis of the mouthspace and the headspace results. Perception of odor occurs in the

Table 1. Kinetics parameters for SIFT-MS analysis of selected volatile compounds in fruit drinks.

Compound	Precursor ion	Product ion	k (10^{-9} $cm^{3/s}$)	m/z	ref
Acetone	NO^+	$NO+.C_3H_6O$	1.2	88	2
Orange juice					
Hexanal	NO^+	$C_6H_{11}O^+$	2.5	99	2
6-methyl-5-hepten-2-one	NO^+	$C_8H_{14}O^+$	2.50	126	3
(*E*)-2-nonenal	NO^+	$C_9H_{15}O^+$	3.80	139	1
ethyl butanoate	NO^+	$C_6H_{12}O_2.NO^+$	2.40	146	5
Strawberry drink					
ethyl butanoate	NO^+	$C_4H_7O^+$	2.40	71	5
(*Z*)-3-hexen-1-ol	NO^+	$C_4H_8O^+$	2.90	72	4
(*E*)-2-hexenal	NO^+	$C_6H_9O^+$	3.80	97	2
(*E*)-2-heptenal	NO^+	$C_7H_{11}O^+$	3.90	111	1
(*E*)-2-pentenal and hexyl acetate	O_2^+	$C_5H_8O^+$	4.20	84	1 & 3
Tomato juice					
(*Z*)-3-hexen-1-ol	NO^+	$C_4H_8O^+$	2.90	72	4
3-methylbutanal	NO^+	$C_5H_9O^+$	3.00	85	1
(*E*)-2-hexenal	NO^+	$C_6H_9O^+$	3.80	97	2
6-methyl-5-hepten-2-one	NO^+	$C_8H_{12}^+$	2.50	108	3
1-penten-3-one	NO^+	$C_5H_8O.NO^+$	2.50	114	3

1. Spanel et al., 2002; **2.** Spanel and Smith, 1997; **3.** Syft, 2008; **4.** Schoon et al., 2007; **5.** Francis et al., 2007.

nose, thus this measurement should be the most accurate measurement of human perception. Similar results were found in studies that showed the headspace comparison of volatile release in water versus an emulsion underestimated the change that occurred in the nosespace (Doyen et al., 2001). The diffusion of volatile compounds under static headspace conditions allows the steady release of volatile compounds including bound volatile compounds due to Eddy diffusion, but in the dynamic conditions of the nose, the release of volatile compounds changes over time as the concentration of volatile compounds in the bulk phase attempts to remain constant (De Roos, 2006).

The addition of oil produced the most significant decrease in volatile compound concentrations in the nosespace of orange juice compared to other food additives in this study (Figure 1). This implies that oil may have the greatest effect on flavor perception. Oil reduces and delays the volatility of compounds because hydrophobic compounds are soluble in the oil droplet (Jo and Ahn, 1999). In an emulsion, esters were at a lower concentration in the nosespace than when in water (Doyen et al., 2001) and volatile concentrations decreased as oil concentration increased (Malone et al., 2000). Others have also reported this effect in the headspace. For instance, the addition of 8% oil significantly reduced headspace concentration of hexanal in an emulsion system (Jo and Ahn, 1999). The initial release of (*E*)-2-hexenal significantly decreased with the addition of 10% oil in a fruit drink (Haahr et al., 2000) and the partition coefficients of ethyl acetate and hexanal in sunflower oil were significant lower than in water (Ventanas et al., 2010b).

The addition of the proteins from whey, milk, and collagen produced the second most significant decreases in volatile concentrations in the nose (Figure 1). There were no significant differences between the different proteins in reduction in volatile concentrations, though differences were expected because of the different structure and binding site of each protein (Kuhn et al., 2006). Volatile compounds may bind to the binding site on protein molecules by hydrogen bonds or hydrophobic interaction depending on the type of volatile compound and the structure of protein, thus reducing the volatility of volatile compounds (Kuhn et al., 2006; Thanh et al., 1992). Again, others have reported these results in headspace analysis so it would be expected to be detectible in the nose as well. Ethyl acetate and ethyl butanoate are bound by sodium

Table 2. Orange juice volatile concentrations in the nosespace, mouthspace, and headspace after addition of oil, whey protein isolate, milk protein isolate, collagen, pectin, sucrose, glucose, and nacl (PPB).

	Control	10% Oil	5% Oil	Whey	Protein Milk	Collagen	Pectin	10% Sucrose	5% Sucrose	10% Glucose	5% Glucose	10% NaCl	5% NaCl
Nosespace													
6-methyl-5-hepten-2-one	2.99^{a}	1.88^{g}	1.87^{g}	1.99^{fg}	1.87^{g}	2.15^{defg}	2.08^{efg}	2.51^{abcd}	2.46^{bcde}	2.30^{defg}	2.33^{cdef}	2.74^{abc}	2.77^{ab}
(*E*)-2-nonenal	2.09^{a}	1.13^{g}	1.19^{fg}	1.29^{defg}	1.25^{efg}	1.20^{fg}	1.46^{cdef}	1.57^{bcd}	1.51^{cde}	1.45^{cdef}	1.60^{bc}	1.90^{a}	1.82^{ab}
ethyl butanoate	11.91^{a}	6.77^{ef}	6.43^{ef}	7.39^{def}	6.81^{ef}	6.29^{f}	7.79^{cdef}	9.46^{abcd}	9.12^{bcd}	7.85^{cdef}	8.59^{bcde}	10.66^{ab}	9.77^{abc}
hexanal	1.84^{a}	1.24^{cd}	1.21^{d}	1.26^{cd}	1.16^{d}	1.07^{d}	1.36^{bcd}	1.37^{bcd}	1.35^{bcd}	1.25^{cd}	1.33^{bcd}	1.59^{ab}	1.53^{abc}
Mouthspace													
6-methyl-5-hepten-2-one	2.27^{a}	1.68^{cd}	1.54^{d}	1.89^{abcd}	1.72^{cd}	1.89^{abcd}	1.83^{bcd}	2.03^{abc}	1.87^{abcd}	1.88^{abcd}	1.79^{bcd}	2.15^{ab}	1.94^{abcd}
(*E*)-2-nonenal	1.41^{a}	0.96^{c}	0.93^{c}	1.07^{bc}	0.97^{c}	1.05^{bc}	0.98^{c}	1.31^{a}	1.10^{bc}	1.09^{bc}	1.05^{bc}	1.40^{a}	1.23^{ab}
ethyl butanoate	13.97^{a}	9.83^{ab}	9.31^{b}	11.34^{ab}	10.23^{ab}	10.93^{ab}	10.87^{ab}	12.32^{ab}	11.79^{ab}	9.74^{ab}	10.92^{ab}	13.14^{ab}	10.77^{ab}
hexanal	2.01^{a}	1.55^{a}	1.64^{a}	1.69^{a}	1.65^{a}	1.55^{a}	1.87^{a}	2.19^{a}	1.55^{a}	1.56^{a}	1.67^{a}	2.06^{a}	1.62^{a}
Headspace													
6-methyl-5-hepten-2-one	5.10^{ab}	3.55^{c}	3.64^{c}	5.10^{ab}	5.54^{ab}	5.50^{ab}	5.36^{ab}	4.84^{bc}	5.45^{ab}	5.16^{ab}	5.40^{ab}	6.24^{a}	6.20^{a}
(*E*)-2-nonenal	3.27^{abc}	2.68^{c}	2.53^{c}	2.78^{bc}	3.26^{abc}	3.24^{abc}	3.18^{abc}	3.05^{abc}	3.18^{abc}	3.12^{abc}	3.19^{abc}	3.74^{a}	3.65^{ab}
ethyl butanoate	577.7^{a}	332.1^{d}	394.9^{cd}	542.0^{ab}	566.8^{a}	567.2^{a}	462.3^{bc}	508.0^{ab}	554.7^{ab}	530.2^{ab}	563.0^{a}	545.1^{ab}	571.5^{a}
hexanal	88.15^{ab}	69.92^{b}	76.47^{ab}	84.10^{ab}	93.57^{a}	90.52^{ab}	81.05^{ab}	76.04^{ab}	86.10^{ab}	82.09^{ab}	88.65^{ab}	93.33^{ab}	94.01^{a}

*Means in the same row that do not share a letter are significantly different.

caseinate, which is a milk protein (Thanh et al., 1992; Landy et al., 1995). Hexanal and (*E*)-2-hexenal are also bound by sodium caseinate by schiff base formation or Michael addition with the amino acid lysine, or the interaction between double bonds of alkenals with the imidazole ring of the amino acid histidine (Meynier et al., 2004).

Addition of pectin reduced volatiles almost as much as proteins in orange juice (Figure 1). Pectin decreases volatile concentrations due to its three-dimensional cross-linked network (Chinachoti, 1995). Others have also found that pectin decreases the volatility of volatile compounds in the nosespace (Boland et al., 2004, 2006). The addition of only 0.95 to 1% high-methoxyl pectin significantly reduced the partition coefficient of hexanal and its release rate in the nosespace (Boland et al., 2006). When pectin dissolves in water, the molecules align by hydrogen and hydrophobic bonds forming micelles, which create a more hydrophobic environment (Chinachoti, 1995). Pectin also reduces water mobility by the formation of a cross-linked network, thus reducing the release rate of volatile compounds (Lubbers and Guichard, 2003).

Sucrose and glucose also significantly reduced volatile compound concentrations in the nosespace of orange juice (Table 2, Figure 1). This is referred to as a “salting-in effect”, which occurs when the addition of polar molecules enhances the solubility of volatile compounds by increasing the number of

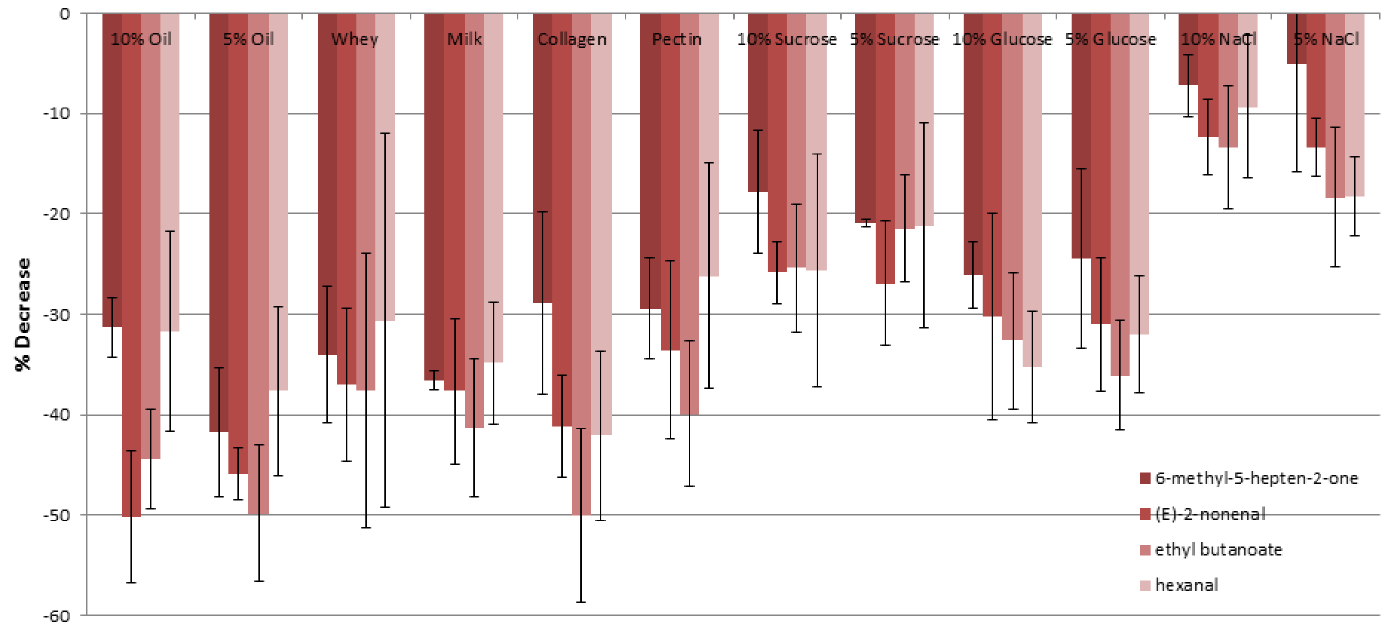

Figure 1. Change in nosespace concentrations of orange juice volatiles with different additives.

hydroxyl groups (Copolovici and Niinemets, 2007; Covarrubias-Cervantes et al., 2005).

There were no significant differences in the nosespace of orange juice with the addition of NaCl (Table 2). An increase in concentration in the nose was expected because of the “salting-out effect”. The “salting-out effect” occurs when the addition of NaCl decreases the amount of free water molecules because of ion-dipole interactions and hydration shell formation which increases the concentration of volatile compounds in the remaining free water thus increasing their volatility (Rabe et al., 2003). This may be because placing the 3 ml sample in the mouth stimulated release of approximately 1 ml of saliva, which may have diluted the sample enough that the salting out effect was no longer significant.

Strawberry and Tomato

The order of the effectiveness of the additives for strawberry drink and tomato puree was similar to orange juice (Tables 3 and 4). In addition, the same volatile measured in different foods was affected by the additives in similar ways. However, there were some specific differences in the different food matrices. In tomato puree, while the concentrations were in the same order as for the other drinks, in most cases the differences were only significant in the headspace. In strawberry and tomato, the addition of NaCl significantly increased some of the volatiles in the mouthspace and headspace while no significant increase was seen in orange juice. Similarly, hexanal, (*E*)-2-hexenal, ethyl acetate, and 3-methylbutanal have been showed to have a significant higher volatility with the addition of NaCl in the headspace of apple juice and vegetable soup (Rabe et al., 2003; Mitchell et al., 2011; Poll and Flink, 1984).

The volatile compound concentrations in the headspace were always the highest, while the mouthspace was usually, but not always higher than in the nosespace. Nosespace concentrations are expected to be lower than in the mouthspace due to the absorption of volatile compounds into the mouth epithelium, loss into the pharyngeal cavity though the velum, or the enzymatic degradation of volatile compounds (Linforth and Taylor, 2006). The headspace volume was the same as the mouth and nose, but it is a static method with significantly longer time to equilibrate into the air phase, so concentrations cannot be directly compared to the other methods.

In the headspace, changing sample size from 3 to 24 ml or adding saliva versus water did not change the effect of the additives. Increasing sample size increased absolute volatile concentrations, indicating that volatiles were being depleted in the lower volume. Adding saliva decreased absolute volatile concentrations. Mucin, a major glycoprotein, has been showed to decrease volatile concentration in headspace due to protein-flavor binding

Table 3. Strawberry drink volatile concentrations in the nosespace, mouthspace, and headspace after addition of oil, whey protein isolate, milk protein isolate, collagen, pectin, sucrose, glucose, and nacl (PPB).

	Control	10% Oil	5% Oil	Whey	Protein Milk	Collagen	Pectin	10% Sucrose	5% Sucrose	10% Glucose	5% Glucose	10% NaCl	5% NaCl
Nosespace													
(*E*)-2-heptenal	0.96^{a}	0.42^{h}	0.45^{gh}	0.69^{cdef}	0.59^{efg}	0.55^{fgh}	0.55^{fgh}	0.76^{bcd}	0.71^{bcde}	0.62^{def}	0.62^{def}	0.85^{ab}	0.82^{abc}
(*E*)-2-hexenal	0.45^{a}	0.21^{f}	0.23^{f}	0.26^{def}	0.24^{ef}	0.23^{ef}	0.26^{def}	0.34^{bc}	0.33^{cd}	0.29^{cde}	0.28^{cdef}	0.42^{a}	0.41^{ab}
ethyl butanoate	17.90^{a}	10.06^{a}	12.72^{a}	16.42^{a}	14.14^{a}	15.19^{a}	12.72^{a}	13.50^{a}	19.00^{a}	14.73^{a}	16.05^{a}	14.46^{a}	16.08^{a}
(*E*)-2-pentenal and hexyl acetate	7.60^{a}	2.93^{c}	3.00^{c}	7.50^{a}	5.49^{ab}	4.90^{bc}	5.87^{ab}	6.12^{ab}	6.22^{ab}	5.45^{ab}	5.63^{ab}	6.58^{ab}	6.97^{ab}
(*Z*)-3-hexen-1-ol	3.09^{a}	1.65^{b}	1.89^{ab}	2.85^{ab}	1.93^{ab}	2.18^{ab}	1.98^{ab}	2.08^{ab}	2.61^{ab}	2.04^{ab}	2.02^{ab}	2.11^{ab}	2.35^{ab}
Mouthspace													
(*E*)-2-heptenal	56.05^{c}	42.85^{c}	56.51^{bc}	41.69^{c}	51.96^{c}	48.34^{c}	59.48^{abc}	33.73^{c}	55.25^{c}	34.12^{c}	38.55^{c}	83.87^{a}	82.71^{ab}
(*E*)-2-hexenal	1.37^{bcd}	1.07^{e}	1.19^{cde}	1.28^{cde}	1.40^{bc}	1.36^{bcd}	1.33^{bcd}	1.17^{de}	1.34^{bcd}	1.24^{cde}	1.23^{cde}	1.63^{a}	1.49^{ab}
ethyl butanoate	125.81^{bcde}	76.89^{de}	72.71^{e}	162.76^{abc}	147.7^{bc}	137.3^{bcd}	149.8^{bc}	113.3^{cde}	164.1^{abc}	117.2^{cde}	135.7^{bcd}	212.7^{a}	187.3^{ab}
(*E*)-2-pentenal and hexyl acetate	65.95^{bc}	45.61^{e}	53.10^{cde}	57.38^{cde}	67.86^{abc}	61.55^{bcde}	66.93^{abc}	47.77^{de}	63.33^{bcd}	47.92^{de}	52.75^{cde}	84.08^{a}	77.00^{ab}
(*Z*)-3-hexen-1-ol	67.08^{bcd}	48.36^{f}	50.36^{ef}	63.97^{cde}	67.16^{bcd}	64.87^{cd}	67.97^{bc}	53.98^{cdef}	66.73^{cd}	53.59^{def}	59.01^{cdef}	86.26^{a}	81.20^{ab}
Headspace													
(*E*)-2-heptenal	64.56^{bc}	14.06^{e}	20.32^{e}	49.93^{d}	55.20^{cd}	53.87^{cd}	55.70^{cd}	62.00^{bcd}	54.33^{cd}	56.40^{cd}	54.77^{cd}	79.63^{a}	71.43^{ab}
(*E*)-2-hexenal	18.97^{a}	17.39^{a}	16.27^{a}	14.55^{a}	14.77^{a}	12.85^{a}	21.08^{a}	19.15^{a}	12.16^{a}	18.50^{a}	15.92^{a}	16.96^{a}	17.89^{a}
ethyl butanoate	4,209^{a}	2,834^{d}	3,190^{cd}	3,655^{abc}	3,694^{abc}	3,785^{ab}	3,269^{bcd}	4,073^{a}	3,827^{ab}	3,834^{ab}	3,686^{abc}	4,045^{a}	4,163^{a}
(*E*)-2-pentenal and hexyl acetate	1,524^{bc}	324.5^{e}	480.0^{e}	1,155^{d}	1,287^{cd}	1,282^{cd}	1,305^{cd}	1,470^{bcd}	1,288^{cd}	1,297^{cd}	1,257^{cd}	1,880^{a}	1,695^{ab}
(*Z*)-3-hexen-1-ol	400.6^{a}	264.4^{d}	302.2^{cd}	350.4^{abc}	356.8^{abc}	363.3^{abc}	309.3^{bcd}	396.6^{a}	372.4^{ab}	364.1^{abc}	352.2^{abc}	389.5^{a}	408.6^{a}

*Means in the same row that do not share a letter are significantly different.

Table 4. Tomato puree volatile concentrations in the nosespace, mouthspace, and headspace after addition of oil, whey protein isolate, milk protein isolate, collagen, pectin, sucrose, glucose, and nacl (PPB).

	Control	10% Oil	5% Oil	Whey	Protein Milk	Collagen	Pectin	10% Sucrose	5% Sucrose	10% Glucose	5% Glucose	10% NaCl	5% NaCl
Nosespace													
6-methyl-5-hepten-2-one	0.88^{a}	0.83^{a}	0.84^{a}	0.80^{a}	0.76^{a}	0.83^{a}	0.85^{a}	0.81^{a}	0.80^{a}	0.82^{a}	0.81^{a}	0.94^{a}	0.84^{a}
(*E*)-2-hexenal	0.26^{abc}	0.25^{abc}	0.22^{c}	0.23^{bc}	0.23^{abc}	0.23^{abc}	0.24^{abc}	0.25^{abc}	0.26^{abc}	0.26^{abc}	0.24^{abc}	0.28^{a}	0.27^{ab}
3-methylbutanal	1.92^{a}	1.62^{a}	1.61^{a}	1.83^{a}	1.88^{a}	1.8^{a}	1.76^{a}	2.08^{a}	1.95^{a}	2.03^{a}	1.87^{a}	2.17^{a}	2.10^{a}

Table 4. Contd.

1-penten-3-one	1.44^{a}	1.47^{a}	1.55^{a}	1.59^{a}	1.57^{a}	1.58^{a}	1.52^{a}	1.72^{a}	1.60^{a}	1.60^{a}	1.50^{a}	1.71^{a}	1.60^{a}
(*Z*)-3-hexen-1-ol	1.10^{a}	1.11^{a}	1.04^{a}	1.09^{a}	1.13^{a}	1.10^{a}	1.11^{a}	1.09^{a}	1.05^{a}	1.14^{a}	1.07^{a}	1.13^{a}	1.14^{a}
Mouthspace													
6-methyl-5-hepten-2-one	1.01^{a}	0.89^{a}	0.93^{a}	0.93^{a}	0.96^{a}	0.97^{a}	0.96^{a}	0.95^{a}	0.92^{a}	0.97^{a}	1.02^{a}	0.96^{a}	0.95^{a}
(*E*)-2-hexenal	6.06^{a}	6.83^{a}	7.09^{a}	4.92^{a}	6.04^{a}	5.55^{a}	5.74^{a}	5.44^{a}	5.11^{a}	5.85^{a}	5.49^{a}	5.86^{a}	5.58^{a}
3-methylbutanal	1.75^{a}	2.11^{a}	2.12^{a}	2.01^{a}	1.98^{a}	1.94^{a}	2.00^{a}	1.92^{a}	1.92^{a}	2.01^{a}	1.75^{a}	1.93^{a}	1.80^{a}
1-penten-3-one	1.79^{a}	1.71^{a}	1.71^{a}	1.57^{a}	1.61^{a}	1.61^{a}	1.55^{a}	1.69^{a}	1.65^{a}	1.74^{a}	1.78^{a}	1.80^{a}	1.73^{a}
(*Z*)-3-hexen-1-ol	1.59^{a}	1.41^{a}	1.46^{a}	1.39^{a}	1.45^{a}	1.42^{a}	1.44^{a}	1.48^{a}	1.52^{a}	1.45^{a}	1.51^{a}	1.35^{a}	1.42^{a}
Headspace													
6-methyl-5-hepten-2-one	7.32^{ab}	1.98^{e}	2.42^{de}	5.00^{c}	4.21^{cde}	4.48^{cd}	4.14^{cd}	7.27^{b}	6.71^{b}	7.16^{b}	6.40^{bc}	9.277^{a}	8.26^{ab}
(*E*)-2-hexenal	427.5^{bcd}	170.0^{f}	178.3^{f}	237.7^{ef}	204.0^{ef}	253.4^{cdef}	234.6^{def}	435.5^{abc}	410.5^{abcd}	435.4^{abcd}	381.0^{bcde}	570.7^{a}	493.9^{ab}
3-methylbutanal	23.72^{ab}	15.37^{d}	16.73^{cd}	15.73^{d}	15.18^{d}	15.94^{cd}	15.78^{cd}	25.41^{ab}	23.84^{ab}	24.35^{ab}	21.60^{bc}	28.84^{a}	25.89^{ab}
1-penten-3-one	37.54^{ab}	19.48^{b}	18.8^{b}	19.63^{ab}	18.31^{ab}	20.34^{b}	18.67^{b}	37.34^{ab}	35.28^{ab}	37.41^{ab}	33.26^{ab}	46.46^{a}	41.4^{a}
(*Z*)-3-hexen-1-ol	7.35^{abc}	3.96^{e}	4.30^{e}	4.56^{de}	4.14^{e}	4.85^{de}	5.00^{cde}	6.60^{bcd}	6.94^{bcd}	6.64^{bcd}	6.02^{bcde}	9.21^{a}	7.75^{ab}

*Means in the same row that do not share a letter are significantly different.

(Friel and Taylor, 2001; Van Ruth et al., 2001).

CONCLUSION

Nosespace results, which are the most accurate predictors of perceived odor, indicate that additives can produce a greater change in volatile concentrations than are predicted from headspace results. Oil produced the most significant decrease in volatile compound concentrations in the nosespace followed by proteins, pectin, sugar, and NaCl, respectively. NaCl produced no significant effect on the nosespace concentration while producing a significant increase in some volatiles in the headspace of strawberry and tomato. In tomato there was almost no significant effect of any of the additives on nosespace or mouthspace volatiles. Thus the effect was not the same for nosespace, headspace, mouthspace, and different types of fruit drink. The food matrix, composition, and static versus dynamic conditions affect the volatile compound concentrations.

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