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Determination of furan levels in commercial orange juice products and its correlation to the sensory and quality characteristics

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ABSTRACT

The objective of current study was to determine the furan levels in commercial orange juices (OJs) and relate to the sensory and quality characteristics of OJs. The factors among sensory and quality characteristics that showed high correlation to furan were identified. The furan levels found in 18 commercial OJs ranged from 0.59 to 27.39 ng/mL. Freshly-squeezed type OJs ($n = 4$) had significantly lower furan levels (4.68 ng/mL) than other OJs treated with heat processing ($p < 0.05$). Vitamin C content, specifically, dehydroascorbic acid showed higher correlation to the furan level in OJs ($r = 0.833$). A descriptive sensory analysis result revealed the different flavor profile of commercial OJs according to the processing method and added ingredient in OJs. Current approach of using sensory analysis for prediction of furan level in food products can be applied to future studies in many other food commodities.

1. Introduction

Furan is a colorless, heterocyclic aromatic compound (C_4H_4O) and is highly volatile. The International Agency for Research on Cancer classified this compound as Group 2B, a potential human carcinogen (Kromhout, 1995). According to the National Toxicology Program, furan is hepatoxic and results in cancer in mice and rats (NTP, 1993). Numerous studies have previously been conducted to determine the formation mechanisms of furan in food products. These have shown that the furan formation is not limited to one specific type of processing, and a variety of precursors exist, including amino acids, carbohydrates, polyunsaturated fatty acids, ascorbic acids, and carotenoids (Anese & Suman, 2013; Mariotti et al., 2012; Van Lancker, Adams, Owczarek-Fendor, Meulenaer, & De Kimpe, 2011; Kim, Her, Kim, & Lee, 2015) To date, thermal processing has been identified as the most likely cause in commercial food products, such as canned and jarred foods (4.9–48.5 ng/mL), coffee (67.8–1476 ng/mL), soy sauce (44.32–178 ng/mL), and baby foods (Kim, Lee, Kim, Park, & Lee, 2009; Kim, Kim, & Lee, 2010; Sijia, Enting, & Yuan, 2014; Zoller, Sager, & Reinhard, 2007; Feng et al., 2013; Limacher, Kerler, Davidek, Schmalzried, & Blank, 2008).

Orange juice (OJ) is a highly popular fruit juice, due to its unique taste and nutritional benefits, which include high vitamin C content (Kim, Lee, Kwak, & Kang, 2013). In 2012, South Korea was the 13th highest OJ-consuming country worldwide, consuming 37 metric tons, which equates to a market share of approximately $240 million (CITRUSBR. Brazilian association of citrus exporters., 2015; Gil-Izquierdo, Gil, & Ferreres, 2002). Commercial OJ-processing involves squeezing fresh orange, followed by a centrifuging step, and subsequent heat processing. The typical pasteurization temperature of fresh juice is set at 75 °C for 30 s, whereas frozen, concentrated juice is pasteurized at 95 °C for 30 s, with a subsequent freezing and thawing process (Gil-Izquierdo et al., 2002). The sensory characteristics and physiochemical properties of OJ can be affected by different thermal processing conditions (Gil-Izquierdo et al., 2002; Kim et al., 2013; Bettini, Shaw, & Lancas, 1998).

Although the majority of commercial OJs undergo the thermal processing step, limited research has been conducted to investigate the levels of furan in OJ products. A recent study (Wegener & Lopez-Sanchez, 2010) evaluated the levels of furan in fruit and vegetable juices, but OJ was not included in the fruit juice category. Only one previous study has reported the furan levels in commercial OJ products, and the average amount of furan found ranged from 3.33 to 7.59 ng/mL (Kim et al., 2010). Since commercial OJ products undergo heat treatment, and contain a relatively high level of vitamin C, one of the known precursors for furan formation, a high level of furan is to be expected. To date, very few studies have investigated furan levels in OJ products and related the result to sensory and quality properties. In the present study, the furan levels were determined in 18 commercial OJ products. The descriptive sensory analysis and quality characteristics, including vitamin C content, were further investigated to determine the factors affecting the formation of furan.

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2. Materials and methods

2.1. OJ samples for testing

Eighteen OJ samples were selected on the basis of their market share and processing types (Table 1). The selected OJs are readily available in grocery stores in Korea, and are widely consumed by Korean people. Of the 18 samples, 13 were made via "diluted from frozen concentrate (DFC)"processing, and four were made by "freshly-squeezed (FS-R)" processing. Seven of the 13 DFC juices required refrigeration during storage (DFC-R; samples 1–7), and six required room temperature storage (DFC-RT; samples 8–13). The four FS-R OJs had not been thermally processed, so they had a short shelf-life (samples 14–17). One OJ sample was prepared in the lab by squeezing an orange (sample 18), and this served as a control. A detailed description of each OJ can be found in Table 2. All OJs were purchased at a local grocery store, with the exception of sample 18, and were stored at 4 °C until further analysis was carried out.

2.2. Chemical reagents and materials

Furan and d4-furan with purity higher than 99% were purchased from the Sigma-Aldrich Corporation (St. Louis, MO, USA). Water and methanol (high-performance liquid chromatography [HPLC] grade) were bought from J. T. Baker (Phillipsburg, NJ, USA) for the analysis of furan concentration. Chemical reagents for measuring the vitamin C content of commercial OJs were purchased from Sigma-Aldrich Corporation (St. Louis, MO, USA), that included metaphosphoric acid (65.0% purity), 2,4-dinitrophenyl hydrazine (97.0% purity), and sulfuric acid (99.9% purity), thiourea (99.0% purity) and L-ascorbic acid (Vitamin C, 99.0% purity) and 2, 6- dichloroindophenol sodium salt hydrate (25 g, indicator grade).

2.3. Quality characteristics of commercial OJ samples

The pH of the 18 OJ samples was determined using a pH meter (S20 SevenEasy™ pH meter, Mettler Toledo GmbH 8603, Switzerland). The sugar content was measured by a Refractometer (Master-T series, Cat. No. 2312, Atago®, Japan), with a range of °Brix from 0.0 to 33.0%. The color of the OJ products was measured by a color-difference meter (NE 4000, Nippon Denshoku, Tokyo, Japan), according to the methods specified in the equipment manual. The results were reported as L* (lightness), a* (redness), and b* (yellowness) values, and △E (the formula of the $\triangle E = \sqrt{[(\Delta L^*)^2 + (\triangle a^*)^2 + (\triangle b^*)^2]}$ was calculated.

2.4. Determination of Vitamin C content of commercial orange juice samples

A total of 5 mL of OJ and the same amount of 5% metaphosphoric acid solution were mixed. The 5% metaphosphoric acid solution was prepared by mixing 15 g of metaphosphoric acid (HPO_3, 35% purity) and 40 mL of citric acid in 100 mL of water, after which the volume was increased by adding distilled water in a 250 mL volumetric flask. Once thoroughly mixed, 5 mL were aliquoted into a 100 mL volumetric flask and increased to 100 mL via the addition of weak metaphosphoric acid solution for extraction processing. Following the extraction, the extraction solution was filtered using filter paper (Whatman No. 2) ahead of vitamin C analysis. The 4-dinitrophenyl hydrazine (DNP) method was chosen for this analysis, in order to gauge the overall vitamin C content, including total ascorbic acid, ascorbic acid, and dehydroascorbic acid. The procedure for manufacturing via the DNP method was used in accordance with the Korean Food Standards Codex for analyzing vitamin C content (MFDS, 2012) and involves oxidation, formation of osazone, and dissolution

Table 1
Sample description and quality characteristics of 18 commercial OJs included in this study.

Sample	Storage condition	Ingredients	Quality characteristics					
			pH	Sugar Content (%, Brix)	Color measurements			
					*L**	*a**	*b**	*ΔE*
No 1.	DFC-R	Concentrated orange juice (100%), Purified water	4.46 ± 0.02^{a}	10.27 ± 0.12^{fg}	61.07	−3.13	44.85	0
No 2.		Concentrated orange juice, Purified water, Natural flavoring substances (orange)	4.43 ± 0.06^{a}	10.00 ± 0.00^{h}	54.58	−2.79	43.37	6.27
No 3.		Orange squash (100%), Purified water, Vitamin C	4.38 ± 0.01^{ab}	10.13 ± 0.12^{gh}	57.02	−3.35	41.39	5.33
No 4.		Concentrated orange juice (organic), Natural flavoring substance (orange), Purified water	4.32 ± 0.05^{b}	11.80 ± 0.00^{b}	53.87	−2.52	47.76	7.79
No 5.		Concentrated orange juice (100%), Synthesized flavoring substances (orange), Purified water	4.12 ± 0.05^{ef}	10.47 ± 0.12^{de}	52.23	−3.68	44.16	8.89
No 6.		Concentrated orange juice (100%), Orange juice extraction, Natural flavoring substances (orange), purified water	4.18 ± 0.01^{e}	10.73 ± 0.12^{c}	49.15	0.17	33.54	16.76
No 7.		Orange squash (100%), Purified water, Natural flavoring substances (orange)	4.02 ± 0.03^{fg}	13.2 ± 0.20^{a}	62.01	−3.51	47.58	2.91
No 8.	DFC-RT	Orange concentrate, Purified water, Natural flavoring substances (orange), Vitamin C	4.20 ± 0.01^{de}	10.6 ± 0.00^{cd}	47.68	−2.55	31.85	18.67
No 9.		Concentrated orange juice, Purified water, High fructose corn syrup, Vitamin C, White sugar, Calcium gluconate, Calcium lactate, maize starch, Citric acid	4.12 ± 0.02^{ef}	10.4 ± 0.00^{ef}	52.19	2.17	48.13	10.84
No 10.		Concentrated orange juice, Orange juice extraction, Purified water, Natural flavoring substances (orange)	4.29 ± 0.02^{bcd}	10.73 ± 0.12^{c}	52.77	−1.99	36.95	11.52
No 11.		Concentrated orange juice, Purified water, High fructose corn syrup, Calcium lactate, Citric acid, Vitamin C	4.30 ± 0.01^{bc}	8.73 ± 0.12^{k}	52.68	−4.13	36.03	12.21
No 12.		Concentrated orange juice, Purified water, Natural flavoring substances (orange)	4.21 ± 0.02^{cde}	10.13 ± 0.12^{gh}	53.01	−1.11	35.99	12.15
No 13.		Orange squash concentrate, Purified water, High fructose corn syrup, milk, Synthesized flavoring substances (orange), Citric acid, Vitamin C	3.97 ± 0.06^{g}	10.53 ± 0.12^{de}	51.99	−1.47	35.79	12.94
No 14.	FS-R	Orange (100%)	3.83 ± 0.12^{h}	9.07 ± 0.12^{j}	49.49	2.34	52.85	15.10
No 15.		Orange squash (92%), Orange flesh (8%)	4.39 ± 0.08^{ab}	10.53 ± 0.12^{de}	53.29	−1.03	42.98	8.27
No 16.		Orange squash (98.3%), Orange flesh (1.7%)	4.37 ± 0.09^{ab}	10.47 ± 0.12^{de}	53.14	−2.78	34.83	12.78
No 17.		Orange (100%)	3.99 ± 0.11^{g}	9.80 ± 0.00^{i}	50.26	−0.28	48.32	11.71
No 18.		Orange (100%)	3.88 ± 0.06	9.73 ± 0.12	43.84	−0.74	43.62	17.44

Numbers in a column followed by different letters represents significant difference at $p < 0.05$ using Duncan's multiple range tests DFC-R represents diluted from frozen concentrate-Refrigerated storage, DFC-RT represents Diluted from frozen concentrate-room temperature storage, FS-R represents freshly squeezed-refrigerated storage.