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RESEARCH ARTICLE

Quality Evaluation of Fresh Tomato Juices Prepared Using High-speed Centrifugal and Low-speed Masticating Household Juicers

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Abstract The aim of this study was to evaluate and compare the physicochemical, nutritional, and sensory properties of homemade fresh tomato juices prepared using 2 types of household juicers, a high-speed centrifugal juicer (HSC juicer) and a low-speed masticating juicer (LSM juicer). Juice yield, soluble solids, and the contents of total polyphenol, vitamin C, and lycopene in LSM tomato juice were significantly higher than those in HSC tomato juice. The DPPH radical scavenging activity of LSM tomato juice was also higher than that of HSC tomato juice. HSC tomato juice easily separated into 2 layers with many fine bubbles, while LSM tomato juice was homogeneous. Sensory evaluation revealed that panels significantly preferred LSM tomato juice to HSC tomato juice. In conclusion, the LSM juicer shows several advantages over the HSC juicer for preparing tomato juice of superior quality and taste that is rich in antioxidant phytochemicals at a high yield.

Keywords: tomato juice, household juicer, antioxidant, lycopene, homogeneity

Introduction

Vegetables and fruits are well-known as good sources of antioxidants such as polyphenols, carotenoids, anthocyanins, flavonoids, and vitamins. Fruit and vegetable juices offer a convenient method for consuming these beneficial compounds; therefore, juice consumption is gradually increasing worldwide (1,2). However, some phytochemicals are inevitably lost from fruit juice during commercial processing (3,4). Therefore, many people prepare juices freshly from vegetables and fruits at home, using a juicer. This household processing technique may result in extraction of juice with varying amounts of phytochemicals according to the type of juicer used (5).

Conventional household juicers involve centrifugation with a flat blade disk rotating at high speeds of 8,000-12,000 rpm (HSC juicer); in this type of juicer, the raw materials are ground and filtered. The recovery of phytochemicals, however, appears to be very low due to the low juice yield. Additionally, some antioxidants may be destroyed by the instant heat generated from the high-speed rotating blade and the catalytic activity of the metallic rotating disk surface. Recently, a novel juicer that uses a squeezing method rather than grinding was developed and has increased in popularity among consumers. This is known as a masticating juicer that is capable of squeezing juice from fruits and vegetables using a horizontal or vertical helical screw (auger) rotating at a low speed of approximately 80 rpm (LSM juicer). The vertical-type LSM juicer is composed of an auger, mesh drum, and brush holder, and residue is discharged while squeezing the raw materials. Bioactive phytochemicals and intrinsic flavor in the vegetables and fruits are known to be recovered using the LSM juicer, with high efficiency and yield. Additionally, oxidation is likely to be minimized because the heat generated by the rotating auger at low speed is negligible. However, an objective evaluation and comparison of juice qualities prepared using HSC and LSM juicers have not been reported.

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Tomatoes (*Lycopersicon esculentum* Mill.) are commonly consumed worldwide both as fresh and processed products (paste, juice, sauce, etc.). Tomatoes, one of the world's healthiest foods, are currently the second highest produced and consumed fruit in the USA (6). Additionally, this vegetable has remarkably high concentrations of vitamin C and carotenoids such as lycopene and β-carotene, a type of provitamin A. Tomatoes and their products are a rich source of lycopene, improve antioxidant defenses, and reduce the risk of inflammatory diseases such as cardiovascular disease upon consumption (7).

Many studies have recently been published on the characterization of phenolic antioxidants in fruit and vegetable juices (8,9). However, few studies have evaluated the physicochemical properties and antioxidant effects in fruit or vegetable juices processed using a household juicer (5). The purpose of the present study was to compare the quality of tomato juices prepared using LSM and HSC juicers by characterizing the physicochemical properties, quantifying phytochemicals, and evaluating sensory aspects.

Materials and Methods

Materials Ripe tomatoes were purchased from a local market in Gimhae, Korea. Lycopene, Folin-Ciocalteu reagent, tannic acid, pyrogallol, DL-dithiothreitol (DTT), DPPH, and L-ascorbic acid were purchased from Sigma-Aldrich (St. Louis, MO, USA). Other chemicals were of reagent grade.

Preparation of tomato juice Tomatoes were washed with tap water, and fruits of similar size were selected. Tomato juice was prepared using a vertical-type LSM juicer (SJ200B; Hurom Co., Ltd., Gimhae, Korea) or an HSC juicer (SJ600; Dongah Co., Ltd., Gimhae, Korea) according to the manufacturer's instructions.

Physicochemical analyses The pH of tomato juice was measured with a pH meter (AG 8603; Mettler Toledo, Switzerland), and the amount of soluble solid was evaluated as °Bx at 25°C, using a refractometer (Pal-1; Atago, Tokyo, Japan). Titratable acidity (TA, % tartaric acid) was determined by titrating 20 mL of tomato juice, after diluting it with 80 mL of distilled water, to pH 8.3 with a 0.1 N NaOH solution.

Total polyphenol analysis Total polyphenol content was determined using the method described by Folin-Denis with some modifications (10). One milliliter of tomato juice was added to 4 mL of 100% methanol, mixed thoroughly by vortexing, and incubated for 2 h at 4°C in the dark. An aliquot of supernatant was taken for total polyphenol analysis after centrifugation at 850×*g* and 4°C for 20 min. First, 200 μL of 50% Folin-Ciocalteu reagent was added to 400 μL of sample and the mixture was incubated for 3 min at room temperature. After 3 min, 400 μL of 2% Na_2CO_3 was added to the mixture, and the mixture was then incubated for 1 h at room temperature. Absorbance was recorded at a wavelength of 750 nm using a spectrophotometer (Libra 22; Biochrom, Cambridge, UK), and total polyphenol content was quantified using tannic acid as a standard. Analyses were performed in triplicate. Results were expressed as mg of tannic acid equivalents (TAE) per 100 mL of juice or 100 g of raw material tomato.

Vitamin C analysis Total vitamin C content (ascorbic acid+dehydroascorbic acid) was determined using the method described by Furusawa (11). One milliliter of tomato juice was added into 1 mL of 2 mg/mL DTT in 2% (w/v) acetic acid, and the mixture was incubated for 3 h at 4°C in the dark. Dehydroascorbic acid was reduced to L-ascorbic acid by DTT, a reducing agent. The concentration of L-ascorbic acid in the supernatant was analyzed using HPLC after centrifugation at 850×*g* and 4°C for 10 min. An HPLC instrument (UltiMate 3000; Dionex, Sunnyvale, CA, USA) equipped with an analytical C_{18} column (Gemini 5 μm C18 110A, 250×4.6 mm; Phenomenex, Torrance, CA, USA) and a photodiode array detector (PDA) was used with an isocratic elution of 2% (v/v) acetic acid as a mobile phase. A 20 μL sample was injected to the column with a flow rate of 1 mL/min, and the peaks were monitored at 254 nm. Each sample was filtered through a membrane filter (Advantec Dismic-13HP, PTFE, 0.45 μm; Toyo Roshi Kaisha Ltd., Tokyo, Japan) before injection. Vitamin C content was determined using L-ascorbic acid as a standard and expressed as mg of L-ascorbic acid per 100 mL of juice or 100 g of raw material tomato. Analyses were performed in triplicate.

Lycopene analysis Lycopene content was determined using the method described by Perkins-Veazie *et al.* (12) with some modifications. Ten milliliter of hexane: acetone: ethanol (2:1:1, v/v/v) solution was added to 0.1 g of juice, and the mixture was homogenized for 30 min at 4°C in the dark. After 30 min, 2 mL of distilled water was added to the solution, and the solution was allowed to stand for 30 min to separate the mixture into distinct polar and nonpolar layers. Next, 1 mL of the upper layer (hexane layer) containing lycopene was used to determine absorbance at a wavelength of 472 nm. Lycopene content was estimated based on the molar extinction coefficient ($\varepsilon=1.72\times10^{-5}$/cm/M) and expressed as mg per 100 mL juice or 100 g of raw material tomato. Analyses were performed in triplicate.

Analysis of DPPH radical scavenging activity DPPH radical scavenging activity was measured based on the method described by Blois (13). Briefly, 0.8 mL of 0.1 mM DPPH solution in 80% ethanol was added to an aliquot (0.2 mL) of tomato juice after centrifugation at 850×*g* for 10 min, followed by incubation in the dark for 10 min at room temperature. The decrease in absorbance (Abs) due to the proton donating activity of antioxidants was measured at 517 nm. Distilled water was used as a control. Analyses were performed in triplicate. DPPH radical scavenging activity was calculated as follows:

$$\text{DPPH radical scavenging activity (\%)} = \left(1-\frac{\text{Abs of juice}-\text{Abs of control}}{\text{Abs of control}}\right)\times 100$$

Microscopic observation of tomato juice One droplet of tomato juice was placed on a slide glass and covered with a cover glass. The tomato juice preparation was examined using optical microscopy (DM 500; Leica, City, Germany) at a magnification of ×40 or ×100.

Sensory evaluation Sensory evaluation of fresh tomato juice prepared using an LSS or HSC juicer was performed with 10 experienced panelists (female, 20-24 years old) who were graduate students of Inje University, Korea. Samples (50 mL) were served in 100 mL glasses labeled with a 3-digit number. Panelists were asked to taste and rank the samples between "0" (extremely dislike) and "9" (very much like). Sensory attributes, including color, aroma, homogeneity, throat, flavor, and overall acceptability, were evaluated. A cup of water was served to cleanse the palate between samples. Results were expressed as the mean and standard deviation.

Statistical analysis All data are presented as the mean ±SD of 3 independent experiments (n=3). To compare samples, the data were analyzed using Student's t-test (version 19; SPSS, CSPSS Inc., Chicago, IL, USA). Significance was accepted as a probability of 5% (p<0.05).

Results and Discussion

Physicochemical properties The general physicochemical properties of tomato juices prepared using household HSC and LSM juicers are shown in Table 1. As expected, the juice yield of the LSM juicer (79.9±1.6%) was remarkably higher than that of the HSC juicer (54.8±1.3%). Since the flat blade disk in the HSC juicer rotates at a very high speed (8,000-12,000 rpm), a considerable amount of tomato was not ground and was deflected off the disk into a draff outlet port, resulting in lower yield than that obtained with the LSM juicer, which squeezed an entire tomato without loss. The soluble solids in LSM tomato juice (5.13±0.06 °Bx), therefore, were also significantly higher than in HSC juice (4.73±0.06°Bx). The pH values of HSC and LSM tomato juices were the same at pH 4.25, but the acidity of LSM juice (0.50±0.01) was slightly lower compared to that of HSC juice (0.52±0.01).

Table 1. Physicochemical properties of tomato juices prepared using household LSM and HSC juicers[1)]

	LSM juicer	HSC juicer
Yield (%)	79.9±1.6*[2)]	54.8±1.3[3)]
°Bx	4.73±0.06	5.13±0.06*
pH	4.25±0.00	4.25±0.01
Acidity (%)	0.50±0.01	0.52±0.01*

[1)]LSM juicer, low speed masticating juicer; HSC juicer, high speed centrifugal juicer
[2)]Data with asterisk are significantly different (p<0.05).
[3)]The results are expressed as mean±SD (n=3).

Total polyphenol content The chemical structures of polyphenols include aromatic ring(s) and more than one hydroxyl group, and are grouped into flavonoids and phenolic acids. Polyphenols are essential antioxidant groups that are present in tomato together with lycopene and vitamin C. The main flavonoids in tomato are known to be rutin and naringenin, while the main phenolic acids are chlorogenic and caffeic acid (14). Total polyphenol contents of tomato juices prepared using HSC and LSM juicers are shown in Table 2. The amount of total polyphenol in 100 mL of LSM tomato juice was 49.0±0.6 mg TAE, which was slightly higher than that in HSC tomato juice (47.7±0.1 mg TAE). Furthermore, the amount of total polyphenol extracted from 100 g of tomato using an LSM juicer was 39.2±0.4 mg TAE, which was much higher than that using an HSC juicer (26.1±0.1 mg TAE) due to the low yield of the HSC juicer. When the same amount of tomato was used for juice extraction, 50% more total polyphenol was detected in LSM juice compared to that in HSC juice. Wootton-Beard *et al*. (15) demonstrated that total polyphenol is an important component of ingested antioxidants, which can be used in the body. Therefore, LSM tomato juice is a better supplement of antioxidants than HSC juice.

Vitamin C content Ascorbic acid (vitamin C) may play a role in oxidative defense functions by quenching various free radicals and the singlet form of molecular oxygen (16). Jacob *et al*. (17) reported that vitamin C as well as lycopene and other tomato micronutrients in tomato juice have synergic effects on reducing oxidative stress and inflammation. Tomato is known to contain high levels of vitamin C (170 mg/kg fresh wet weight), and it is responsible for 58% of the total antioxidant power of the

Table 2. Total polyphenol, vitamin C, and lycopene contents of tomato juices prepared using household LSM and HSC juicers[1)]

	mg/100 mL of juice		mg/100 g of tomato[2)]	
	LSM juicer	HSC juicer	LSM juicer	HSC juicer
Total polyphenol[3)]	49.0±0.6*[4)]	47.7±0.1[5)]	39.2±0.4*	26.1±0.1
Vitamin C	15.3±0.2*	13.6±0.3	12.2±0.2*	7.4±0.1
Lycopene	3.02±0.01*	2.20±0.05	2.42±0.01*	1.20±0.03

1)LSM juicer, low speed masticating juicer; HSC juicer, high speed centrifugal juicer
2)From 100 g of raw material tomato
3)Total polyphenol contents are expressed as mg of tannic acid equivalent (TAE) per 100 mL of juice or 100 g of tomato.
4)Data with asterisk are significantly different (p<0.05).
5)The results are expressed as mean±SD (n=3).

fruit (18). In the present study, the total vitamin C content of tomato juice prepared using an LSM juicer (15.3±0.2 mg/100 mL) was significantly higher than using an HSC juicer (13.6±0.3 mg/100 mL) (Table 2). When taking into account the yield of each juicer, the difference in vitamin C content was higher, and only 60.8% of vitamin C in LSM juice could be recovered in HSC juice from tomato raw material. The higher vitamin C content in LSM tomato juice can be explained by the higher juice yield of the LSM juicer than that of the HSC juicer and the destruction of vitamin C by the heat generated from the blade and the oxidation with the metallic surface of the blade in the HSC juicer. Therefore, LSM tomato juice provides more vitamin C than does HSC juice.

Lycopene content Lycopene is a red-colored carotenoid with antioxidant activity and has been shown to play a role in reducing the risk of chronic diseases such as cancer and cardiovascular diseases (7). Lycopene was also reported to reduce DNA damage, prevent atherosclerosis through its anti-inflammatory effect, and preserve endothelial function (19). Lycopene is the primary carotenoid in tomato, and its content was determined to range from 1.82-11.89 mg per 100 g wet weight (20). Tomato is a major source of lycopene in the human diet, with more than 80% of dietary lycopene provided by tomato and its products. Lycopene concentrations of tomato juices prepared using the LSM and HSC juicers are shown in Table 2. The results showed a similar trend as those for polyphenol and vitamin C. Lycopene content in 100 mL of LSM tomato juice was 3.02±0.01 mg which was significantly higher than that in HSC juice (2.20±0.05 mg). From 100 g of tomato, 2.42±0.01 mg of lycopene was extracted using the LSM juicer, and this was 2-fold higher than that extracted using the HSC juicer. Sánchez-Moreno *et al*. (21) reported that the lycopene content of tomato juice freshly prepared using a blender was 1.024 mg/100 mL, which is lower than the value determined in this study. This discrepancy may be because we used a different variety of tomato. Böhm and Bitsch (22) reported that lycopene from tomato juice was better absorbed in the intestines than lycopene from raw tomato. Therefore, LSM tomato juice is a good choice for obtaining dietary lycopene compared with HSC juice or raw tomato.

Table 3. DPPH radical scavenging activity of tomato juices prepared using household LSM and HSC juicers[1)]

	LSM juicer	HSC juicer
DPPH radical scavenging activity (%)	55.6±0.2*[2)]	49.8±0.1[3)]

1)LSM juicer, low speed masticating juicer; HSC juicer, high speed centrifugal juicer
2)Data with asterisk are significantly different (p<0.05).
3)The results are expressed as mean±SD (n=3).

DPPH radical scavenging activity DPPH is a free radical donor widely used for evaluating the free radical scavenging effects of natural antioxidants (23). DPPH free radical is purple-colored and shows absorbance at 515 nm, but the purple color changes to yellow upon reduction by antioxidants. The decrease in absorbance is proportional to the radical scavenging activity of the antioxidant. The DPPH radical scavenging activity of LSM tomato juice was 55.6±0.2%, which was 11.7% higher than that of HSC juice (49.8±0.1%), which may be caused by the high contents of polyphenols, vitamin C, and lycopene in LSM tomato juice (Table 3). This indicates that radical scavenging activity is highly correlated with natural antioxidant content in tomato juice.

Homogeneity of tomato juice As shown in Fig. 1A, tomato juice prepared using the LSM juicer was homogeneous and did not separate into 2 layers for several hours. Tomato juice prepared using the HSC juicer, however, was unstable and readily separated into 2 layers just after preparation (Fig. 1B). Layer separation results in decreased overall juice quality. To investigate this phenomenon, each type of tomato juice was examined under an optical microscope. The HSC tomato juice was observed to have a large number of fine air bubbles in the upper layer (Fig. 2B). The bubbles appeared to be formed as a result of denatured proteins or pectic substances at the grinding step involving high-speed rotation of a flat blade

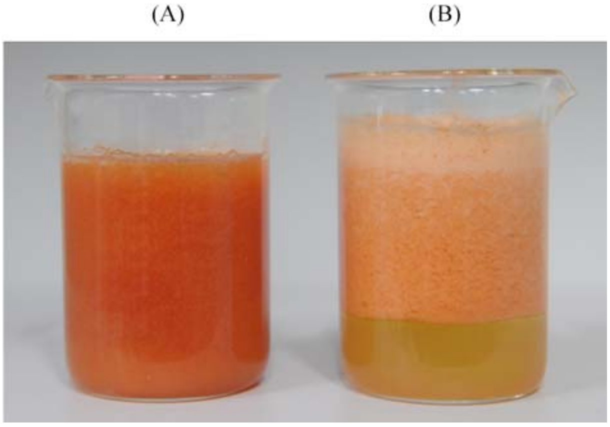

Fig. 1. Photographs of tomato juices just after preparation using household juicers. (A) LSM juicer; (B) HSC juicer

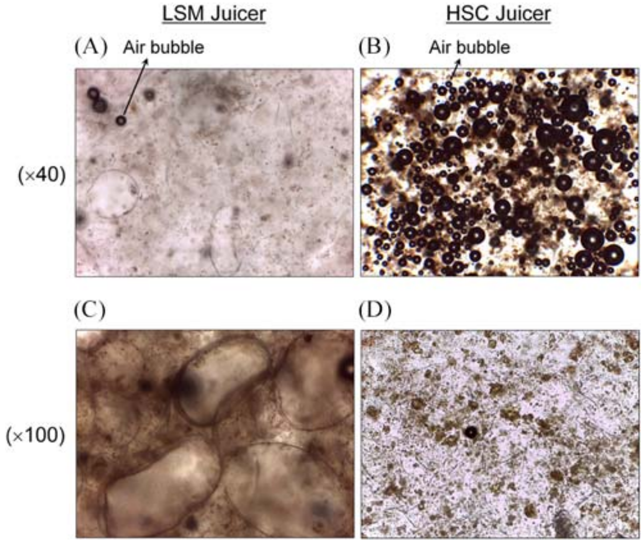

Fig. 2. Photomicrographs of tomato juices prepared using household juicers. (A) Homogenous tomato juice prepared using LSM juicer at a magnification of ×40; (B) upper layer of tomato juice prepared using HSC juicer at a magnification of ×40; (C) homogenous tomato juice prepared using LSM juicer at a magnification of ×100; (D) lower layer of tomato juice prepared using HSC juicer at a magnification of ×100

disk in the HSC juicer. The bubbles were able to incorporate insoluble components of tomato juice, such as tissues and fiber, causing the layer separation. In contrast, only a few air bubbles were observed in the LSM tomato juice (Fig. 2A). Additionally, cell shapes were clearly distinguishable in LSM tomato juice, whereas most cells were disrupted in HSC juice (Fig. 2C, 2D). Cell debris in HSC tomato juice readily attaches to air bubbles, contributing to layer separation. Since cell walls were severely damaged during the grinding step in HSC tomato juice, the cell components were discharged into the juice, leading to decreased freshness and increased quality deterioration caused by undesirable reactions such as oxidation, as indicated in a report by Gonzalez *et al*. (24). Additionally, air bubbles increase the area in contact with air or oxygen and may accelerate oxidation of the juice. In LSM tomato juice, the tomato was squeezed during juice extraction rather than ground, and thus cell structure was maintained, producing a homogeneous and good-quality tomato juice.

Table 4. Sensory evaluation of tomato juices prepared using household LSM and HSC juicers[1)]

Attributes	LSM juicer	HSC juicer
Color	6.60±1.14*[2)]	5.50±0.28[3)]
Aroma	7.20±1.00*	6.00±2.45
Homogeneity	7.20±0.05*	6.25±2.37
Throat	7.00±1.26*	5.50±3.11
Flavor	7.00±0.58*	4.50±2.08
Overall acceptability	7.80±0.50*	4.50±2.08

[1)]LSM juicer, low speed masticating juicer; HSC juicer, high speed centrifugal juicer
[2)]Data with asterisk are significantly different (p<0.05).
[3)]The results are expressed as mean±SD (n=10).

Sensory evaluation A survey to evaluate the sensory properties of fresh tomato juices prepared using LSM and HSC juicers was conducted, involving 10 young panelists. The results revealed distinct differences in the panelists' preferences between LSM and HSC tomato juices for color, aroma, homogeneity, throat, flavor, and overall acceptability (Table 4). Scores for LSM juice ranked significantly higher than those for HSC juice in all attributes tested (p<0.05). Additionally, the relative standard deviations of LSM juice ranged from 0.7-18.0% (average 10.8%), which were much lower than those for HSC juice, which ranged from 5.1-56.5% (average 38.8%), indicating that LSM tomato juice shows very small differences for individual preference and is appealing. Particularly, the smooth feeling in the throat when drinking LSM tomato juice ('throat' attribute in Table 4) was more pronounced than when drinking HSC juice, as expected based on the results of the homogeneity test discussed above. The overall acceptability of LSM juice was 1.7-fold higher than that of HSC juice. In other reports examining sensory evaluation of fruit juices, antioxidant phytochemicals and polyphenols were suggested to positively contribute to pungency, bitterness, color, and flavor of grape juices in addition to their free radical scavenging properties, and a relative positive correlation was previously observed between total acidity and sensory properties of orange juice (25,26). In the present study, the contents of phytochemicals including polyphenols, vitamin C, and lycopene were shown to affect sensory properties of fresh tomato juice rather than total acidity since the total acidities of LSM and HSC juices were similar (Table 1). Although the number of panelists (n=10) was relatively small, the results of sensory evaluation indicate that consumers prefer LSM tomato juice to HSC juice.

In conclusion, tomato juice prepared using a household LSM juicer had more desirable qualities in terms of physicochemical and sensory properties, phytochemical contents, and homogeneity than tomato juice prepared using a household HSC juicer. Therefore, the LSM juicer shows many benefits for preparing healthy and delicious tomato juice.

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