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Textural and Organoleptic Properties of Tofu Manufactured with Micronized Full-fat Soyflour Fortified with Food Ingredients

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Abstract

Textural properties of tofu manufactured with micronized full-fat soyflour (MFS) were enhanced by the addition of soy protein isolate, whey protein concentrate, chitosan oligosaccharide and mushroom powder. The MFS solution (14.2% solid content) was converted to semi-solid tofu by a two-stage heat treatment with the addition of 4% coagulant mix. The MFS tofu was evaluated by a compression test as well as sensory evaluation. To produce the semi-solid gel (MFS tofu) with reasonably high strength and toughness, the MFS solution with 14.2% solid content and 7.0% protein had to be heat treated at 121°C for 3min. The relative toughness of MFS tofu was increased by the addition of SPI, showing a 144% increase. The toughness of MFS tofu prepared with the MFS/SPI mixture was greatly increased by the addition of WPC at the level of 0.7% and the water separation from MFS tofu was greatly reduced. Furthermore, the toughness and strength of MFS/SPI tofu was enhanced by the addition of 0.1% chitosan oligosaccharide and 0.2% mushroom powder. The sensory evaluation of the tofu fortified with SPI, chitosan oligosaccharide and mushroom powder was superior to that of MFS tofu, with a higher score for overall preference.

Key words: micronized full-fat soyflour, tofu, texture, chitosan

INTRODUCTION

Soybean (*Glycine Max.*) is an important ingredient in the food production industries in Oriental countries. In particular, soybean protein is an important vegetable protein source that has been utilized for protein fortification in various processed foods (1). Among them, tofu, a concentrate of soy protein, has been produced and utilized as an important dietary food in Korea and Japan (2). In recent years, the consumption of tofu has gradually increased since researcher has demonstrated that soybean consumption reduces the incidence of important chronic diseases such as, hypertension, arteriosclerosis, diabetes, and obesity (3-7).

The quality of tofu is, in general, dependent upon the type and quality of proteins, total soluble contents, temperature and time for heating the protein solution (8,9). The texture of tofu, a critical quality factor, is also affected by the type, concentration of coagulants, temperature and time for coagulation. In addition, stirring conditions and compression during curd formation greatly influence the texture of tofu (10,11).

Generally, Korean tofu can be classified as hard, regular, soft, and uncompressed curd. Manufacturing of tofu is a relatively complicated process, including filtration, sterilization of soymilk, formation and pressing of curd, cooling and packaging of curd. Tofu processing requires lots of water for steeping the soybeans and cooling of the tofu. In a typical tofu-making process there is about a 30% yield of tofu from soybean. Soybean curd residue includes some protein, carbohydrate, and dietary fiber that are by-products of the tofu making industry. In addition the liquid including soluble carbohydrate and flavone is removed during the semi-solid curd formation and is sometimes separated and saved for use as a functional ingredient (12,13). Although the soybean curd residue has been utilized as an ingredient for lactic acid fermentation (14), more research is needed to develop new ways to make use of this nutrient-rich byproduct.

Recently, advancements in particulate technology have permitted the production of micronized powder from whole soybean, with minimal denaturation of protein and rancidity of fat. Micronized full-fat soyflour (MFS) has a small particle size (above 300 mesh) and good functional properties with retained flavor and nutritional value (15). Therefore, micronized full-fat soyflour is a potentially useful ingredient for the food industry, providing maximal utilization of soybean and wholesome nutritional value.

Tofu (Cheon tofu), a semi-solid soybean curd prepared with MFS by the non-pressing method is a common soy

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food in Korea. Cheon-tofu manufacturing is a relatively simple process, with soymilk preparation from MFS, sterilization and curd formation; compared with the conventional tofu-making process (16). Kim et al. reported that the texture of Cheon-tofu is dependent upon the heating treatment (17). Types and concentration of coagulant also affect the texture, physicochemical properties and sensory evaluation of Cheon-tofu prepared with micronized full-fat soyflour (18). Since various types of Cheon-tofu have been produced from many varieties of soybean, food scientists have been interested in Cheon-tofu as a promising healthy food. Recently, Cheon-tofu has been produced on a commercial scale by a local food company. In spite of its nutritional and economic value, Cheon-tofu has inferior texture compared with conventional tofu. The texture of Cheon-tofu prepared with MFS is believed to be affected by the type and concentration of coagulants, heating conditions, and the use of additional ingredients. Although research on the manufacture of Cheon-tofu has been carried out, additional research is needed to establish the optimal processing methods for the manufacture of high quality Cheon-tofu.

Therefore, we investigated the effects of various heat treatments and additives on the texture and sensory characteristics of Cheon-tofu.

MATERIALS AND METHODS

Materials

Micronized full-fat soyflour (MFS) was purchased from Perican Co. (Japan). Protein, carbohydrate, lipid and moisture concentrations of MFS were 39.1%, 24.8%, 23.7% and 5.8%, respectively. Soy protein isolate (SPI) and whey protein concentrate (WPC) were purchased from Archer Dianiels Midland Co. and American Meta-Pack Company Inc. (USA), respectively. Protein concentrations of SPI and WPC were 90.0% and 80.0%, respectively. Chitosan oligosaccharide and a shiitake mushroom powder as domestic products were obtained from Kitto Life Co. (Korea) and Korea Agriculture Union, respectively. GDL (glucono-δ-lactone) and $MgSO_4 7H_2O$ for uses as tofu coagulants were purchased from Sigma Chemical Company (P.O. Box 14508, ST. Louis, MO, USA). A bamboo salt (Baek-Oon Inc., Korea) was used for the coagulant in MFS tofu.

Manufacture of MFS tofu

The MFS tofu was prepared from an MFS solution fortified with SPI, WPC, chitosan oligosaccharide or a shiitake mushroom powder. The total solid content of the MFS solution was adjusted to between 13% and 15% by dilution with hot water (95°C) with a solid to liquid ratio of 1 : 6.5, 6.0, 5.5. The MFS solution was treated with a homogenizer (Model AM, Nihonseiki Kaisha LTD, Japan) at 10,000 rpm for 1 min and then sterilized at 95°C for 30 min or 121°C for 3 min for protein denaturation. The heat treated MFS solution was directly cooled to 10°C in an ice bath. The MFS solution mixed with a coagulant (Salt 0.1%, GDL 0.1%, $MgSO_4 7H_2O$ 0.2%) at a total concentrations of 0.4% was transferred to a plastic container ($7.8 \times 11 \times 4$ cm), and then a heat sealed container was subjected to heat treatment at 95°C ~98°C for 30 min in water bath. A semi-solid MFS tofu was cooled down to room temperature within 30 min (19).

Texture analysis of MFS tofu

The texture properties of MFS tofu were evaluated using Rheometer (Model RT-3010D, Rheotech, Japan). Tofu samples ($2 \times 2 \times 2$ cm) were prepared by cutting the MFS tofu. The textural characteristics including toughness and strength of MFS tofu were measured by determining the force required for causing deformation or disruption of tofu structure, respectively (20). The texture of MFS tofu was measured under the condition of full force scale (2 kg), table speed (30 mm/min), and clearance (4 mm). A probe with a round cylindrical adaptor (15 mm) was applied to the MFS tofu with compression ratio of 20%. The average value was obtained from five measurements. Strength, gel strength, softness and hardness of MFS tofu were evaluated by a breaking test. Toughness, adhesion, viscosity, cohesiveness, elasticity, chewiness and gumminess of MFS tofu were measured by the chewing test (21).

Sensory evaluation of MFS tofu

For the sensory evaluation of various MFS tofu samples, twelve panelists were selected among graduate students and were trained for sensory evaluation. The MFS tofu fortified with SPI, WPC and/or chitosan oligosaccharide and shiitake mushroom powder was prepared. The test was accomplished by six grade scoring test, and results were evaluated by a dispersion analysis and Duncan's multiple range tests using ANOVA ($p<0.05$) (21).

RESULTS AND DISCUSSION

Effect of total solid content and heat treatment

MFS tofu and MFS tofu fortified with SPI were prepared so as to manipulate the textural properties. MFS tofu had a less favorable structure with a lower hardness than seen in previous studies. However, MFS tofu manufactured with various solid additives exhibited the semi-solid characteristics of a typical soybean curd. Therefore, to improve the texture of MFS tofu the total solid content in MFS tofu was increased by the addition of SPI, resulting in an increase in protein content from 6.6% to 7.6% (w/w).

As shown in Fig. 1, the toughness of MFS tofu was enhanced by increasing the total solid content, from 13.3 % to 14.2% and 15.4% (w/w) in the ratio of solid to water (1 : 6.5, 6.0, 5.5). The MFS tofu manufactured after heating at 121°C for 3 min showed greater toughness and strength than tofu heat-treated at 95°C for 30 min. It is known that the denaturation of soy protein at higher temperatures for a shorter time enhances the gel formation by the interaction of disulfide interchange and the exposure of free thiol groups (22). On the basis of the lowest total solid content (13.3%) used for tofu manufacture by heating at 121°C for 3 min, MFS tofu prepared with 14.2% and 15.4% of total solids increased the relative toughness by 138% and 144%, respectively. The strength of MFS tofu was also influenced by the total solid content. The MFS tofu with 14.2% (w/w) total solids reached the maximum strength, with no further changes up to 15.4% solids. Furthermore, MFS tofu prepared with more than 8.0% protein content had a lower value for strength (unpublished results). This implies that benefits from higher total solid content, including higher protein content, may be limited by the potential for protein hydration and the limitations of heat treatment because of the higher consistency of the MFS solution. It has been shown that with 7.0% (w/w) protein and 14.2% (w/w) total solids, MFS solutions fortified with SPI produce a reasonably low consistency tofu, even after the addition of coagulant, resulting in the formation of a semi-solid gel with a smooth surface (18). Under the same conditions MFS tofu had greater toughness and strength (Fig. 1). Ku and Kim (1) reported that

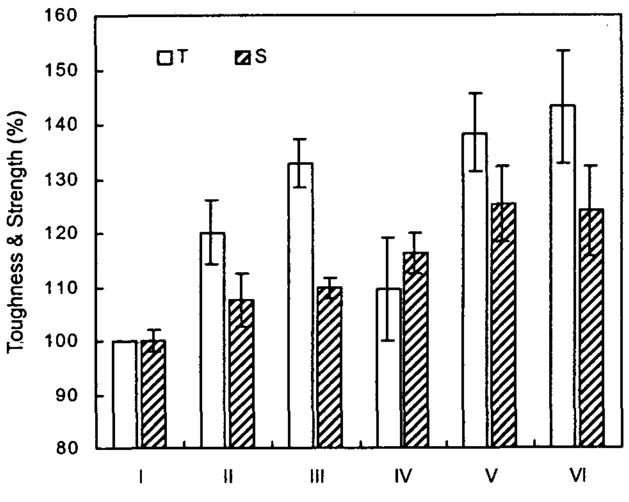

Fig. 1. Comparison of relative toughness and strength of MFS tofu according to the solid contents and heat-treatment. Symbol: T, toughness; S, strength; heat treatment: I, II, III (95 °C, 30 min); IV, V, VI (121°C, 3 min); ratio of solid to water: I, IV (1 : 6.5); II, V (1 : 6.0); III, VI (1 : 5.5).

soft tofu with smooth texture was obtained by a non-compressed process with a highly diluted SPI solution. The MFS tofu was prepared with 10% solids and additional fortification with sodium alginate; hardness was decreased when heating temperature was increased from 80°C to 100°C (23).

Compared with traditional tofu, MFS tofu is simple procedure of serial steps, including the homogenization of the MFS suspension, heat treatment and uncompressed curd formation in a container. For optimal curd formation in MFS tofu manufacture, the heat treatment of high viscous MFS suspension is an essential step. The optimal heat treatment causes an interaction between the denatured proteins which forms the three-dimensional gel structure with high water holding capacity. For the preparation of soybean curd with higher springiness, it has been reported that the major soy proteins, conglycinin (7S) and glycinin (11S), need to be denatured by heating at 90°C (19). In addition to the first heat treatment at higher temperature for denaturation of MFS protein, the second heat treatment is important to form the optimum semi-solid gel through the interaction between denatured proteins and coagulants. Therefore, in the manufacture of MFS tofu, the heat treatment should be optimally manipulated to obtain a good textured MFS tofu. Previously, it was determined that MFS/coagulant solutions form a good textured tofu with the second heat treatment at 95~98°C for 30 min.

Effect of SPI and WPC

To evaluate the effect of WPC on MFS tofu, the WPC solution was added to the MFS solution and cooled after the first heat treatment at 121°C for 3 min. It was previously found that the addition of WPC at the level of 0.7% protein has a positive effect on the texture of MFS tofu. Addition of large amount of WPC did not change the toughness or strength of MFS tofu (unpublished results). On the basis of the lowest concentration of MFS (5.7% protein) the effect of SPI, WPC or SPI and WPC on the strength, toughness and water loss of MFS tofu is shown in Fig. 2. The addition of WPC enhanced the toughness of MFS tofu, increasing relative toughness by 113%. β-Lactoglobulin, a major whey protein in milk, is known to be a functional protein that plays an important role in gelation (24,25). During heat treatment the sulfuhydryl groups of β-lactoglobulin are exposed and interact in the disulfide interchange reaction, supporting the formation of semi-solid gel (26). Furthermore, coaddition of WPC and SPI in MFS solution had a synergistic effect, increasing the strength and toughness of tofu, with a 141% increase in relative toughness. In addition the water loss from MFS tofu was minimized by the

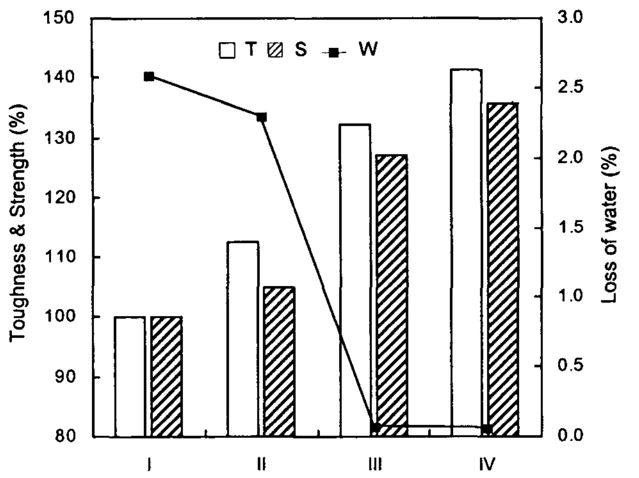

Fig. 2. Comparison of the relative toughness, strength and syneresis of MFS tofu according to the addition of different types of protein.
I: MFS, II: MFS with WPC (0.7%), III: MFS fortified with SPI, IV: MFS fortified with SPI and WPC. Symbol: T, relative toughness; S, relative strength; W, loss of water.

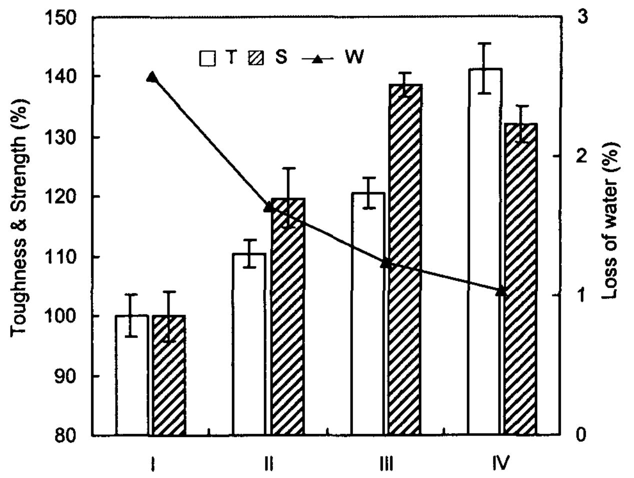

Fig. 3. Comparison of the relative toughness, strength and syneresis of MFS tofu according to the addition of different ingredients.
I: Control (MFS with SPI), II: control with chitosan oligosaccharide (0.1%), III: control with chitosan oligosaccharide (0.1%) and mushroom powder (0.2%), IV: control with chitosan oligosaccharide (0.1%) and mushroom powder (0.4%). Symbol: T, relative toughness; S, relative strength; W, loss of water.

addition of SPI and WPC. This implies that fortification of MFS tofu with WPC as a source of milk protein increases the nutritive value as well as textural properties. Although the texture of MFS tofu was improved with 15.4% total solids and 7.6% protein content, it is necessary to evaluate the relationship between MFS tofu and solid contents including MFS, SPI and WPC.

Effect of chitosan oligosaccharide and mushroom powder

MFS is valuable ingredient because of its versatile applications in processed foods. MFS tofu can be made from whole soybean powder, without the production of by-products such as insoluble residues of soybean milk. In particular, the fortification of additional nutrients can be easily performed in MFS tofu that is prepared by the uncompressed process. The effects of chitosan oligosaccharide and a shiitake mushroom power on the texture of MFS tofu were evaluated. MFS tofu manufactured with 7.0% total protein and 14.2% (w/w) total solids was made with the addition of 0.1% of chitosan oligosaccharide, because the addition of large amounts of chitosan oligosaccharide causes weak cohesiveness and rough texture of MFS tofu (unpublished results). As shown in Fig. 3, the toughness and strength of MFS tofu were increased by the addition of 0.1% chitosan oligosaccharide by 110 % and 120%, respectively. The addition of 0.2% shiitake mushroom powder to MFS tofu increased the relative toughness by 121%, and adding 0.4% shiitake mushroom powder increased the relative toughness to twice that of MFS/SPI tofu. In addition the water loss from MFS tofu was decreased by the addition of chitosan oligosaccharide and mushroom powder. These results imply that fortification with chitosan oligosaccharide and mushroom powder enhances the texture of MFS tofu. Considering the strength of MFS tofu fortified with chitosan oligosaccharie and a shiitake mushroom powder, fortification with 0.1% chitosan oligosaccharide and 0.2% shiitake mushroom powder is optimal for improving MFS and MFS/SPI tofu texture.

In addition to improving tofu texture, functional properties of chitosan oligosaccharide are known to include: adsorption of heavy metals, moisture absorption, emulsion, anti-microbial properties and cholesterol reduction (27). It has been reported that shiitake mushroom has anticancer or anti-tumor effects (28). Tofu is generally consumed following a short storage time even though tofu is distributed in a cold chain system. There is considerable interest in increasing the shelf life of tofu in the soy food industry. First of all, the inhibition of microbial contaminated in tofu is a crucial process for preservation. Therefore, the shelf life of MFS tofu can be improved by the addition of chitosan oligosaccharide, which has anti-microbial properties. Consequently, the textural, nutritional and functional properties of MFS tofu can be effectively enhanced by the addition of functional ingredients without a loss of any desirable properties.

Textual evaluation of MFS tofu

To evaluate the textural properties of MFS tofu, MFS tofu fortified with SPI, WPC and/or chitosan oligosaccharide and shiitake mushroom powder were prepared and compared with a commercial hard tofu manufactured by P Company. The textural properties of MFS tofu were determined by the breaking test and chewing test. As shown in Table 1, the commercial hard tofu in general had the higher strength (45 g), gel strength (96 g) and hardness (24040 dyne/cm^2) by the breaking test. However, only MFS tofu had a substantially lower hardness value (15670 dyne/cm^2) whereas fortification of MFS tofu with both chitosan oligosaccharide and shiitake mushroom powder increased the hardness (19167 dyne/cm^2) and strength (30 g) to values approaching those of the commercial tofu. In general the MFS had higher values for softness compared than the commercial tofu (Table 1). In the chewing test the toughness, adhesiveness and chewiness of the commercial tofu were higher than those of the MFS tofu. The MFS tofu with SPI or WPC showed higher values for all textural properties than those of MFS tofu (Table 2). The toughness, adhesiveness, chewiness, gumminess and viscoelasticity of MFS tofu were increased by the addition of SPI. In particular, MFS tofu prepared together with SPI, shiitake mushroom powder, and chitosan oligosaccharide had the highest value (10 g) for toughness, similar to that of the commercial hard tofu. These results confirm that MFS tofu fortified with these three ingredients has a hard texture property with two fold increases compared with MFS tofu prepared with only MFS. As a means for fortifying protein content, the MFS tofu with SPI had relatively higher value of adhesiveness (965 erg) similar to that of a commercial hard tofu (1065 erg). This implies that MFS/SPI tofu with 7.0% of total protein content and 14.2% of total solid content may have an optimum solid concentration for formation of a strong gel structure with higher adhesiveness and viscoelasticity.

In general, MFS tofu is composed of micronized particle of whole soybean components. Because of insoluble components, the semi-solid gel derived from heat treatment with a coagulant had a soft gel structure that is different from a commercial tofu with a firm texture. Now, this is a major obstacle for the effective utilization of MFS in tofu manufacture. Therefore, it is necessary to devise procedures for the production of an MFS tofu with a hard texture. As shown in Table 1 and Table 2 the toughness and strength of MFS tofu was greatly enhanced by the addition of SPI, chitosan oligosaccharide and shiitake mushroom powder. From these data we conclude that these compounds improve the textural properties in MFS tofu, making it commercially viable to manufacture tofu from MFS.

Sensory evaluation of MFS tofu

The MFS tofu products fortified with SPI, WPC and/or chitosan oligosaccharide and shiitake mushroom powder were evaluated by panelists, and then was compared with mechanical measurements. The MFS tofu was cooked before serving samples to panelists and was evaluated for texture, taste and overall characteristics. As shown in Table 3 the texture and taste were not significantly different. But the texture score was highest for MFS tofu with SPI, and the taste score was highest for MFS tofu

Table 1. Breaking test of MFS tofu manufactured with MFS supplemented with SPI, WPC, and/or food ingredients

Sample	Textural properties			
	Strength (g)	Gel strength (g · cm)	Softness (cm/1000 g)	Hardness (dyn/cm^2)
I	45	96	46	24040
II	23	39	72	15670
III	27	39	65	16887
IV	25	42	66	16736
V	30	53	58	19167

I: Market product, II: MFS, III: MFS + SPI, IV: MFS + WPC, V: MFS + SPI + mushroom powder (0.2%)/chitosan oligosaccharide (0.1%), water : total solid = 1 : 6.0.

Table 3. Sensory evaluation of MFS tofu supplemented with SPI and/or food ingredients evaluated by analysis of variance and Duncan's multiple range test

Characteristics	F value	369	357	394	321
Texture	1.58*	2.4^a	3.1^a	2.1^a	2.7^a
Taste	1.54*	3.2^a	2.8^a	2.8^a	3.9^a
Overall	2.99*	3.1^{ab}	2.7^b	2.8^b	3.9^a

369: MFS, 357: MFS + SPI, 394: MFS + WPC, 321: MFS + SPI + mushroom powder (0.2%) + chitosan oligosaccharide (0.1%). Means with the same letter are not significantly different at $p < 0.05$.

Table 2. Chewing test of MFS tofu manufactured with MFS supplemented SPI, WPC and/or food ingredients

Sample	Textural properties						
	Tough. (g)	Cohes.	Elas.	Adhen. (erg)	Chew.	Gumm.	Visco. (g)
I	13	0.9	1.0	1065	12.6	13.1	2.2
II	5	0.8	1.1	627	4.7	4.3	1.4
III	9	0.8	1.0	965	6.5	5.5	2.1
IV	10	0.9	2.2	646	8.9	8.8	1.5
V	10	0.8	1.0	909	8.4	8.4	1.9

I: Market product, II: MFS, III: MFS + SPI, IV: MFS + WPC, V: MFS + SPI + mushroom powder (0.2%)/chitosan oligosaccharide (0.1%), water : total solid = 1: 6.0, Tough: toughness, Cohes: cohesiveness, Elas: elasticity, Adhen: adhesiveness, Chew: chewiness, Gumm: gumminess, Visco: viscosity.

fortified with SPI, shiitake mushroom powder and chitosan oligosaccharide. The overall preference was significantly higher for MFS tofu with SPI, mushroom powder and chitosan oligosaccharide than for the other tofu samples, except MFS. In addition the MFS with three ingredients had the highest value for both taste and overall preference. The taste results of the sensory evaluation were closely related to the strength obtained by the instrument test. The MFS tofu fortified with three ingredients showed the highest strength from instrumental analysis (Fig. 3). This implies that the toughness, strength and adhesiveness of MFS tofu may be critical textural properties. This suggests that the addition of mushroom power to MFS may affect the overall preference, supplying enhanced texture and unique flavor. In particular, the MFS fortified with SPI had the highest score for texture in sensory evaluation as well as the highest score of adhesiveness in the chewing test.

These results demonstrate that MFS can be used to manufacture a highly nutritious tofu that is well accepted by consumers.

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