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RESEARCH NOTE

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Classification of starch gel texture for the elderly diets based on instrumental and sensory methodology

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Abstract
An experimental attempt was made to bridge the gap between instrumental and sensory texture for the elderly diets in a corn starch gel system. Uniaxial compression was applied to measure the instrumental hardness of corn starch gels that was correlated with their sensory properties perceived by the elderly aged 60 and older. Instrumental and sensory hardness values of the starch gel samples were found to have good polynomial and linear correlations (R^2 =.99) with the level of corn starch, respectively. A fairly linear relationship (R^2 =.96) was observed between the instrumental and sensory hardness in terms of the logarithm of stress. In principal component analysis, two principal components that accounted for 86.71% of the total variability, separated the gel texture in terms of hardness/springiness and moistness, respectively. The categories of the starch gel samples were subdivided into five groups with different stress ranges. This classification suggested in this study appeared to provide useful information for modifying the texture of solid foods for the elderly diets.

Practical applications
As the elderly population is increasing throughout the world, there are growing interests in developing food products for older adults with difficulties in chewing and swallowing in the food industry. In this study, the instrumental texture of solid foods in a starch gel system was correlated with the sensory properties perceived by the people aged 60 and older. Based on the principal component analysis, the corn starch gel samples with different hardness were classified into the five groups that were presented with the ranges of stress values. The results obtained in this study may thus provide valuable information on the standard criteria and guidelines customized for the elderly.

KEYWORDS
elderly, gel, instrumental, sensory, texture classification

1 | INTRODUCTION

The number of persons aged 60 and older are reported to continuously increase. The proportion of the population aged 60 years or over in the more developed regions was 12% in 1950, rose to 23% in 2013, and is expected to probably constitute 32% of the populations in 2050 (United Nations, 2013). Specifically, Korea is now considered to have the most rapidly aging population in the world. The percentage of people aged 65 and older was 7.2% in 2000 and this figure will be projected to reach 20.8% in 2026 (Korea Satistics, 2016). With this trend, the aging populations have recently become the global focus of substantial research interest in a variety of industrial fields and the food industry is also no exception.

Texture is a critical factor to influence the consumer acceptance of food products. Achieving the desired texture of foods has therefore important considerations while the appropriate range of texture attributes is dependent on the target consumers. A great deal of effort is thus necessary to modify the texture of food products for the elderly

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diets since chewing and swallowing disorders such as dysphagia are common in older people (Cichero & Lam, 2014). Several experimental approaches in preceding studies have been introduced to soften the texture of various foods such as rice (Hayashi, Kato, Umene, & Masunaga, 2014), squid (Eom, Lee, Chun, Park, & Park, 2015), and meats (Kim et al., 2015). In addition, the universal design foods have been suggested in Japan for the elderly (Umene, Hayashi, Kato, & Masunaga, 2015). More extensive studies are however needed to establish the guidelines or criteria for controlling the food texture for the elderly with different living and cultural backgrounds. Furthermore, the food texture should be taken into account from the instrumental and sensory points of view. For doing so, it is necessary to correlate the instrumental texture properties of foods with their sensory properties perceived by the elderly.

This study was conducted to correlate the instrumental texture and sensory properties of corn starch gels in a model solid food system, providing a reference texture range for the elderly diets. Corn starch gel samples with different hardness were prepared and their instrumental texture was systematically measured by a uniaxial compression test. The instrumental hardness was then correlated with the sensory properties evaluated by the elderly aged 60 and older.

2 | MATERIALS AND METHODS

2.1 | Preparation of starch gel samples

Corn starch was used as a base ingredient to prepare gel samples with the same dimension that could cover a wide range of hardness. The starch gels were then applied as a model solid food system for the instrumental texture and sensory evaluations. Corn starch provided from Samyang Co. Ltd. (Incheon, Korea) was mixed with distilled water at eight different concentrations (8, 15, 20, 25, 30, 35, 40, and 45%, wt/wt) and heated with agitation in a boiling water bath for 20 min. In the case of 35, 40, and 45% starch samples, they were additionally treated with steaming for 10 min to be completely gelatinized. At the end of the heating period, a part of the hot pastes was poured to cylindrical molds (2.6 cm diameter, 2 cm height) and placed in a refrigerator overnight to prepare gels with the same dimension.

2.2 | Instrumental measurements

A controlled stress rheometer (AR1500ex, TA Instruments, New Castle, DE) equipped with a 40-mm parallel plate was used in order to characterize the dynamic viscoelastic properties of the corn starch samples. A frequency sweep test was conducted at 25C in the frequency range of 0.1–10 Hz and a strain of 0.5% was used which was within the linear viscoelastic limit. The exposed sample surface was covered with a thin layer of mineral oil for preventing dehydration during the rheological testing.

A uniaxial compression test was carried out to investigate the instrumental hardness of the corn starch gels. For doing so, a texture analyzer (TMS-Pro, Food Technology Co., Sterling, VA) equipped with a 500 N load cell was used with a 50-mm radius cylindrical probe that was larger in diameter than the samples. The corn starch gel samples were placed on the platform of the texture analyzer, the strain was 50% of the original sample height, and the crosshead speed was 50 mm/min which was reported to be suitable for the high correlation between instrumental and sensory responses (Huang, Kennedy, Li, Xu, & Xie, 2007). Hardness was measured as the maximum force of the plots of force versus time during the compression.

2.3 | Sensory evaluation

Sensory evaluation of the starch gels was carried out by 30 elderly participants consisting of 23 females and 7 males aged 60–75 years. Participants were recruited from the residents of Seoul metropolitan region through online advertisement and were screened through individual interview by asking any difficulty in chewing foods, their ability of expressing a variety of texture-related terms, and their availability for testing. Participants gave informed consent and were compensated for their participation. Before sensory evaluation, four starch gel samples with different concentrations of starch (8, 20, 30, and 40%, wt/wt) were presented to the participants to discriminate the level of hardness and they were then asked to express their individual perception after chewing and swallowing the samples for the collection of elderly people's expression on the starch gels. The collected words from each participant were used for check-all-that-apply (CATA) list: hard to swallow without mastication, hard, firm, springy, coarse, crumbly, friable, not sticky, not springy, easy to bite off, soft, moist, thin, smooth, easy to swallow. For sensory evaluation, the gel samples prepared with eight different concentrations of starch (8, 15, 20, 25, 30, 35, 40, and 45%, wt/wt) were served in disposable containers labeled with three-digit random codes and presented in a random order. Participants were instructed to rinse their mouths with water between sample evaluations. They were asked to rate the perceived hardness on a 5-point intensity scale (1 = "weak" and 5 = "strong") after chewing and swallowing each sample and asked to check all the terms from the CATA questionnaire that they considered appropriate to describe each sample.

2.4 | Statistical analysis

Three batches of corn starch gel samples were prepared for each starch concentration and data were reported in mean ± standard deviation. Experiments were statically analyzed with SAS software (SAS Institute, Cary, NC). Duncan's multiple range tests were performed to determine any significant difference among samples at a confidence level of 95%. For the sensory results, principal components analysis (PCA) (Sensotool, Sensomerics, Inc., Seoul, Korea) was performed to examine any possible grouping of the starch samples depending on their hardness.

3 | RESULTS AND DISCUSSION

The rheological properties of corn starch gel samples were investigated by measuring their dynamic viscoelastic properties. As shown in Figure 1, the values of G' (storage modulus) and G'' (loss modulus) increased with increasing starch concentrations as expected. All the samples also

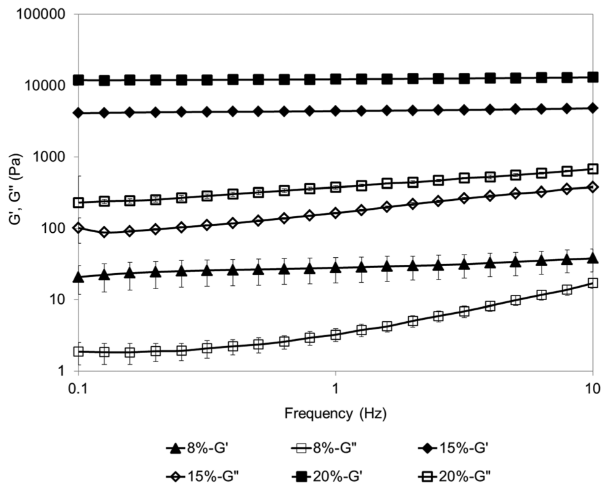

FIGURE 1 The dynamic viscoelastic properties of gels with different levels of corn starch

exhibited higher G' than G'' with less frequency dependence of the G', showing elastic gel-like characteristics. However, the viscoelastic properties of the samples with higher starch concentrations than 20% could not be measured since they were not allowed to be loaded onto the instrument due to their highly firm structure. A uniaxial compression test was thus applied to cover the samples with a wider range of hardness.

The instrumental hardness of corn starch gels was measured by using a uniaxial compression test that is a suitable method for determining the mechanical characteristics of solid and semisolid foods (Alishahi, Farahnaky, Majzoobi, & Blanchard, 2015). In this study, the compression measurements were made with the probe that was larger in diameter than the starch samples (Bourne, 2002) since the use of a probe smaller than a sample may cause variations in the surface area of the probe side contacting with the samples depending on their hardness. Figure 2a shows the instrumental hardness of the gel samples with different concentrations of corn starch. In Figure 2a, the instrumental hardness was expressed in terms of stress instead of force. When the compressive force is applied on a body, both the magnitude and area that it inflicts on the body are involved. It suggests that both magnitude and area need to be taken into account for rheological measurements. Therefore, stress (force per unit area) is commonly used as a fundamental rheological parameter (Steffe, 1996). The hardness values significantly increased with increasing starch concentrations ($p < .05$). Specifically, a polynomial trend line was satisfactorily obtained with the formula ($y = 403.07x^2 - 10837x + 73237$) describing the relationship between instrumental hardness and starch concentration ($R^2 = .99$). On the other hand, the sensory hardness had a tendency to increase in a relatively linear way with increasing concentrations of starch ($R^2 = .99$).

The relationship between the instrumental texture and sensory perception is commonly investigated to predict consumer preferences and to control product quality. The instrumental and sensory hardness was thus correlated as shown in Figure 2b. When the stress was correlated with the sensory hardness, a linear correlation was observed with a coefficient of determination ($R^2 = .879$, data not shown). However, the use of logarithmic transformation exhibited the improved correlation of coefficients. As can be seen in Figure 2b, the perceived intensity of hardness could be related to the physical hardness (stress) measured by the instrument based on a semilogarithmic relationship known as Weber-Fechner's law scale (Benedito, Carcel, Gonzalez, & Sanjuan, 2000). The highly linear correlation was thus observed with a high coefficient of determination ($R^2 = .96$). The linear correlation between sensory hardness and the logarithm of instrumental hardness, that is, their nonlinear relationship might be explained by the distortion derived from sensory scale or the loss of sensitivity over the stimulus intensity (Meullenet, 1998).

Principal component analysis was carried out to visualize the differences and similarities between the samples (Bender et al., 2009). As shown in Figure 3, the proportions of eigenvalues of the correlation matrix for the first and second principle components were 62.45% and 24.26%, respectively. The two principal components accounted for 86.71% of the total variability, indicating that the two components provided a good summary of the data. The dimension 1 (D1) separated the samples according to hardness and springiness. Thus, the starch gels with hard, firm, and springy textural properties were located in the positive zone of x-axis and the samples which were not springy, were loaded negatively along the D1. The dimension 2 (D2) appeared to separate the samples according to moistness. Thereby, the moist and thin

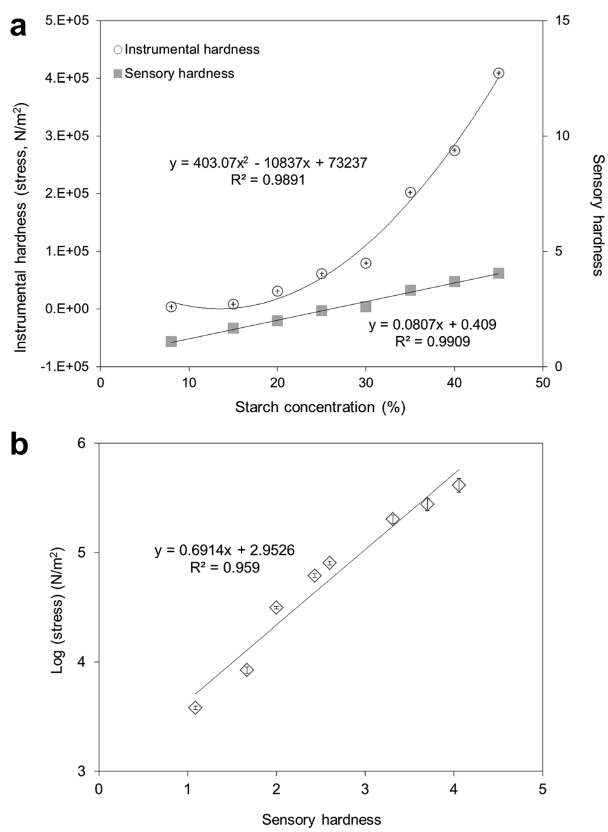

FIGURE 2 Instrumental and sensory hardness of gels with different levels of corn starch (a) and correlation between sensory and instrumental hardness (stress) of corn starch gels (b)

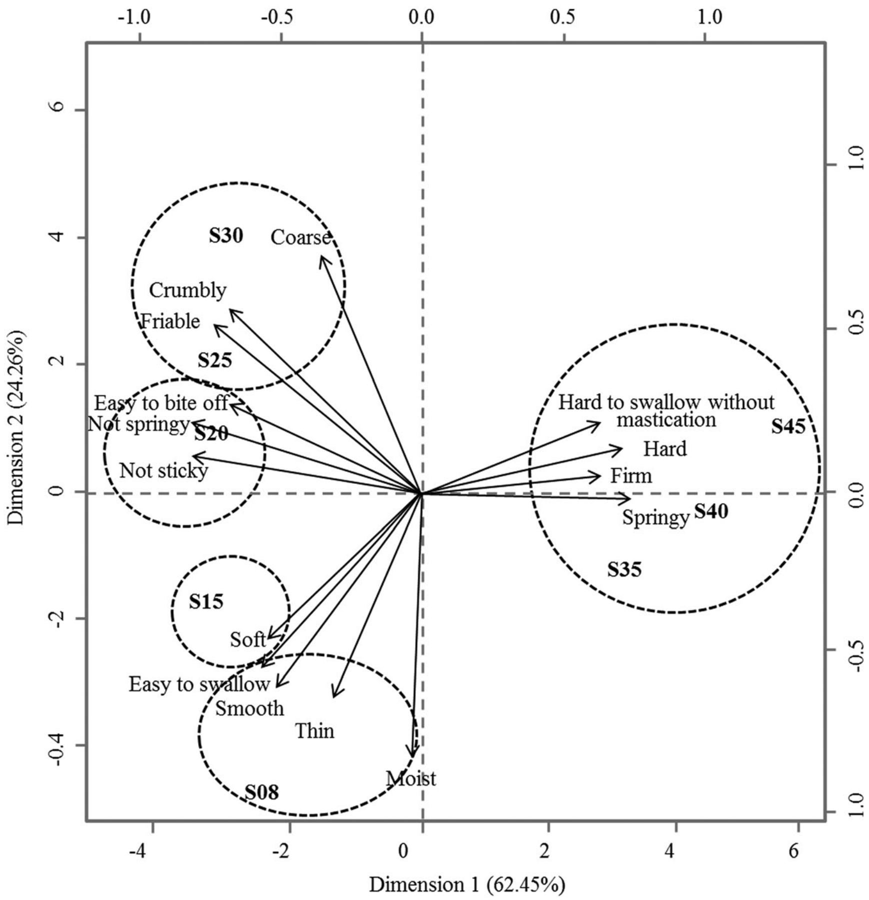

FIGURE 3 Principle component analysis of corn starch gels with different hardness (the number of S08, S15, S20, S25, S30, S35, S40, and S45 indicates the weight percentage of starch in the gel samples)

samples were located in the negative zone of the D2. Overall, the score plot seemed to exhibit three groups of the starch gel samples—(S45, S40, S35), (S30, S25, S20), and (S15, S08). However, they can be separated more specifically into five groups depending on the high/low D1 and D2 loadings. The first one (group I) contained S45, S40, and S35 with high D1 loadings. S30 and S25 with high D2 loadings formed the second group (group II) and S20 with low D1 loadings formed the third group (group III). Also, depending on the D2 loadings, the group IV and V contained S15 and S08, respectively.

Based on the results of Figure 3, the categories of the starch gel samples were presented with the ranges of stress values in Table 1. The consumer languages by the elderly panels were also included for each category. As shown in Table 1, the "hard," "firm," and "springy" textural properties were characteristic of the group I whose stress range was higher than 5.0 (N/m^2, log). The stress ranges of group II, III, and IV corresponded to 4.5∼5.0, 4.0∼4.5, and 3.5∼4.0 (N/m^2, log), respectively. The group V had the stress range values lower than 3.5 (N/m^2, log) and showed "moist," "thin," and "smooth" texture. Based on

TABLE 1 Categories and stress range of corn starch gels based on instrumental and sensory texture measurements

Classification (based on PCA)	Starch concentration (%, wt/wt)	Measured average stress (N/m^2, log)	Suggested stress range (N/m^2, log)	Consumer language
I	45	5.9a	5.0<	Hard to swallow without mastication, hard, firm, springy
	40	5.4b		
	35	5.3c		
II	30	4.9d	4.5–5.0	Coarse, crumbly, friable
	25	4.7e		
III	20	4.4f	4.0–4.5	Not sticky, not springy, easy to bite off
IV	15	3.9g	3.5–4.0	Soft
V	8	3.5h	<3.5	Moist, thin, smooth, easy to swallow

Note. Means with different letters in the same column differ significantly at $p < .05$. PCA = principle component analysis.

the universal design foods established by the Japan Care Food Conference (Kumagai, Tashiro, Hasegawa, Kohyama, & Kumagai, 2009), foods are classified into four categories by hardness and viscosity that are characteristic of solid and liquid materials, respectively. On the other hand, the research target of this study was placed mainly on solid foods in a starch gel system that were subdivided into five categories based on the instrumental and sensory texture measurements.

4 | CONCLUSION

The relationship between instrumental and sensory texture was investigated with corn starch gel samples with different hardness for the elderly diets. The sensory hardness perceived by the people aged 60 and older was linearly correlated with the logarithm of the stress obtained from the uniaxial compression test ($R^2 = .96$). Furthermore, based on principal component analysis, the texture of the starch gel samples was classified into five groups depending on the high and low loadings of dimension 1 (hardness/springiness) and 2 (moistness). Thereby, the categories of the starch gel samples could be successfully provided with corresponding stress range and consumer languages that can be used as a reference tool to establish the guidelines or criteria for developing the elderly foods. Further studies with a wider variety of foods including liquids may be necessary to provide standard guidelines for texture-modified foods for older adults with chewing and swallowing difficulties.

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ETHICAL STATEMENTS

Conflict of Interest: The authors declare that they do not have no conflict of interest.

Ethical Review: Ethical issues have been fully considered throughout the study and an approval has been given by the Department of Food Science and Technology, Sejong University.

Informed Consent: Written informed consent was obtained from all study participants.

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