Textural Properties of Mung Bean Starch Gels Prepared from Whole Seeds

Junhee No and Malshick Shin*

Department of Food and Nutrition and Human Ecology Research Institute, Chonnam National University, Gwangju 61186, Korea

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*Corresponding Author
Tel: +82-62-530-1336
Fax: +82-62-530-1339
E-mail: msshin@jnu.ac.kr

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Abstract The textural properties of mung bean starch gels (MSG) made by starches purified from whole seeds of *Dahyeon* were investigated to improve the quality of Korean traditional starch gel, *cheongpomuk*. Based on our investigation, the protein and dietary fiber contents of starch from whole mung beans (WM) were significantly higher than those from hulled mung beans (HM); however, apparently, WM had lower amylose contents than HM (their respective apparent amylose contents were 32.42 and 33.09%). The fresh gels (WMSG and HMSG), stored gels (WMSG-S4 and HMSG-S4), and reheated gels (WMSG-R4 and HMSG-R4) were also compared. The stored gels showed the highest L and b values, translucence, hardness, and gumminess. While HMSG showed a denser network structure than WMSG, the structure of stored gels was recovered after reheating. The fresh gels showed V type crystallinity, but the stored gel changed into B type crystallinity. WMSG showed higher sensory bending properties and smoothness than HMSG, but more similarities in the overall qualities.

Keywords: *cheongpomuk*, mung bean starch gel, texture property, whole seed, stored gel

Introduction

Starch granule grows spherically, alternating between amorphous regions which are a complex of crystalline amylopectin (AP) and the intermediate amorphous regions which are primarily composed of the branch points in the AP (1). Starch is composed of linear amylose (AM) and branched AP. In the excess water, starch gelatinizes at elevated temperature and changes to an amorphous polymer. Gelatinized starch is the result of a phase transition from a partially crystalline structure into a disordered hydrated state.

Starch gel, prepared by cooling the gelatinized starch dispersion, was considered as composites in swollen granule containing AP, and reinforced an interpenetrating AM gel matrix (2,3). The properties of starch gel are affected by the volume fraction of dispersed granular particles, chain length of AM, degree of swelling, rigidity, surface interactions, and interactions between starch and other materials. Alternatively, gelation may be dominated by phase separation mechanisms involving the de-mixing of macromolecular AM and AP after disintegration of the structure of granular. The initial development of gel firmness is attributed to formation of the AM gel matrix (4). AP forms the continuous phase owing to its higher mass and volume ratio, compared to AM (5). The gel network formation and firmness were found to be also related to crystallization of AP which was associated with the branches with DP15 (4).

Recrystallization of AM and AP in the gel matrix during cooling and

storage generated a composite structure and further modified the gel characteristics of the entire network (5). The granule-associated protein containing mung bean starch (MS) was able to regulate the envelope permeability, the leaching of starch and thermo-mechanical characteristics of the starch network (6,7). The addition of a small amount of hydrocolloid influences the properties of a starch-based gel. A starch-hydrocolloid gel exhibited increases in peak and final viscosities and short-term retrogradation, and decreases in the temperature of the initial rapid viscosity, granule swelling, starch polymer molecules leaching from swollen granules and long-term retrogradation, but the opposite effects have also been observed (8).

In Korea, mung bean (*Vigna radiate* L.) is widely consumed in the form of starch noodle, mung bean sprout, soup, pancake, flour paste and starch gel (9,10). MS has a high level of AM (33-35%), and the long AM chain holds the AP structure (11). These features allow translucent appearance and resistance to shearing upon heating (9,12). Qian and Shin (10) reported that the starch purified from hulled mung bean (HM) using water instead of alkaline solution improved textural properties of mung bean starch gel (MSG). The starch purified with water made a gel that has higher resilience (bending property) and hardness than the starch purified with alkaline solution, because of starch granule-associated protein (6). MS has unique characteristics of having a low glycemic index and a potentially high RS that has been attributed to its high AM content

and AP's molecular structures (13).

Generally, Korean traditional starch gel, *cheongpomuk* has been made from MS purified from HM using water. It is supposed that mung bean hull contains health functional materials with high antioxidative activities and dietary fiber (14). To improve the functionality of *cheongpomuk* in health, MSG should be developed by using the crude starch isolated from whole mung beans (WM) with hull.

Therefore, the objectives of this study were to compare the textural properties and network structure of the MSGs prepared from starch purified from WM to those of the MSGs prepared from starch purified from HM by using water and to evaluate the starch gels by sensory evaluation.

Materials and Methods

Materials The high yielding mung bean Korean variety, *Dahyeon* was provided by Jeonnam Agricultural Research and Extension Services in Sanpo-myeon, Naju-si, Chonnam Province. Each total dietary fiber kit and the total starch kit were purchased from Sigma-Aldrich Chemical Co. (St. Louis, MO, USA) and Megazyme International Ireland Limited (Wicklow, Ireland), respectively.

Starch preparation Starch was isolated from WM and HM using water according to the modified method of Qian and Shin (10). WM seeds were soaked for 20 h at room temperature and were hulled manually. The soaked WM and HM were ground with a food blender for 2 min and the same procedure was repeated. The blended starch slurry was passed through a 100 mesh sieve and then the residue was mixed with distilled water and blended twice more, collected and centrifuged (VS-21 SMT; Vision Scientific Co., Ltd., Seoul, Korea, at 1,100×g for 10 min). The purified starches from WM and HM were dried at room temperature, ground, passed through a 100 mesh sieve and stored in a desiccator until use.

Composition analysis Moisture (Method 44-15.02), protein (Method 46-13.01), ash (Method 08-01.01) and crude fat (Method 30-10.01) contents of the starches were measured, according to the AACCI methods (15). The total starch and the total dietary fiber contents were determined by the methods of AACCI 76-13.01 (15) and the AOAC Method 991.43 (16), respectively. The apparent AM content was determined by Park *et al.* (9) method modified from the Williams *et al.* (17) method and calculated using the equation for the standard curve. To obtain the standard curve, the AM and AP from potato starch were used. The equation was calculated by the following formula: $Y = 0.0097X + 0.0565$ ($R^2 = 0.992$). (X being the AM content and Y being the absorbance at 680 nm).

Preparation of mung bean starch gels The starch gels were prepared from starch pastes (w/w, 14% moisture basis) after running the rapid

visco analyzer (RVA model 3D; Newport Scientific Pty, Ltd., Warriewood, Australia). The stainless steel columns (ϕ 1.8×1.5 cm) were stood on the petri dish and the starch paste was poured into the columns without air bubble and covered the columns with glass plate. After cooling at room temperature and removing starch gels from the columns, starch gels were sealed with polyethylene wrap to control the moisture content. The three gel types, whole and hulled mung bean starch gels (WMSG and HMSG), starch gels stored at 4°C for four days (WMSG-S4 and HMSG-S4), and stored gels reheated for 2 min in the boiling water (WMSG-R4 and HMSG-R4) were prepared.

Physical properties

Morphology: In order to observe the inner network structure of starch gels, a scanning electron microscope (SEM) (JAM-540; JEOL, Tokyo, Japan) was used at the accelerating potential of 15 kV at 200× magnification. The gel was rapidly frozen using liquid nitrogen and dried by a freeze dryer (FD 5505; Vision Scientific Co., Ltd.). The dried gel sample was attached to a SEM stub with the double-sided cellophane tape. The sample was coated with gold-palladium, examined, and photographed.

Color value: The color values of starch gel were assessed using a Spectrophotometer (Spectra Magic™ NX; Konica Minolta, Tokyo, Japan) in which L, a, and b values were measured. The color difference (ΔE) was calculated with a white plate as control (L, a, b=96.81, -0.09, -0.18, respectively) using equation $\Delta E = \sqrt{\Delta L^2 + \Delta a^2 + \Delta b^2}$.

X-ray diffractometry: The X-ray diffractometer (D/Max 1200; Rigaku Co., Tokyo, Japan) was used to investigate the crystalline type and intensity of the samples. The starch gel was dehydrated using absolute ethanol with a homogenizer (M133/1281-O; ESGE, Bartlesville, Switzerland), filtrated using Whatman No. 2 filter paper, dried, ground, and passed through a 100 mesh sieve. The starch and gel powders were kept in a desiccator to moisturize constantly. The conditions of diffractometer were as follows: target, Cu-K α ; filter, Ni; full-scale range, 3000 cps; scanning speed 8°/min; diffraction angle (2 θ) 5–40°; 20 mA; 40 kV. The total dietary fiber content of MSG was determined by the same method as composition analysis.

Differential scanning calorimetry: The thermal properties of MS and MSG were determined by a DSC (DSC823^e; Mettler Toledo, Nord Urdorf, Switzerland). MSG was dehydrated using ethanol and filtrated, dried, ground, passed through a 100 mesh sieve. The sample (3.0 mg, dry basis) was weighed in an aluminum pan and twice the amount of distilled water (6.0 mg) was added. The pan was then hermetically sealed and kept overnight at room temperature. The DSC studies were carried out in a range of 30–130°C with a heating rate of 10°C/min. The empty pan was used as a reference pan.

Texture analysis: The textural properties were assessed with a Texture analyzer (model TA-XT plus; Stable Micro System, Surrey, UK). A texture profile analysis (compression test, deformation rate 50%, 20 mm diameter aluminum probe, sample size ϕ 1.8×1.5 cm³) was conducted on MSGs. Values for hardness, springiness, adhesiveness, cohesiveness, gumminess, and resilience were measured. The tensile

test was conducted by texture analyzer with spaghetti tensile rig. For the tensile test, starch paste was poured into the template (17.4x1.4 x0.3 cm³) and cooled for 3 h at 20°C. The starch gel was divided into two pieces (17.4x0.7x0.3 cm³). The measuring conditions were tension, spaghetti tensile rig; sample size, 17.4x0.7x0.3 cm³; test speed, 1.0 mm/s; target mode, distance, 60.00 mm. The break force (g) and the length (mm) at that point were measured.

Sensory evaluation The sensory evaluation test for MSGs was performed twice by 15 trained panelists using a nine-point scoring test. The training programs were completed repeatedly using various commercial- and lab-made starch gels. The samples, coded with 3-digit numbers, were presented to the panelists one by one, alternatively. The assessed attributes of starch gels, *cheongpomuk*, were color, clarity, hardness, brittleness, bending properties, cohesiveness, springiness, moistness and smoothness for the difference test, and overall quality for the preference test.

Statistical analysis All samples showed mean values and standard deviations. Statistical analyses were performed by student t-tests and Duncan's multiple range tests using a SPSS 12.0K (SPSS Inc., Chicago, IL, USA).

Results and Discussion

General compositions General compositions of WMS and HMS are shown in Table 1. The crude protein content was higher in WMS (3.63%) than in HMS (2.79%) and the total starch and total dietary fiber (TDF) contents of WMS and HMS were 77.79 and 11.94%, and 82.18 and 8.71%, respectively ($p<0.05$). Mung bean has high protein content (20-33%) and it is almost free from flatulence producing factors (18,19). When the starch is purified from mung bean, types of solvents affect the protein content of starch. Mung bean is composed of three types of proteins, 47% water-extractable albumins, 19.5% salt-extractable globulins, and protein concentrate by alkaline extraction (pH 9) followed by isoelectric precipitation (pH 4.5) (20). Qian and Shin (10) reported protein and the TDF contents of starch purified from a Korean mung bean variety, *Eohul*, using water were lower than the results of our study. It was due to the difference in sieves used: Qian and Shin (10) used 100 and 200 mesh sieves instead of a 100 mesh-sieve during purification of starch. Also, in this study, alkaline soluble proteins were not removed from WMS and HMS, and WMS had cell wall bound proteins of hull. The total starch content was relatively higher in HMS than in WMS because of hull materials of WMS. The TDF content of WMS was 3.23% higher than that of HMS. The color of WMS showed greenish white, because chlorophyll in hull materials of WMS was mixed with starch powder. The apparent amylose contents of WMS and HMS were 32.42 and 33.09%, respectively. Many scientists reported the apparent amylose content of MS ranged from 29.70 to 42.20% (9-13,21). It has been

Table 1. General compositions of starches purified from whole and hulled mung beans¹⁾

	WMS	HMS
Moisture (%)	10.49±0.09	9.79±0.25* ²⁾
Crude protein (%)	3.63±0.06	2.79±0.05*
Ash (%)	0.52±0.01	0.50±0.01
Crude lipid (%)	0.24±0.03	0.16±0.00
Total starch (%)	77.79±0.12	82.18±0.52*
Total dietary fiber (%)	11.94±0.36	8.71±0.28*
Apparent amylose (%)	32.42±1.02	33.09±0.95

Each value represents mean±SD.

¹⁾WMS and HMS mean starches prepared from whole and hulled mung beans, respectively.

²⁾Significantly different between WMS and HMS by *t*-test ($p<0.05$).

proposed that the unique characteristics of MS to form a firm and elastic gel is caused by its high AM content and AP's molecular structure, and MS's mechanical property of the entire network is influenced by the strength of swollen AM-rich discrete gel particles rather than the surrounding matrix (2).

Color values and total dietary fiber contents of MSG The color values and TDF contents of MSGs, MSGs-S4 and MSGs-R4 are shown in Table 2. The MS suspension becomes a transparent gel after heating and cooling, and the transparent gel changes into the opaque gel during storage. The lightness (L) of HMSG was higher than that of WMSG. The redness (a) and yellowness (b) of HMSG were lower than those of WMSG, because WMSG had greenish color due to chlorophyll in starch. When the gel was stored in a refrigerator, L values were increased regardless of dehulling of mung bean. It meant a starch gel changed from transparent to opaque due to starch retrogradation. The clarity of a starch gel is affected by starch source, concentration, and molecular weight, degree of polymerization of AM and storage conditions (3). The gel matrix formed a double helix with leached AM linear chains. But L values of the reheated gels (WMSG-R4 and HMSG-R4) reverted back to L values similar to WMSG's and HMSG's. The color difference of WMSG was higher than that of HMSG. The reheated gels showed color differences similar to WMSG and HMSG. The TDF contents of WMSG and HMSG were 17.43 and 14.58%, those of WMSG-S4, WMSG-R4, HMSG-S4, and HMSG-R4 were 17.62, 18.03, 13.74, and 14.95%, respectively. The starch gels prepared from WMS had higher TDF content than those prepared from HMS. The TDF contents of MSGs did not change when MSG was stored for four days in a refrigerator and reheated by boiling water.

Morphology, thermal properties, and X-ray diffractometry The MSGs were made from starch pastes after completion of the RVA heating and cooling program. The concentration of MS was 9.35% (w/w, dry basis). The network structure of the native, stored and reheated WMSG and HMSG is shown in Fig. 1. WMSG formed a large sized network structure with regular shapes compared to HMSG. The

Table 2. Color values and total dietary fiber contents of starch gels prepared from whole and hulled mung bean starches

Starch gels ¹⁾	Color values			E	TDF ⁴⁾ content (%)
	L	a	b		
WMSG	36.13±0.47 ^{b2)}	-1.84±0.06 ^b	10.47±0.29 ^b	61.64±0.49 ^a	17.43±0.34
WMSG-S4	47.59±0.26 ^a	-2.07±0.05 ^c	10.69±0.25 ^{ab}	50.45±0.29 ^b	17.62±0.20
WMSG-R4	36.18±0.33 ^b	-0.93±0.14 ^a	11.09±0.49 ^a	61.68±0.33 ^a	18.03±0.51
HMSG	44.58±0.31 ^{b*3)}	-2.65±0.01 ^{b*}	-5.16±0.36 ^{b*}	52.55±0.33 ^{a*}	14.58±0.98 ^{*3)}
HMSG-S4	60.77±0.31 ^{a*}	-3.88±0.02 ^{c*}	-5.05±0.13 ^{b*}	36.58±0.32 ^{b*}	13.74±0.96 [*]
HMSG-R4	45.02±0.59 ^{b*}	-2.47±0.06 ^{a*}	-4.43±0.21 ^{a*}	52.03±0.59 ^{a*}	14.95±0.23 [*]

Each value represents mean ± SD.

¹⁾WMSG, HMSG, WMSG-S4, HMSG-S4, WMSG-R4, and HMSG-R4 mean starch gels from whole and hulled mung beans, 4 day stored starch gels and reheated stored starch gels, respectively.

^{2)a-c}Values with different superscripts in the same column are significantly different at $p<0.05$ by Duncan's multiple range test for WMS and HMS gels separately.

^{3)*}Significantly different between the WMS and HMS gels by t-test ($p<0.05$).

⁴⁾TDF content means total dietary fiber content determined by AOAC method.

Fig. 1. Scanning electron microphotographs of starch gels, stored starch gels, and reheated starch gels prepared from whole and hulled mung bean starches (scale bar=100 mm). WMSG, HMSG, WMSG-S4, HMSG-S4, WMSG-R4, and HMSG-R4 mean starch gels from whole and hulled mung beans, 4 day stored starch gels and reheated stored starch gels, respectively.

HMSG network was densely packed with a slime matrix; however, it was caused by a linear AM gel matrix. But WMSG was composed of a firm and coarse matrix with a thick wall. It might be due to interactions between linear AM and fibrous cell wall materials. In the stored gels, the gel network was disrupted and the network structure showed no distinction between matrices. It was suggested that the foregoing was resulted because AP molecules retrograded with the AM matrix and formed a double helix. Starch gels are metastable and non-equilibrium states and therefore, undergo a structural transformation (chain aggregation and recrystallization) during storage (6,22). After reheating, the network was recovered to the initial regular structure with a clear matrix. The changes of gel structure caused reversible melting of the AP during heating and rearrangement of interactions

between AP and fiber. Generally, a retrograded AM gel matrix is irreversible during heating.

The endotherm of WMS and HMS showed a single peak from 59.79 to 77.30°C and from 60.07 to 77.98°C, respectively. The peak temperature and enthalpy of WMS (68.50°C and 5.23 J/g) were significantly lower than those of HMS (69.09°C and 6.96 J/g). The difference of enthalpy was caused by starch content of the sample and dietary fiber content. But the endotherms of MSGs were not found at a certain temperature not only in WMSG or HMSG but also in the stored or reheated gel. It meant AP of MSG was not retrograded to be melted, regardless of starch purification methods. The x-ray diffractogram (XRD) patterns of MS and starch gels are presented in Fig. 2. The native WMS and HMS showed A-type crystalline with peaks at a diffraction angle (2θ)=15.3, 17.1, 18.0, and 23.2°. WMSG and HMSG exhibited an amorphous polymer with no peak in the XRD pattern. Although WMSG and HMSG formed a gel structure with the AM matrix, the stored gels, WMSG-S4 and HMSG-S4 showed B-type crystalline patterns with peaks at 2θ =5 and 17.1°. Miles *et al.* (3) reported that gels form in cooling entangled AM solutions and occur as a result of a phase separation which produces a three-dimensional polymer network. Crystallization, as detected by XRD, was observed to be a slower process originating in the polymer-rich phase. There is no relation between the kinetics of network formation and crystallization. Gelation, or the early stages of retrogradation, appears to involve phase separation followed by slow crystallization in the polymer-rich phase. For storing gels in refrigerator, the starch gels retrograded to form a double helix between AM and AP, and AP and AP. In the case of reheated starch gels, XRD showed no peaks at 2θ =5–40° and the starch gels changed B-type crystal to amorphous after reheating. This result suggests that the crystallization of starch gel is influenced not by retrogradation of AM but by retrogradation of AP.

Textural properties The texture profile analysis data of MSGs by compression test are shown in Table 3. Hardness, adhesiveness, springiness, cohesiveness, gumminess, and resilience of WMSG and

Fig. 2. X-ray diffraction patterns of starches and starch gels from whole and hulled mung beans and mung bean starches. WMS, HMS, WMSG, HMSG, WMSG-S4, HMSG-S4, WMSG-R4, HMSG-R4 mean starch, starch gels from whole and hulled mung beans, 4 day stored starch gels, and reheated stored starch gels, respectively.

HMSG were significantly different from their stored and reheated gels ($p<0.05$). Hardness and gumminess of WMSG were higher than those of HMSG, but adhesiveness, springiness, cohesiveness, and resilience showed reverse trends. Most of textural properties of WMSG and WMSG-R4, and HMSG and HMSG-R4 showed similar patterns, but those of WMSG-S4 and HMSG-S4 were different from the other two gels. The degree of recovery in hardness by reheating was lower in WMSG-R4 than in HMSG-R4; however, the recovery of adhesiveness was higher in WMSG-R4 than in HMSG-R4. The high

quality for Korean traditional MSG, *cheongpomuk*, is represented not only by its low adhesiveness and high springiness and resilience but also by its high bending property. In the case of the compression test, HMSG and HMSG-R4 had better quality than WMSG and WMSG-R4. The tensile strength and distance to break of gels were measured by tensile test to compare the bending properties of starch gels. The tensile strength of WMSG, HMSG, WMSG-R4, and HMSG-R4 were 13.20, 13.80, 19.08, and 15.44 g, respectively. The distance to break of WMSG, HMSG, WMSG-R4, and HMSG-R4 were 14.64, 15.89, 27.82, and 22.66 mm, respectively. The stored gels did not show any tensile strength and distance to break. The tensile strength and distance to break of WMSG and HMSG presented similar values, but those of WMSG-R4 and HMSG-S4 increased significantly ($p<0.05$). Especially WMSG-R4 showed much higher tensile strength and distance to break than HMSG-R4 ($p<0.05$). From these texture results, it was discovered that WMSG-R4 presented the best textural qualities of bending properties as *cheongpomuk*.

Sensory evaluation The sensory evaluation data for starch gels and reheated starch gels which was stored at 4°C for four days are presented in Table 4. The color, clarity, hardness, bend property, and acceptability scores of four different starch gels were significantly different ($p<0.05$). Reheating increased clarity and bending property of HMSG. Acceptability scores of MSGs were higher in fresh-made starch gels, WMSG and HMSG than in the reheated starch gels, WMSG-R4 and HMSG-R4. In WMSG, clarity, hardness, and acceptability scores increased after reheating of WMSG-S4. But color, clarity, hardness, and bending property scores of HMSG were significantly lower than those of HMSG-R4. When the acceptability of MSG compared to that of MSG-R4, reheating of MSG-S4 in boiling water helped improvement of the sensory properties. In the case of textural properties using the compression test, springiness, cohesiveness, and resilience of HMSG and HMSG-R4 were higher than those of WMSG and WMSG-R4. But tensile strength and distance-to-break of MSG strands were higher in the reheated MSG than the fresh MSG, and were higher in WMSG-R4 than HMSG-R4. The acceptability of MSG

Table 3. Textural properties of starch gels prepared from whole and hulled mung bean starches

Starch gels ¹⁾	Texture profile analysis						Tensile test	
	Hardness (g)	Adhesiveness	Springiness	Cohesiveness	Gumminess	Resilience	Tensile strength (g)	Distance to break (mm)
WMSG	330.69±16.18 ^{c2)}	-2.82±1.71 ^a	0.97±0.00 ^a	0.83±0.01 ^a	275.47±10.55 ^b	0.58±0.01 ^b	13.20±0.67 ^b	14.64±0.80 ^b
WMSG-S4	1230.00±35.96 ^a	-31.06±8.51 ^b	0.96±0.00 ^b	0.65±0.03 ^b	803.22±47.75 ^a	0.46±0.02 ^c	-	-
WMSG-R4	422.55±10.50 ^b	-3.38±0.74 ^a	0.97±0.02 ^a	0.78±0.02 ^a	331.20±14.52 ^b	0.57±0.01 ^a	19.08±0.63 ^a	27.82±1.26 ^a
HMSG	313.85±23.90 ^b	-0.87±0.80 ^a	0.99±0.01 ^{a*}	0.84±0.00 ^a	263.95±19.52 ^b	0.62±0.01 ^{a*}	13.80±1.06 ^b	15.89±0.95 ^b
HMSG-S4	1208.17±46.17 ^a	-23.20±2.56 ^b	0.97±0.00 ^{b*}	0.74±0.02 ^{c*}	892.45±56.94 ^{a*}	0.54±0.01 ^{c*}	-	-
HMSG-R4	375.54±22.17 ^{b*3)}	-4.69±2.06 ^a	0.98±0.01 ^b	0.82±0.04 ^b	307.36±16.52 ^{b*}	0.62±0.01 ^{b*}	15.44±1.63 ^{ab*}	22.66±0.30 ^{a*}

Each value represents mean±SD.

¹⁾WMSG, HMSG, WMSG-S4, HMSG-S4, WMSG-R4, and HMSG-R4 mean starch gels from whole and hulled mung beans, four day stored starch gels and reheated stored starch gels, respectively.

²⁾a-c Values with different superscripts in the same column are significantly different at $p<0.05$ by Duncan's multiple range test for WMS and HMS gels separately.

³⁾*Significantly different between the WMS and HMS gels by t-test ($p<0.05$).

Table 4. Sensory evaluation data for mung bean starch gels prepared from WMSG and HMS

	WMSG ¹⁾	WMSG-R4	HMSG	HMSG-R4
Color	7.20±0.45 ^{a2)}	7.40±0.55 ^a	2.40±0.55 ^c	3.40±0.55 ^b
Clarity	4.80±0.45 ^c	6.40±0.55 ^{ab}	6.00±0.00 ^b	6.80±0.45 ^a
Hardness	5.20±0.84 ^b	6.40±0.89 ^{ab}	5.60±0.89 ^b	7.00±1.00 ^a
Brittleness	5.20±0.84	4.80±0.45	4.60±0.55	4.40±0.89
Bend property	7.50±0.55 ^a	7.33±0.52 ^a	4.67±1.03 ^c	6.00±1.10 ^b
Cohesiveness	5.40±0.89	5.80±0.84	5.00±0.71	5.40±0.89
Springiness	5.60±0.89	6.80±1.30	6.00±1.00	6.20±1.30
Moistness	5.80±0.84	6.00±1.00	6.40±0.89	6.00±1.00
Smoothness	6.00±1.00	6.20±0.45	6.20±0.45	5.80±0.45
Acceptability	6.00±0.00 ^c	7.40±0.55 ^a	6.80±0.45 ^b	7.00±0.00 ^{ab}

Each value represents mean±SD.

¹⁾WMSG, HMSG, WMSG-R4, and HMSG-R4 mean starch gels from whole and hulled mung beans, reheated stored starch gels from whole and hulled mung beans, respectively.

²⁾a,b Values with different superscripts in the same row are significantly different at $p < 0.05$ by Duncan's multiple range test.

was correlated with tensile strength and distance to break by tensile test.

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