



Research article

Effects of extrusion cooking on physicochemical properties of white and red ginseng (powder)

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ARTICLE INFO

Article history:

Received 15 April 2013

Received in Revised form

4 December 2013

Accepted 4 December 2013

Available online 18 December 2013

Keywords:

antioxidant activity

extrusion

Panax ginseng

physicochemical properties

white and red ginseng

ABSTRACT

A systematic comparison of the physicochemical properties of white ginseng (WG), extruded white ginseng (EWG), red ginseng (RG), and extruded red ginseng (ERG) was performed. The aim of the present study was to identify the effects of the physicochemical properties of ginseng by extrusion cooking. The highest value of the water absorption index (WAI) was 3.64 g/g obtained from EWG, and the highest value of the water solubility index (WSI) was 45.27% obtained from ERG. The ERG had a better dispersibility compared with other samples. Extrusion cooking led to a significant increase in acidic polysaccharide and total sugar content but resulted in a decrease in crude fat and reducing sugar contents. Enzyme treatment led to a sharp increase in acidic polysaccharide content, especially the cellulose enzyme. Extrusion cooking led to a significant increase in 2,2-diphenyl-1-picrylhydrazyl (DPPH) radical scavenging activity and reducing power, and the increases in WG and RG were 13.56% (0.038) and 3.56% (0.026), respectively. The data of this study provide valuable information about the effects of extrusion on quality changes of EWG and ERG.

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1. Introduction

Ginseng (*Panax ginseng* Meyer) is a herb mostly used in Asia for its medicinal properties and functional food for over 1,000 years. It is found that ginseng contains a lot of bioactive ingredients such as acidic polysaccharides, ginsenosides, proteins, and phenolic compounds [1–3]. In Asia, there are two traditional preparations of ginseng, white ginseng (WG) and red ginseng (RG), and they have been used for different purposes. WG is produced by sun drying of fresh ginseng and RG is manufactured by steaming fresh ginseng at 90–100°C for a reasonable time and then drying until the moisture content is less than 15%. Ginseng is recognized worldwide as a natural healthy food along with the global trend of preference for natural products. Therefore, in modern times, the biochemical and pharmacological activities of ginseng have attracted a great deal of attention.

Many previous researches have reported that the steaming process increased the effective components and anticancer activities of ginseng products, compared with unsteamed ones [4–6]. However, the production of RG is complicated and time-consuming. In addition, it is also difficult to extract the active

components of RG because of its dense texture. Thus, researchers have investigated the production of expanded ginseng using a twin-screw extruder.

Extrusion, classified as a high-temperature short-time process, is a versatile, low cost, efficient, and widely used industrial technology for the continuous production of expanded product from cereals. Recently, a lot of studies have been conducted to improve the physical and chemical properties of extruded ginseng samples [7–9]. Ha and Ryu [10] reported that acidic polysaccharide content increased by 2–3%; crude saponin and ginsenoside (Rg1 and Rg2) content also increased and ginsenoside Rg3 was detected in extruded red ginseng (ERG) after extrusion cooking. Additionally, Han et al [11] reported that α -amylase susceptibility of extruded ginseng has been found to be higher than that of traditionally dried ginseng. By contrast, an antioxidant compound was found in the extruded ginseng sample using the thin layer chromatography method. Although research on functional characteristics of extruded ginseng has been well documented, a comparison of physicochemical properties of extruded white ginseng (EWG) and ERG processed by the same extrusion condition has not yet been conducted.

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With the increased use of twin-screw extruders for the manufacture of ginseng products, it is also necessary to have enough data on the extrusion of ginseng. We have previously reported that white ginseng extruded at a moisture content of 25% and barrel temperature of 110°C showed high antioxidant activity and effective component content [8]. Therefore, the objective of the present study is to give a comprehensive summary of the changes in the physicochemical properties by the extrusion processing of ginseng samples to help us take action for future study in this discipline.

2. Materials and methods

2.1. Materials

The 5-year-old white and red ginseng powder was purchased from a local market in Seoul, South Korea. Standards of ginsenoside Rg1, Re, Rf, Rh1, 20(S)-Rg2, 20(R)-Rg2, Rb1, Rc, Rb2, Rd, 20(S)-Rg3, 20(R)-Rg3, 20(R)-Rh2, and 20(S)-Rh2 were purchased from ChromaDex (Seoul, Korea). HPLC-grade acetonitrile and methanol were purchased from Merck Co. (Merck, Darmstadt, Germany). Deionized water was purified using the Milli-Q system (Millipore, Bedford, MA, USA). Other reagents used in this study were analytical grade.

2.2. Extrusion process

A corotating intermeshing twin-screw extruder (THK31T, Incheon, Korea) with a screw length of 690 mm and a screw diameter of 30 mm (Length/Diameter = 23:1) was used. The screw configuration is shown in Fig. 1. Extrusion parameters were feed moisture content of 25% (dry basis), screw speed of 200 rpm, feed rate of 100 g/min and die diameter of 3.0 mm. The temperature profile from feed section to die exit was set to 50°C/110°C/110°C. The extrudate was dried directly in an air oven at 60°C for 8 hours, and ground in a laboratory grinder to pass through a 400- μ m sieve, then stored in plastic bags for further analysis.

2.3. Proximate analysis

Moisture content, crude fat, protein, and ash were analyzed by the standard methods described in the Official Methods of Analysis of the Association of Official Analytical Chemists (AOAC) [12]. Total sugar and reducing sugar contents were determined according to the phenol-H₂SO₄ and dinitrosalicylic acid (DNS) methods, respectively [13,14].

2.4. Physical analysis

The expansion ratio was determined by dividing the diameter of the extrudate by the diameter of the die (3 mm). The specific length was evaluated as the straight length divided by the weight of extrudates. A total of 10 readings were recorded for each sample. Bulk density was determined after the extrudates were cut into pieces of approximately 2 cm in length by using a seed

displacement method [15]. The color of the extrudate was measured with a colorimeter (CR-300; Minolta, Osaka, Japan). Color parameters *L*, *a*, and *b* were recorded separately. Water solubility index (WSI) and water absorption index (WAI) were measured by the modified method of Anderson et al [16]. A 1.5 g sample was dissolved in 30 mL of distilled water and shaken in the thermostatic water bath at 30°C for 30 minutes, and then centrifuged at 1000 \times g for 10 minutes. The supernatant was decanted into a preweighed evaporating dish. The weight of the sediment was taken as WAI and was expressed as the unit g/g. The WSI is the weight of dry solids in the supernatant, which is expressed as a percentage of the original weight of the sample. Measurements were performed in triplicate for each sample. The dispersibility of the ginseng sample powder was determined according to the method of Shin et al [17] with minor modification. One gram of the ginseng powder was mixed with 30 mL distilled water. It was then shaken 10 times by hand and was left standing. The dispersion state after 10 minutes was observed and evaluated.

2.5. Mechanical analysis

Mechanical properties were determined with a Sun Rheometer (Compac-100; Sun Scientific Co., Ltd., Tokyo, Japan) equipped with a 2-kg load cell. The cross-head speed was set at 60 mm/minute. Ten replicates of extrudate were randomly selected and a mean value was recorded.

2.6. Microstructure

The microstructure of extruded sample was examined with a field emission scanning electron microscope (MIRA II LMH; Tescan USA Inc., Cranberry Township, PA, USA). The accelerating voltage of scanning electron microscope was 10.0 kV.

2.7. Chemical analysis

2.7.1. Crude saponin contents

Crude saponin contents were determined according to the water-saturated *n*-butanol extraction method of Park et al [18] with some modification. The ground ginseng samples (4 g) were placed into the body of a reflux machine and extracted with 80 mL 70% ethanol at 70°C for 12 hours. The extract was filtered through Whatman No.1 (Whatman Ltd., Cambridge, UK) filter paper and concentrated at 45–50°C. The concentrate was dissolved in 100 mL of distilled water and washed twice in a separation funnel with 100 mL diethyl ether to remove fats. The aqueous layer was extracted three times with 100 mL water-saturated *n*-butanol. The *n*-butanol extracts were pooled and washed twice with 100 mL of distilled water to remove impurities. The resulting *n*-butanol layer was evaporated at 55°C using a rotary vacuum evaporator. Finally, the round flask with the evaporated residue was dried at 105°C until it reached a constant weight. The weight of the evaporated residue was measured and used as the crude saponin content.

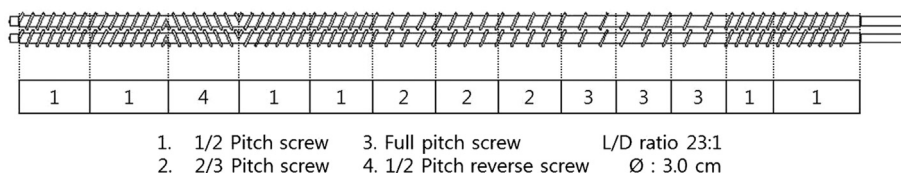


Fig. 1. Screw configuration for extrusion process (model THK 3). Screw length: 690 mm. Screw diameter: 30 mm. Extrusion conditions: moisture content 25%, screw speed 200 rpm, temperature 110°C.

2.7.2. Ginsenosides analysis

Ginsenosides were determined using ultra performance liquid chromatography (UPLC; Acquity UPLC System; Waters, Milford, MA, USA) equipped with a binary solvent delivery system, an autosampler, a tunable UV detector, and an Acquity UPLC bridge ethylene hybrid-based particles C₁₈ column (1.7 μM, Φ2.1 × 100 mm; Waters). The samples (0.5 g) were dissolved in 10 mL of 50% methanol and were ultrasonicated for 30 minutes, and then the mixtures were centrifuged at 1000 × g for 10 minutes. The injection volume was 2 μL and the absorbance was measured at 203 ± 0.2 nm. The two mobile phases were phase A: water; phase B: acetonitrile, and the UPLC elution conditions were as follows: 0–0.5 minutes, A-B (85:15 v/v); 0.5–14.5 minutes, A-B (70:30 v/v); 14.5–15.5 minutes, A-B (68:32 v/v); 15.5–16.5 minutes, A-B (60:40 v/v); 16.5–20.0 minutes, A-B (45:55 v/v); 20.0–22.0 minutes, A-B (10:90 v/v); and 22.0–27.0 minutes, A-B (85:15 v/v). The flow rate was set at 0.6 mL/minute and the column temperature was maintained at 40 ± 2°C.

2.7.3. Acidic polysaccharide content

Acidic polysaccharide content was measured according to the carbazole-sulfuric acid method [19] using galacturonic acid as a standard. Briefly, 0.5 mL of the sample extract solution was mixed with 0.25 mL of carbazole-absolute ethanol (0.1%, v/v) and 3 mL of concentrated sulfuric acid. Then the mixed solution was reacted in 80°C water for 5 minutes and cooled. The absorbance was read in a cuvette at 525 nm.

2.8. Enzyme treatment

The acidic polysaccharide content after enzyme treatment was determined according to the method of Lee and Do [20] with minor modification. The ginseng powder (1 g) was dissolved with distilled water (10 mL) and 0.25% of each enzyme (α-amylase and cellulase) was added. The mixture was incubated at 40–50°C for 60 minutes (pH 4–5). The resulting solution was centrifuged at 1000 × g for 30 minutes and the acidic polysaccharide content of the supernatant was determined.

2.9. Antioxidant properties

The ground ginseng samples (0.5 g) were extracted twice with 10 mL of an ethanol:water (80:20 v/v) solution. The first extraction involved stirring for 2 hours at 30°C and the extracts were pooled. Then, the solid was re-extracted under the same conditions for 12 hours. The extracts were pooled and centrifuged at 1500 × g for 20 minutes. The supernatants (about 20 mL) were transferred into a sample vial for total phenolic content, 2,2-diphenyl-1-picrylhydrazyl (DPPH) radical scavenging activity, and reducing power analyses.

2.10. Total phenolic contents

The total phenolic content (TPC) was determined by the Folin-Ciocalteu reagent method [21] with minor modification. The sample solution (0.1 mL) was mixed with 1.5 mL freshly prepared Folin-Ciocalteu reagent (Sigma-Aldrich, Steinheim, Germany) diluted with distilled water (10-fold). The mixture was allowed to equilibrate for 5 minutes and then 1.5 mL of 6% sodium carbonate was added. After incubation at room temperature for 90 minutes, the absorbance was measured at 765 nm, against 80% ethanol as a blank. Gallic acid was used as a standard for determining the TPC. Determinations were performed in triplicate and the results were expressed as mg of gallic acid equivalents (GAE) per gram of dry sample.

2.11. DPPH radical scavenging activity

The scavenging effect on DPPH radical was performed according to the method described by Brand-Williams et al [22] with some modifications. First, 0.5 mL of the extract was quickly added to 3 mL of DPPH (0.1 mM). After thorough mixing, the solutions were kept in the dark for 30 minutes. The absorbance was measured at 517 nm and the ethanol substituted with the sample solution was used as a control. For comparison, butylhydroxytoluene (BHT) was used as a positive standard. The assay was carried out in triplicate. The capability of scavenging the DPPH radical was calculated according to the following equation:

$$\text{DPPH radical scavenging activity (\%)} = \left[\frac{A_{\text{control}} - A_{\text{sample}}}{A_{\text{control}}} \right] \times 100$$

where A_{control} is the absorbance of the control, and A_{sample} is the absorbance of the sample.

2.12. Reducing power assay

The reducing power (RP) of sample solutions was measured as described by Gülçin et al [23]. The reaction mixture was composed of 1.0 mL of the sample solution, 2.5 mL of 0.2 M phosphate buffer (pH 6.6), and 2.5 mL of 1% potassium ferricyanide solution. The mixture was incubated at 50°C for 20 minutes and 2.5 mL of 10% trichloroacetic acid was added. The resulting solution was centrifuged at 1000 × g for 20 minutes and the supernatant (1.0 mL) was mixed with 2.5 mL of distilled water and 0.5 mL of 0.1% ferric chloride solution. The absorbance was recorded at 700 nm after 10 minutes. For comparison, BHT was used as a positive standard.

2.13. Statistical analysis

Analysis of variance (ANOVA) was carried out using a statistical software program (SAS 9.1, SAS Institute Inc., Cary, NC, USA). Analysis of the result was conducted three times. Data are presented as the mean ± standard deviation (SD). Duncan's range tests were used to detect significance of difference at $p < 0.05$.

3. Results and discussion

3.1. Proximate composition

The proximate compositions of ginseng samples are presented in Table 1. Crude fat content significantly decreased from 1.29% to 0.23%, whereas total sugar content significantly increased from 29.70% to 38.39% after extrusion. Similar phenomena were also observed by Son and Ryu [9] in EWG. Han et al [24] also reported that an increase of total sugar content was observed in EWGs when the extrusion temperature increased from 110°C to 120°C. By contrast, the extrusion process significantly decreased ($p < 0.05$) the crude protein and reducing sugar contents of WG, whereas no significant difference was found between RG and ERG. Hagenimana et al [25] reported that decreases in the crude fat, crude protein, and reducing sugar content occurred through the many chemical and structural transformations such as starch gelatinization, protein denaturation, and complex formation between amylose and lipids during the extrusion process. In the case of RG, a higher total sugar content than WG was attributed to the production of glucose, fructopyranose, and maltose by a steaming process [26].

Table 1
Proximate Compositions of White and Red Ginseng Samples (Unit: % Dry Base)

Sample	Composition						
	Moisture	Fat	Protein	Ash	Carbohydrate ¹⁾	Total sugar	Reducing sugar
WG	4.74 ± 0.13 ^{c, 2)}	1.29 ± 0.13 ^a	15.42 ± 0.14 ^a	5.18 ± 0.04 ^a	73.37	29.70 ± 0.28 ^c	2.79 ± 0.01 ^b
EWG	8.11 ± 0.23 ^b	0.36 ± 0.02 ^c	14.53 ± 0.26 ^b	5.41 ± 0.37 ^{ab}	71.60	32.69 ± 1.50 ^b	1.53 ± 0.03 ^c
RG	4.10 ± 0.32 ^d	0.87 ± 0.05 ^b	13.71 ± 0.28 ^c	4.82 ± 0.42 ^b	76.50	32.83 ± 1.51 ^b	19.82 ± 0.26 ^a
ERG	9.56 ± 0.29 ^a	0.23 ± 0.02 ^d	13.61 ± 0.08 ^c	4.90 ± 0.17 ^{ab}	71.70	38.39 ± 0.73 ^a	19.41 ± 0.78 ^a

ERG, extruded red ginseng; EWG, extruded white ginseng; RG, red ginseng; WG, white ginseng.

¹⁾ Carbohydrate contents were calculated as the difference of 100 - (fat + protein + ash + moisture).

²⁾ Means in the same column with different letters are significantly different at $p < 0.05$.

3.2. Physical properties

Influences of the extrusion on physical properties of ginseng samples are shown in Table 2. No significant difference was found in expansion ratio, specific length, and bulk density between EWG and ERG. Ding et al [27] reported that the expansion index can vary considerably depending on extruder type, feed moisture, screw speed temperature profile in the barrel, and die geometry. The highest value of WAI was 3.64 g/g obtained from EWG, and the lowest was 2.57 g/g from WG. The highest value of WSI was 45.27% obtained from ERG. Extrusion cooking was found to have no significant effect on the WAI of RG and the WSI of WG. The WAI measures the volume occupied by the starch polymer or granule after swelling in excess water and can be used as an index of gelatinization. As expected, an increase in WAI of EWG was caused by the protein denaturation and starch gelatinization. However, the RG was cooked by the steaming and drying process. As a result, the dextrinization phenomenon can be dominant during the extrusion process, resulting in no significant difference in WAI of ERG. However, extrusion cooking led to a significant increase in WSI of RG. The observed increase in WSI indicates that dextrinization and melting appears to play an important role in the RG extrusion process. In general, WSI often used an indicator of the amount of soluble polysaccharide released from the starch component after extrusion. Also, the WSI depends on the quantity of the solubles, which was increased by degradation of amylose and chain split of amylopectin molecules [28]. The higher soluble polysaccharide content (total sugar, free sugar) of ERG would explain why the WSI value was higher than other samples. By contrast, no difference in the WSI content between WG and EWG indicates that little dextrinization occurred during the extrusion process, resulting in the lower soluble sugar content in EWG.

The dispersibility of ginseng samples is shown in Fig. 2. The solution of extrudate was darker and showed more uniform distribution than the nonextruded ginseng. The dispersed ingredients in distilled water were soluble polysaccharide, phenols, pigments, Maillard reaction products, etc. Compared with raw material, the

extruded powder easily dissolved and dispersed well in water. The powders of EWG and ERG dissolved in distilled water uniformly in less than 10 seconds, whereas the EG and RG solutions needed strong shaking for about 1 minute until the powder dissolved well. Apparently, the ERG powder had the best dispersibility.

Table 2 also exhibits that the extrudate powder was darker and had higher *a* and *b* values than their corresponding control (unextruded) samples. The ERG had the lowest *L* (75.39) and highest *a* (3.22) and *b* (23.81) values. During the extrusion process, these color changes were caused by nonenzymatic browning and sensitive pigments destruction [29].

3.3. Mechanical properties

Low hardness, which is also a favored property of extrudates, was observed in ERG (Table 2), that is, the breaking strength of ERG was lower than EWG. Previous studies also reported that the breaking strength was strongly influenced by cell structure and protein content. Increased protein content in raw material produced a more rigid network, resulting in higher resistance to shear [30]. There was no significant difference in elastic modulus between EWG and ERG.

3.4. Microstructure of extruded samples

Fig. 3 illustrates the cross-sectional microstructure of EWG and ERG. The magnification used was 35× and 150×. EWG showed a homogeneous surface and less porosity, indicating that the starch granules were disrupted, whereas ERG had a rough and irregular surface, which could be an indication of the dextrinization of starch. Also, the ERG showed a great number of air cells with a nonuniform air cell distribution and thinner cell walls compared with the EWG. Apparently, it is speculated that the extrudate microstructure (air cells number, air cells size, cell walls thickness) could be related to expansion ratio and breaking strength. In our study, the results were consistent with the mechanical data (breaking strength)—namely, the more air cell and the thinner the cell walls, the lower the shear force (breaking strength). The microstructure was found

Table 2
Physical Properties of White and Red Ginseng Samples

Sample	WG	EWG	RG	ERG
Expansion ratio	—	1.76 ± 0.10 ^a	—	1.75 ± 0.09 ^a
Specific length (m/kg)	—	102.14 ± 9.82 ^a	—	103.32 ± 4.34 ^a
Bulk density (g/cm ³)	—	0.38 ± 0.07 ^a	—	0.35 ± 0.03 ^a
WAI (g/g)	2.75 ± 0.03 ^{c, 2)}	3.64 ± 0.06 ^a	3.25 ± 0.05 ^b	3.18 ± 0.01 ^b
WSI (%)	34.54 ± 0.05 ^c	34.34 ± 0.32 ^c	42.86 ± 0.13 ^b	45.27 ± 0.22 ^a
<i>L</i> ¹⁾	86.88 ± 0.09 ^a	77.10 ± 0.70 ^b	83.25 ± 0.09 ^c	75.39 ± 0.50 ^d
<i>A</i>	0.19 ± 0.02 ^c	3.21 ± 0.18 ^a	0.90 ± 0.04 ^b	3.22 ± 0.19 ^a
<i>B</i>	14.20 ± 0.26 ^d	22.53 ± 0.59 ^b	17.68 ± 0.10 ^c	23.81 ± 0.62 ^a
Breaking strength (N/m ²)	—	5.30E + 05 ^a	—	3.20E + 05 ^b
Elastic modulus (N/m ²)	—	3.62E + 08 ^a	—	2.43E + 08 ^a

ERG, extruded red ginseng; EWG, extruded white ginseng; RG, red ginseng; WAI, water absorption index; WG, white ginseng; WSI, water solubility index; E, exponential.

¹⁾ *L*, lightness (ranged from black 0 to white 100); *A*, redness; *B*, yellowness.

²⁾ Means in the same row with different letters are significantly different at $p < 0.05$.

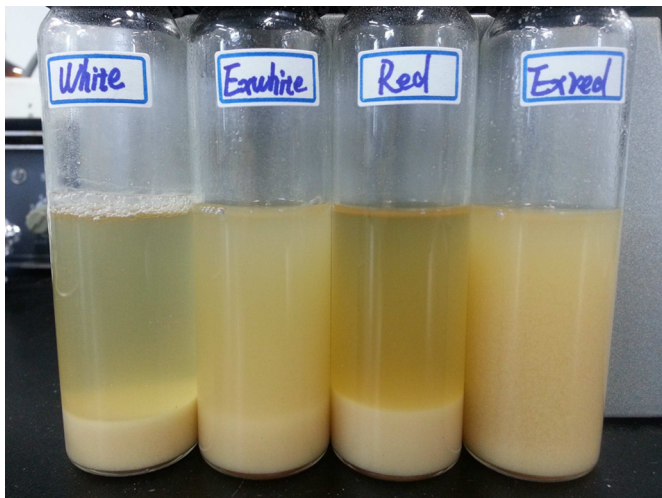


Fig. 2. The dispersibility of white ginseng (WG, White), extruded white ginseng (EWG, Exwhite), red ginseng (RG, Red), and extruded red ginseng (ERG, Exred).

to be dependent on the combination of the extrusion conditions (feed moisture, barrel temperature), cellular structure, and the type of protein and starch molecules.

3.5. Chemical properties

3.5.1. Crude saponin and ginsenoside contents

The crude saponin and ginsenoside contents of ginseng samples are presented in Table 3. According to the calculations, the total

ginsenoside contents were found to be 9.66 mg/g, 9.91 mg/g, 16.53 mg/g, and 15.66 mg/g for WG, EWG, RG, and ERG, respectively. Extrusion cooking was observed to have no significant effect on the ginsenoside in this work. The total ginsenoside content of RG was about 1.7 times higher than that of WG. The ginsenoside 20(S)-Rg3 and 20(R)-Rg3 were present in RG and ERG but not in WG and EWG. Sun et al [31] reported that extensive conversion of original ginsenosides in WG to new degradation compounds in RG occurred during the steaming process, leading to different ginsenoside profiles between WG and RG. Du et al [32] reported that the degree of reduction in malonyl ginsenosides was 65.1%, whereas the growth in neutral ginsenosides was only 20.7% as the drying temperature increased, so that the total ginsenosides were actually decreased. Nevertheless, we found that the total ginsenoside content was increased (1.26–1.37 times) after extrusion in another paper. This was illustrated in the heating trial, in which the concentration of ginsenosides was affected by the thermal processing condition and the degree of conversion between malonyl and neutral ginsenosides. Consequently, a direct comparison of ginsenoside contents in the literature is difficult due to the difference in extrusion conditions and the species of ginseng used. In the case of crude saponin content, apparently, there was a slight increase after extrusion. The extrusion cooking caused a significant increase of the free sugars content by hydrolysis reaction. So, the increase of the crude saponin content seems to be caused by the increase of the soluble ingredients in the *n*-butanol extraction.

3.5.2. Acidic polysaccharide content

In general, the main activity constituents of ginseng are believed to be ginsenosides, but researchers have paid attention to acidic

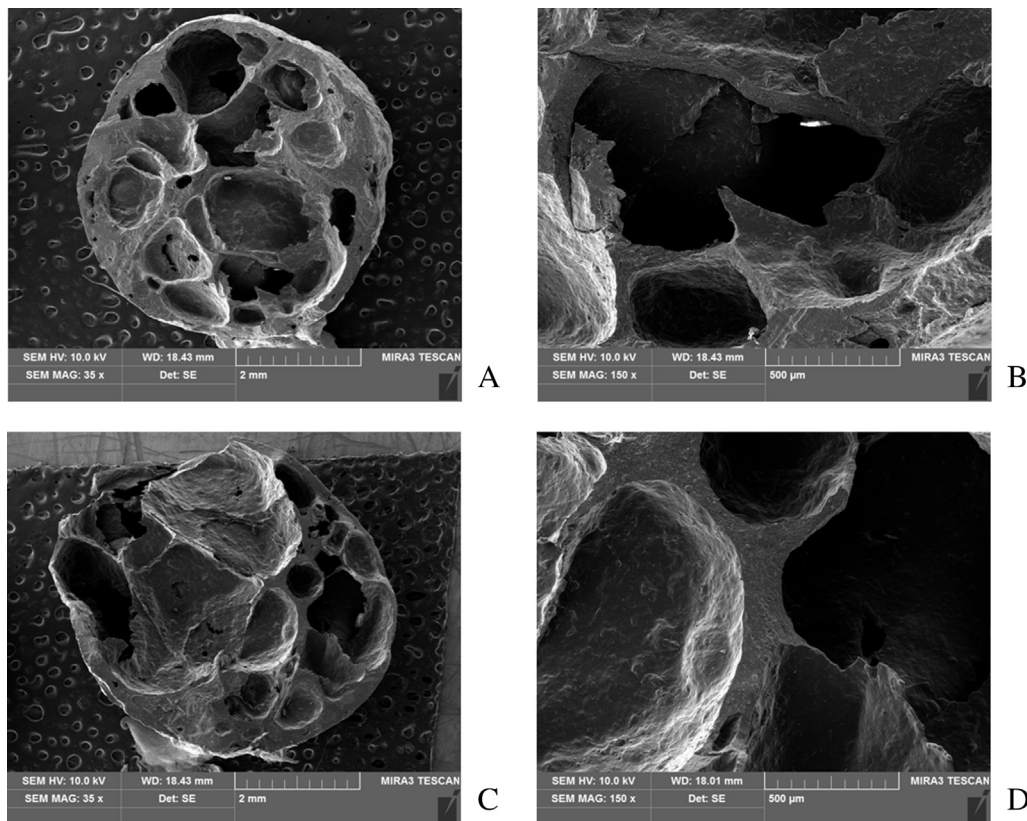


Fig. 3. Scanning electron micrographs of extruded white ginseng (EWG) and extruded red ginseng (ERG). (A,B) EWG (magnification 35 \times , 150 \times), (C,D) ERG (magnification 35 \times , 150 \times), accelerating voltage: 10.0 kV. Extrusion conditions: moisture content 25%, screw speed 200 rpm, temperature 110 $^{\circ}$ C.

Table 3
Crude Saponin and Ginsenoside Contents of White and Red Ginseng Samples

Sample	Ginsenoside (mg/g)										
	Rg1	Re	Rf	Rh1	Rg2s	Rb1	Rc	Rb2	Rd	20(S)-Rg3	20(R)-Rg3
WG	33.62 ± 0.29 ^{c-1)}	1.85 ± 0.02	0.47 ± 0.01	0.14 ± 0.01	0.15 ± 0.00	2.60 ± 0.02	0.87 ± 0.01	0.84 ± 0.00	0.16 ± 0.01	N/D	N/D
EWG	42.30 ± 0.89 ^b	1.81 ± 0.01	0.50 ± 0.02	0.13 ± 0.01	0.15 ± 0.00	2.76 ± 0.01	0.93 ± 0.01	0.89 ± 0.01	0.18 ± 0.00	N/D	N/D
RG	41.46 ± 0.74 ^b	1.87 ± 0.01	0.73 ± 0.00	0.21 ± 0.00	0.21 ± 0.00	5.28 ± 0.02	2.13 ± 0.00	1.97 ± 0.01	0.60 ± 0.00	0.16 ± 0.00	0.09 ± 0.00
ERG	44.23 ± 0.67 ^a	1.78 ± 0.01	0.69 ± 0.01	0.21 ± 0.00	0.20 ± 0.00	4.99 ± 0.01	2.01 ± 0.01	1.86 ± 0.01	0.57 ± 0.01	0.16 ± 0.00	0.09 ± 0.00

ERG, extruded red ginseng; EWG, extruded white ginseng; N/D, not detected; RG, red ginseng; WG, white ginseng.

¹⁾ Means in the same column with different letters are significantly different at $p < 0.05$.

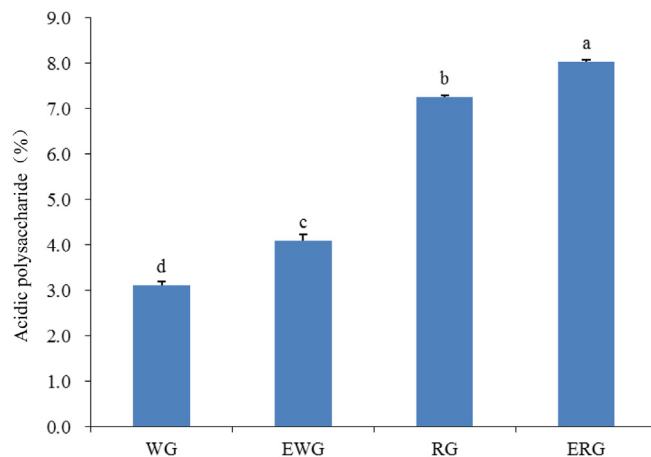


Fig. 4. Acidic polysaccharide contents of EWG and ERG. Extrusion conditions: moisture content 25%, screw speed 200 rpm, temperature 110°C. Each bar represents the mean ± SD. Different letter (a, b, c, d) denote significant difference ($p < 0.05$). ERG, extruded red ginseng; EWG, extruded white ginseng; RG, red ginseng; SD, standard deviation; WG, white ginseng.

polysaccharides as bioactive constituents of ginsengs. Nowadays, significant importance is attributed to polysaccharides by biochemical and nutritional researchers due to their various biological activities used in health care, food, and medicine. The acidic polysaccharide levels in WG, EWG, RG, and ERG were 2.80%, 4.75%, 7.33%, and 8.22%, respectively (Fig. 4). Apparently, the content of acidic polysaccharides after extrusion cooking was increased, which means an increase of 1.7 times in WG and 1.1 times in RG. Similar results have also been reported by Ha and Ryu [10]. The increases in WG and RG were 1.95 and 0.89%, respectively. The increase in the levels of acidic polysaccharides after extrusion can be attributed to the release of the saccharides and its derivatives from the cell walls of the plant matter. Previous studies reported that the cell wall was present in WG (prior to extrusion) but not in EWG [33]. During the extrusion process, the cell wall structure was damaged by the shear force coming from screw rotation with heating and pressure. This result is similar to the finding [34] that the soluble fiber content increased due to cell wall damage when the byproduct of tofu (dried soy pulp) was put through the extrusion process. In addition, Yoon et al [35] reported that the contents of acidic polysaccharides increased with the increase in heating temperature and time. The availability of ginseng was improved due to the increasing polysaccharides (*Panax ginseng* Meyer) [36].

3.6. Enzyme treatment

Acidic polysaccharides can be tightly linked with carbohydrates such as amylose, cellulose, or pectin [37]. Therefore, we used amylase and cellulase enzyme to increase acidic polysaccharide

Table 4
Effect of Enzyme Treatment on the Amount of Acidic Polysaccharides from Ginseng Samples (Unit: % Dry Base)

Enzymes	WG	RG
Nonextruded	3.11 ± 0.08 ^{f, 1)}	7.24 ± 0.06 ^f
α -Amylase	4.28 ± 0.01 ^d	9.45 ± 0.07 ^d
Cellulase	6.13 ± 0.09 ^c	11.29 ± 0.07 ^b
Extrudate	4.08 ± 0.15 ^e	8.03 ± 0.05 ^e
α -Amylase	6.70 ± 0.08 ^b	10.38 ± 0.05 ^c
Cellulase	9.75 ± 0.12 ^a	12.26 ± 0.04 ^a

Data are presented as the mean ± standard deviation (SD; $n = 3$).

ERG, extruded red ginseng; EWG, extruded white ginseng; RG, red ginseng; WG, white ginseng.

¹⁾ Different letter superscripts denote significant difference ($p < 0.05$).

Table 5
Total Phenolics, DPPH Radical Scavenging Activity, and Reducing Power of White and Red Ginseng Samples

Sample	Total phenolics (mg GAE/g)	Antioxidant properties	
		DPPH	RP ¹⁾
WG	2.31 ± 0.07 ^{d, 2)}	23.00 ± 0.12 ^d	0.379 ± 0.02 ^d
EWG	2.67 ± 0.07 ^c	36.56 ± 0.23 ^c	0.417 ± 0.01 ^c
RG	3.82 ± 0.03 ^b	46.39 ± 0.15 ^b	0.926 ± 0.01 ^b
ERG	4.68 ± 0.15 ^a	49.95 ± 0.26 ^a	0.952 ± 0.01 ^a
BHT (0.5 mg/mL)	—	59.20 ± 0.30	1.041 ± 0.01

Data are expressed as the mean ± standard deviation (SD; $n = 3$). The concentration of ginseng samples was 25 mg/mL.

BHT, butylhydroxytoluene; DPPH, 2,2-diphenyl-1-picrylhydrazyl; ERG, extruded red ginseng; EWG, extruded white ginseng; GAE, gallic acid equivalents; RG, red ginseng; RP, reducing power; WG, white ginseng.

¹⁾ RP value was expressed as absorbance at 700nm.

²⁾ Different letter superscripts denote significant difference ($p < 0.05$).

content. The results presented in Table 4 revealed that the enzyme treatment greatly affected the acidic polysaccharide content. Enzyme treatment led to a significant increase in the acidic polysaccharide content, and this increase ranged from 129% to 239%. Similar findings have also been reported by Lee and Do [20]. Acidic polysaccharide content ranged from 4.28% to 12.26%. The ERG powder treated with cellulose enzyme had the highest levels of acidic polysaccharides compared to other ginseng samples. After enzyme treatment (amylase and cellulase), the increase in acidic polysaccharide content of WG was 137% and 197%, respectively, whereas the increase in acidic polysaccharide content of EWG was 164% and 239%, respectively. An increase in the dispersibility increases the specific surface area in contact with enzyme in the solution. This proposal is in agreement with our observations. In addition, the increase in acidic polysaccharides observed in ERG treated with cellulose enzyme was accompanied by an increase in polyphenols and antioxidant activity [37]. The ginseng powder treated with cellulose enzyme had higher levels of acidic polysaccharides than amylase enzyme treatment. These data suggest that the digestibility and bioavailability of acidic polysaccharides in the extrudates (EWG, ERG) could be significantly higher than those of nonextruded ginsengs (WG, RG).

3.7. Antioxidant properties

Table 5 shows the changes in TPC of extruded ginsengs. The TPC in the four ginseng samples ranged from 2.31 GAE/g to 4.68 mg GAE/g. The TPC significantly increased upon extrusion as compared to their corresponding control samples. The TPC in ERG was 2.0 times higher than that in WG, 1.75 times higher than that in EWG, and 1.23 times higher than that in RG. The increase in TPC is thought to be mediated by the increase of free and conjugated phenolic acid contents due to the release of bound phenolic acids from the breakdown of cellular constituents and cell walls by extrusion treatment [38]. Similar studies on the effects of heat stress (100°C) on wheat grain flour indicate an increase in phenolics such as ferulic, vanillic, and *p*-coumaric acids [39]. This was suggested to be due to degradation of conjugated polyphenolics. Furthermore, Anton et al [40] also demonstrated a significant increase in the TPC of extruded snacks obtained from blends of corn starch and small red beans. Hence, another reason could be due to the nonenzymatic browning, chemical oxidation of phenols, and caramelization.

Table 5 also summarizes the impact of extrusion on the antioxidant properties of WG and RG. Extrusion cooking led to a significant increase in DPPH radical scavenging activity and these increases in WG and RG were 13.56% and 3.56%, respectively. It was found that the ERG had the significantly strongest ($p < 0.05$) scavenging activity (49.95%) against DPPH radicals but the activity

did not exceed that of BHT (59.20%). Significant differences were observed between all of the ginseng samples. Table 5 also shows RP values of 0.379, 0.417, 0.926, and 0.952 for WG, EWG, RG, and ERG, respectively. In the same manner, the highest value of RP was obtained from ERG (0.952), and this value was also somewhat lower than the positive control (BHT, 1.041). A similar increase in RP has been reported by other authors upon the roasting process in oats [41]. In Table 5, the antioxidant activity of RG was stronger than that of WG, and the antioxidant activity of ERG was stronger than that of EWG. Similar conclusions were made by Norajit et al [42] who found that the alginate film containing RG exhibited a greater antioxidant activity than that containing WG.

It is widely known that the Maillard reaction products influence the antioxidant activity of plants. Sharma and Gujral [43] have reported that dark color pigments (brown color) are created during the thermal processing of foods due to Maillard browning. Because the Maillard reaction may produce antioxidative compounds, as found by Bressa et al [44], other researches have demonstrated that thermal processing may increase the antioxidant activity of sweet potatoes [45] and sweet corn [38]. Furthermore, Manzocco et al [46] concluded that the pigments (particularly melanoidins) are extensively known to have antioxidant activity. The increase in antioxidant activity could be explained by the formation of Maillard browning pigments, which enhanced the antioxidant activity of extruded products [47]. Another reason for the increase in antioxidant activity could be due to the increase in TPC. Similarly, the potential health benefit of phenolics is mainly attributed to their antioxidant activity [48]. According to the correlation analysis, the TPC was significantly ($p < 0.05$) and positively correlated with DPPH radical scavenging activity ($r = 0.9255$) and RP ($r = 0.9525$). This means that the increase of TPC may partially contribute to the increase in antioxidant properties of extruded products in our findings.

In general, the antioxidant potentials of plants derive from synergism, antagonism, and additivity of various compounds [49]. The antioxidant activity is affected by the quantity and kind of free radical scavengers present in the material, and a slight difference in measuring method may lead to apparently different results from the same sample.

We investigated the effects of extrusion cooking on the physicochemical properties of white and red ginseng. Extrusion cooking exhibited a significant effect on physical properties (WAI, WSI, color, and dispersibility) of extrudates. Also, extrusion cooking led to a significant increase in the effective components, such as acidic polysaccharides and total phenolics. Extrusion cooking was observed to have no significant effect on the ginsenoside content. Enzyme treatment significantly increased the content of acidic polysaccharides of extrudate compared with nonextrudate. After extrusion, the increase in the DPPH radical scavenging activity of EWG and ERG were 13.56% and 3.56%, respectively, whereas the increase in RP assay of EWG and ERG was 0.038 and 0.026, respectively. White ginseng appeared to be more suitable than red ginseng for use as a raw material for extrusion cooking because its antioxidant activity increased to a larger extent. The results indicate that extrusion cooking has great potential as an effective pretreatment for changing the quality of ginseng.

Conflicts of interest

The authors declare no conflicts of interest.

Acknowledgments

This research was supported by the Project for Development in Technology of Agriculture, Industry, and Commerce Fusion, which

was conducted by the Small and Medium Business Administrations (Hanbit Food Ltd., Chungnam, South Korea).

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