

## Effects of Extrusion Conditions on the Physicochemical Properties of Extruded Red Ginseng

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### Abstract

The effects of variable moisture content, screw speed and barrel temperature on the physicochemical properties of red ginseng powder extrudates were investigated. The raw red ginseng powders were processed in a co-rotating intermeshing twin-screw extruder. Primary extrusion variables were feed moisture content (20 and 30%), screw speed (200 and 250 rpm) and barrel temperature (115 and 130°C). Extruded red ginseng showed higher crude saponin contents (6.72~7.18%) than raw red ginseng (5.50%). Tested extrusion conditions did not significantly affect the crude saponin content of extrudates. Increased feed moisture content resulted in increased bulk density, specific length, water absorption index (WAI), breaking strength, elastic modulus and crude protein content and decreased water solubility index (WSI) and expansion ( $p<0.05$ ). Increased barrel temperature resulted in increased total sugar content, but decreased reducing sugar content in the extrudate ( $p<0.05$ ). Furthermore, increased barrel temperature resulted in increased amino acid content and specific length and decreased expansion and bulk density of extrudates only at a higher feed moisture content. The physicochemical properties of extrudates were mainly dependent on the feed moisture content and barrel temperature, whereas the screw speed showed a lesser effect. These results will be used to help define optimized process conditions for controlling and predicting qualities and characteristics of extruded red ginseng.

**Key words:** extrusion, red ginseng, physicochemical properties

### INTRODUCTION

Ginseng is a perennial plant of the *Panax* genus that has been used as a medicinal plant and a functional food for more than 2000 years (1). Ginsenosides and phenolics in ginsengs are the main activity compounds, providing a variety of beneficial effects, including anti-inflammatory, antiemetic, antioxidant, and anticancer effects.

A long time ago, to preserve fresh ginseng for an extended period of time, the fresh ginseng was either dried or steamed. The steaming process causes a color change to make the white ginseng turn to red, hence the name 'red ginseng'. This steaming process can improve the health benefits of ginseng by inactivating catabolic enzymes and releasing the antioxidant substances from the ginseng (2). Several investigators have reported new ginsenosides from red ginsengs that are not usually found in white ginseng. In particular, the ginsenosides Rh<sub>2</sub> and Rg<sub>3</sub> have been found to show various biological activities, including radical scavenging activity (3). Also, red ginseng has demonstrated more pharmacological effects than white ginseng. The ginsenoside Rg<sub>3</sub> in red ginseng inhibits platelet aggregation and cancer cell metastasis, and induces vasorelaxation (4,5). Therefore, it appears

that the steaming and the drying process may give some unique characteristics to red ginseng.

Extrusion cooking is an important processing technique in the food industry as it is considered to be an efficient manufacturing process. It is a powerful processing operation, which utilizes high temperature, high pressure, high force to produce the products with low density, high expansion and unique texture. The process variables such as water injection rate, feed rate, screw speed, barrel temperature and raw materials used in general have a great influence on physicochemical properties of extrusion products (6). The red ginseng was cooked by the steaming and drying process. However, it's difficult to extract the efficient components due to its denser texture. Recently, red ginseng has become an attractive ingredient in the extrusion industry due to its unique attributes such as dense texture and low yield of extraction. Extrusion process causes a structural change to make the red ginseng turn to a more porous structure. These structural changes correspond to the gelatinization of starch and denaturation proteins (7). Ryu (8) reported that the major components that change during red ginseng processing are saponins and non-saponins (polyacetylene, acidic polysaccharide and amino acids). In previous re-

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search, the effects of extrusion process variables (barrel temperature, screw speed, feed moisture and die diameter) on the chemical properties of extruded ginseng have been studied (9,10). Ha et al. (11) reported that crude saponin and ginsenosides content increased after extrusion process. Han et al. (12) also found that puffing treatment of the red ginseng tail root might be useful in increasing the bioactive components and digestibility. In this research of red ginseng, it is used as a control in general, or it is produced by a single condition of extrusion; there have been not enough studies on the changes of physical and chemical compositions of extruded red ginseng by varying process variables.

Therefore, the objective of this study was to investigate the effects of extrusion conditions (feed moisture content, screw speed, and barrel temperature) on the physicochemical properties of an extruded red ginseng.

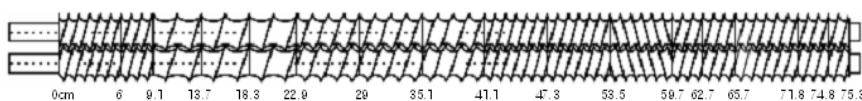
## MATERIALS AND METHODS

### Materials

The red ginseng powder was purchased at National Agricultural Cooperative Federation (NACF) in Seosan, Korea. High grade chemical reagents used were purchased from Sigma (St. Louis, MO, USA).

### Extrusion process

A co-rotating intermeshing twin-screw extruder (Incheon Machinery Co., Incheon, Korea) with a screw length of 768 mm and a screw diameter of 32 mm (L/D = 24:1) was used. The screw configuration is shown in Fig. 1. In this experiment, a circular die (3.0 mm diameter) was used to produce the cylinder-shaped extrudates. The extruder was running at 200 and 250 rpm and barrel temperature varied from 115 to 130°C. Water was injected into the barrel around the feed section to adjust the feed moisture content at 20 and 30%, and the red ginseng powder feed rate was maintained at 120 g/min. The extrudates were collected and dried in an air oven at 60°C for 8 hr. The dried extrudates were ground to powder and sieved through 400 µm mesh, then sealed in polyethylene bags until measurements were taken. The feed moisture content, barrel temperature and screw speed are shown in Table 1.



1	1	3	3	3	2	2	2	1	1	4	1	1	1	1	1
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1. 1/2 Pitch screw      3. Forward paddle      L/D ratio: 24:1  
 2. 2/3 Pitch screw    4. Reverse screw element    φ: 3.2cm

**Table 1.** Process variables of extruded red ginseng

Sample NO.	Extrusion condition		
	Feed moisture (%)	Screw speed (rpm)	Temperature (°C)
EX1	20	200	115
EX2	20	200	130
EX3	20	250	115
EX4	20	250	130
EX5	30	200	115
EX6	30	200	130
EX7	30	250	115
EX8	30	250	130

### Proximate composition

Moisture content, crude fat, protein and ash were analyzed by the standard methods described in the AOAC (13).

### Physical properties

Expansion ratio was determined by dividing the diameter of extrudates by the diameter of the die (3 mm). The specific length was evaluated as the straight length divided by the weight of extrudates. Ten replicates of extrudate were randomly selected and a mean taken. Bulk density was determined by measuring the volume by using a modified seed displacement method (14).

The color of the samples was measured with a colorimeter (CR-300, Minolta, Osaka, Japan). The results were expressed as tri-stimulus values *L*, *a* and *b*. The *L* value ranged from black 0 to white 100, the *a* value ranged from greenness -60 to redness +60 and the *b* value ranged from blueness -60 to yellowness +60. Measurements were made in triplicate.

Water solubility index (WSI) and water absorption index (WAI) were measured by the modified method of Anderson et al. (15). A 1.5 g sample was dispersed in 30 mL of distilled water, then incubated in a 30°C water bath for 30 min. The mixtures were centrifuged at 3000 rpm for 10 min. The supernatant was decanted into an evaporating dish of known weight. The weight of the remaining gel was taken as WAI and was expressed in the unit of g/g. The WSI is the weight of dry solids in the supernatant expressed as a percentage of the original weight of sample. The mean of three replicates was reported.

**Fig. 1.** Screw configuration for extrusion process (model THK 3).

### Mechanical properties

The breaking strength and apparent elastic modulus of extruded red ginseng samples were evaluated using the Sun Rheometer (Compac-100II, Sun Science Co., Tokyo, Japan) equipped with a two-kg load cell. The crosshead speeds was 60 mm/min. The breaking strength and apparent elastic modulus were calculated using the modified method of Ryu and Ng (16). Each assay was the mean of ten repetitions.

### Chemical properties

**Crude saponin:** Crude saponin contents of the samples were determined according to the water-saturated butanol extraction method of Ando et al. (17) and Namba et al. (18). The samples (5.0 g) were dissolved in 50 mL of water-saturated butanol, then extracted at 80°C for 1 hr and filtered. The residue was taken back and re-extracted three more times using fresh solvent each time with the same conditions as above. The filter paper was washed by pouring 10 mL water-saturated butanol. The extraction solution was washed three times in a separatory funnel with 50 mL of distilled water to remove impurities. The supernatant liquid was concentrated, then refluxed and extracted by adding 50 mL of diethyl ether to remove fats. The resulting solution was transferred to a round-flask for evaporation at 55°C using a rotary vacuum evaporator. The flask with the evaporated residue was dried at 105°C for 2 hr and weighed.

**Total sugar:** The content of total sugar was measured according to the Phenol-H<sub>2</sub>SO<sub>4</sub> method (19). The samples (1.0 g) were extracted by stirring them at room temperature in 100 mL of an ethanol-water (80:20 v/v) solution for 2 hr. The extracted solution was filtered through filter paper (Whatman No.2, Maidstone, Kent, England). The reaction mixture was composed of 0.2 mL of sample solution, 1 mL of 5% phenol solution and 5 mL of concentrated sulfuric acid. The absorbance was read at 550 nm after 15 min of incubation at room temperature. D-glucose was used as the standard.

**Reducing sugar:** Reducing sugar contents of samples were determined with the colorimetric method by using the Dinitrosalicylic acid (DNS) reagent (20), using D-glucose as a standard. Samples (1.0 g) were dissolved in 100 mL distilled water. The mixture was extracted at room temperature for 20 min and then filtered through filter paper (Whatman No.1). This solution (1 mL) was added to 3 mL DNS solution. The mixing solution was heated at 100°C for 5 min and then cooled on ice for 15 min. The cooling solution was diluted to 25 mL with distilled water and the absorbance was recorded at 550 nm.

**Amino acid:** Amino acid contents of samples were an-

alyzed according to the Ninhydrin method (21). For 1.0 g of each sample, 100 mL distilled water was added. Then, extraction was done in a water bath at room temperature for 20 min. The mixture was filtered through filter paper (Whatman No.2). A 0.2 mL of this extract solution was added to 0.4 mL of ninhydrin reagent and then heated at 100°C for 20 min. After the solution was cooled on ice, 1 mL of solvent (acetone : 0.1 M sodium phosphate : distilled water = 4:2:4) and 5 mL of distilled water was added. The absorbance was read at 570 nm. Leucine was used as a standard.

### Statistical analysis

Analysis of variance (ANOVA) was carried out using SPSS 18.0 (SPSS Inc., Chicago, IL, USA). All data were recorded as means  $\pm$  SD. Mean values were calculated according to Fisher's least significant difference (LSD) test ( $p < 0.05$ ).

## RESULTS AND DISCUSSION

### Proximate composition

The crude fat, protein, ash and carbohydrate contents of extrudates are shown in Table 2. There was no significant difference of crude ash and carbohydrate contents between raw red ginseng and extruded red ginseng samples. The content of crude fat in raw red ginseng (1.36%) was significantly higher than those of extrudates (0.19~0.50%). Hagenimana et al. (22) stated that these decreases in crude fat content occur through the lipids forming complexes with starch and protein in the extrusion process. Extruded red ginsengs showed lower crude protein contents than raw red ginseng, which means a decrease of 2~10%. Furthermore, increasing

**Table 2.** Proximate compositions of extruded red ginseng<sup>1)</sup>  
(Unit: % dry base)

Sample <sup>2)</sup>	Composition			
	Fat	Protein	Ash	Carbohydrate <sup>3)</sup>
Raw	1.36 $\pm$ 0.03 <sup>a</sup>	14.57 $\pm$ 0.06 <sup>a</sup>	4.90 $\pm$ 0.05 <sup>c</sup>	69.67
EX1	0.24 $\pm$ 0.01 <sup>e</sup>	13.53 $\pm$ 0.03 <sup>f</sup>	4.90 $\pm$ 0.07 <sup>c</sup>	72.90
EX2	0.42 $\pm$ 0.03 <sup>c</sup>	13.67 $\pm$ 0.05 <sup>e</sup>	4.88 $\pm$ 0.05 <sup>c</sup>	70.26
EX3	0.34 $\pm$ 0.04 <sup>d</sup>	13.14 $\pm$ 0.02 <sup>h</sup>	4.95 $\pm$ 0.09 <sup>bc</sup>	70.44
EX4	0.35 $\pm$ 0.02 <sup>d</sup>	13.23 $\pm$ 0.04 <sup>g</sup>	5.21 $\pm$ 0.11 <sup>a</sup>	72.71
EX5	0.48 $\pm$ 0.05 <sup>b</sup>	14.05 $\pm$ 0.04 <sup>d</sup>	4.92 $\pm$ 0.03 <sup>c</sup>	72.15
EX6	0.50 $\pm$ 0.05 <sup>b</sup>	14.13 $\pm$ 0.02 <sup>c</sup>	4.89 $\pm$ 0.06 <sup>c</sup>	72.95
EX7	0.19 $\pm$ 0.05 <sup>e</sup>	14.22 $\pm$ 0.05 <sup>b</sup>	5.08 $\pm$ 0.11 <sup>ab</sup>	72.18
EX8	0.23 $\pm$ 0.03 <sup>e</sup>	14.28 $\pm$ 0.07 <sup>b</sup>	4.96 $\pm$ 0.09 <sup>bc</sup>	69.16

<sup>1)</sup>Values with in the same column with different letters are significantly different at  $p < 0.05$ . Each value is the mean  $\pm$  SD of three replicates.

<sup>2)</sup>Refer to extrusion conditions in Table 1.

<sup>3)</sup>Carbohydrate contents were calculated as the difference of 100 - (fat + protein + ash + moisture).

feed moisture content increased the crude protein content of extrudates. This result may be due to higher feed moisture content leading to lower degrees of protein denaturation.

### Physical properties

The effect of extrusion conditions on the physical properties of extruded red ginseng samples is shown in Table 3. The expansion ratio was significantly affected by feed moisture content, such that the ratio decreased from 2.29 to 0.80 with an increase in feed moisture content from 20 to 30%. An increase in the feed moisture content decreased the melt viscosity. The viscosity affects bubble growth as well as shrinkage, thus bubble shrinkage and collapse are increased at high feed moisture content during the extrusion process (23). The specific length of extrudates correlates their length with their weight as an expression of axial expansion. Increasing feed moisture content resulted in a significant increase in a specific length. Generally, the radial expansion in extrudate is inversely proportional to the axial expansion (24), which agrees with our results. The highest value of specific length was 298.55 m/kg obtained in EX6 (feed moisture 30%, screw speed 200 rpm and temperature 130°C).

Bulk density of extrudates ranged between 0.30 and 0.64 g/cm<sup>3</sup>. The bulk density was found to be most dependent on feed moisture content. Increased feed moisture leads to a sharp increase in extrudate density. However, increased screw speed and barrel temperature caused a slight decrease in the density of extrudate. Increasing feed moisture content would change the amylopectin molecular structure of the material, reducing the melt elasticity of the dough and thus decreasing expansion and increasing the bulk density during the extrusion process. In addition, Fletcher et al. (25) found that increased barrel temperature resulted in an increased

degree of superheated water in the extruder barrel, encouraging bubble formation and a decrease in melt viscosity, thus leading to reduced density. Overall, the extrudates produced with a higher feed moisture content become denser than those produced at a lower feed moisture content. Increasing the temperature lowered the bulk density, resulting in a better expansion. At 30% feed moisture content and barrel temperature of 130°C, there was decreased radial expansion with a concomitant decrease in product bulk density due to greater axial expansion (specific length) of the product.

Compared with the raw red ginseng (WAI 4.57 g/g and WSI 36.12%), a lower WAI value (3.60~4.42 g/g) and a higher WSI value (47.37~54.29%) were observed in extruded samples. The feed moisture content significantly affected WAI and WSI of the extrudate. Increasing feed moisture content significantly increase the WAI but obviously decreased the WSI of the extrudate. The screw speed and barrel temperature were found to have a slight influence on the WAI at only 30% feed moisture content. The WSI values were increased with increasing screw speed.

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 (26), while WSI determines the amount of soluble components released from the starch after extrusion and often used as a parameter that indicates the degradation by starch granules (27). The utilized red ginseng was cooked by the steaming and drying process. The dextrinization phenomenon will be dominant during the extrusion process. The higher WSI of extrudate also illustrates that dextrinization occurred extensively in this experiment. At low feed moisture content (20%), dextrinization may have occurred easily. The effect of feed moisture content and

**Table 3.** Physical properties of extruded red ginseng<sup>1)</sup>

Sample <sup>2)</sup>	Raw	EX1	EX2	EX3	EX4	EX5	EX6	EX7	EX8
Expansion ratio	—	1.89 <sup>d</sup>	2.21 <sup>b</sup>	2.29 <sup>a</sup>	2.16 <sup>c</sup>	1.34 <sup>f</sup>	0.80 <sup>h</sup>	1.46 <sup>e</sup>	0.86 <sup>g</sup>
Specific length (m/kg)	—	89.90 <sup>de</sup>	82.60 <sup>f</sup>	87.27 <sup>ef</sup>	92.34 <sup>d</sup>	125.95 <sup>c</sup>	298.55 <sup>a</sup>	129.11 <sup>c</sup>	247.14 <sup>b</sup>
Bulk density (g/cm <sup>3</sup> )	—	0.44 <sup>c</sup>	0.31 <sup>d</sup>	0.31 <sup>d</sup>	0.30 <sup>d</sup>	0.64 <sup>a</sup>	0.45 <sup>c</sup>	0.59 <sup>b</sup>	0.44 <sup>c</sup>
WAI <sup>3)</sup> (w/w)	4.57 <sup>a</sup>	3.63 <sup>d</sup>	3.68 <sup>d</sup>	3.68 <sup>d</sup>	3.60 <sup>d</sup>	3.90 <sup>c</sup>	3.99 <sup>c</sup>	3.69 <sup>d</sup>	4.42 <sup>b</sup>
WSI <sup>4)</sup> (%)	36.12 <sup>f</sup>	51.68 <sup>c</sup>	53.44 <sup>b</sup>	54.00 <sup>ab</sup>	54.29 <sup>a</sup>	47.37 <sup>e</sup>	46.60 <sup>e</sup>	49.27 <sup>d</sup>	46.97 <sup>e</sup>
<i>L</i>	68.15 <sup>a</sup>	63.44 <sup>bc</sup>	60.97 <sup>d</sup>	61.10 <sup>d</sup>	56.35 <sup>e</sup>	62.79 <sup>bcd</sup>	64.57 <sup>b</sup>	62.13 <sup>cd</sup>	62.90 <sup>bcd</sup>
<i>a</i>	4.58 <sup>d</sup>	5.44 <sup>c</sup>	6.60 <sup>b</sup>	6.61 <sup>b</sup>	7.73 <sup>a</sup>	5.74 <sup>c</sup>	5.55 <sup>c</sup>	5.58 <sup>c</sup>	6.47 <sup>b</sup>
<i>b</i>	28.47 <sup>a</sup>	24.43 <sup>d</sup>	26.83 <sup>b</sup>	26.79 <sup>b</sup>	25.36 <sup>c</sup>	24.45 <sup>d</sup>	27.23 <sup>b</sup>	24.53 <sup>d</sup>	27.25 <sup>b</sup>
Breaking strength (N/m <sup>2</sup> )	—	3.28E+05 <sup>c</sup>	2.08E+05 <sup>e</sup>	2.33E+05 <sup>de</sup>	2.10E+05 <sup>e</sup>	4.93E+05 <sup>a</sup>	2.32E+05 <sup>de</sup>	4.43E+05 <sup>b</sup>	2.72E+05 <sup>d</sup>
Elastic modulus (N/m <sup>2</sup> )	—	3.98E+08 <sup>c</sup>	1.96E+08 <sup>c</sup>	2.05E+08 <sup>c</sup>	2.31E+08 <sup>c</sup>	2.54E+09 <sup>b</sup>	2.50E+09 <sup>b</sup>	1.74E+09 <sup>b</sup>	4.01E+09 <sup>a</sup>

<sup>1)</sup>Values within the same row with different letters are significantly different at  $p < 0.05$ .

<sup>2)</sup>Refer to extrusion conditions in Table 1.

<sup>3)</sup>Water absorption index.

<sup>4)</sup>Water solubility index.

barrel temperature on WAI of extruded red ginseng was consistent with the research by Anderson et al. (26), who found that WAI of extruded maize flour increased progressively with increased feed moisture content and barrel temperature. Mercier and Feillet (28) found that soluble starch increased with increasing barrel temperature and decreasing feed moisture, leading to increase the value of WSI, similar to the results found in this experiment.

Color is an important characteristic of extruded products. Table 3 also shows that the extruded red ginseng powder was darker and had higher *a* values and lower *b* values than the raw red ginseng. This experiment also found that, as barrel temperature and screw speed both increased, *L* values decreased at feed moisture content of 20%. After extrusion, a maximum *L* value (64.57) was obtained with 130°C barrel temperature with 30% feed moisture content. The *a* values of extrudate were significantly affected by the barrel temperature, screw speed and feed moisture content. The *b* values varied from 24.43 to 27.25, and the highest value was obtained in EX6 and EX8 (feed moisture 30%, temperature 130°C and screw speed 200 and 250 rpm, respectively). During the extrusion process, these color changes may be caused by non-enzymatic browning and destruction of heat sensitive pigments (29).

#### Mechanical properties

As shown in Table 3, breaking strength in bending increased from  $2.08E+05$  to  $4.93E+05$  N/m<sup>2</sup> with an increase in feed moisture content. The breaking strength decreased with increasing barrel temperature, particularly at high feed moisture content. Breaking strength depends on degree of expansion and cell wall strength. As already suggested, the decreasing melt viscosity would favor bubble growth, giving a softer texture.

Feed moisture content was found to have the most significant effect on apparent elastic modulus. An increase in feed moisture content caused an increase in the apparent elastic modulus of extrudates. Barrel temperature and screw speed have no significant influence on the apparent elastic modulus. The apparent elastic modulus depends on the intrinsic rigidity and the longitudinal expansion of expanded matrix (16).

#### Chemical properties

Fig. 2 shows the crude saponin contents of extrudates and raw red ginsengs. Extruded red ginseng (6.72~7.18%) contained more crude saponin than raw red ginseng (5.50%), which was an increase of 1.22~1.31 times. This result was caused by weakening of molecular bonds and increased water absorption at the high temperature, pressure and shear force involved in the extrusion process (30). The crude saponin contents slightly increased

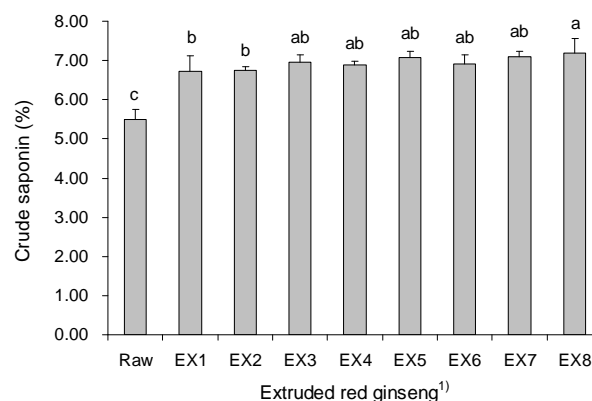


Fig. 2. Comparison of crude saponin contents in extruded red ginseng. <sup>1)</sup>Refer to extrusion conditions in Table 1.

with increasing screw speed and feed moisture content. After extrusion, the highest crude saponin content was 7.18% at EX8 (feed moisture 30%, screw speed 250 rpm and temperature 130°C). The crude saponin content was not significantly affected by the tested extrusion conditions. This result was in agreement with An et al. (2), who investigated the chemical conversion of ginsenosides in puffed red ginseng. Similarly, Yoon et al. (31) also reported that crude saponin content was influenced by the heating time, while heating temperature influenced the contents of soluble solid, acidic polysaccharide and phenolic compounds.

Total sugar, reducing sugar and amino acid contents of red ginseng samples are shown in Table 4. The content of total sugar in extruded red ginsengs ( $497.67 \sim 563.73$  mg/g) was significantly higher than the raw red ginseng ( $388.37$  mg/g). This result was different than the results that the content of total sugar was not changed after extrusion processing (32). The total sugar content of extrudates was significantly affected by extrusion temperature. It was found that content of total sugar in extruded red ginseng increased with increasing extrusion

Table 4. Total sugar, reducing sugar and amino acid contents of extruded red ginseng<sup>1)</sup> (Unit: mg/g dry base)

Sample <sup>2)</sup>	Total sugar	Reducing sugar	Amino acids
Raw	$388.47 \pm 2.70^f$	$140.36 \pm 0.59^a$	$103.53 \pm 0.49^a$
EX1	$533.07 \pm 2.08^c$	$135.70 \pm 0.66^c$	$96.56 \pm 0.47^d$
EX2	$560.50 \pm 4.88^a$	$135.34 \pm 0.68^c$	$89.97 \pm 0.64^f$
EX3	$513.60 \pm 3.33^d$	$137.87 \pm 0.91^b$	$91.64 \pm 0.61^e$
EX4	$549.77 \pm 3.06^b$	$123.06 \pm 0.44^e$	$96.32 \pm 0.36^d$
EX5	$497.67 \pm 1.53^e$	$137.38 \pm 0.58^b$	$88.52 \pm 0.97^g$
EX6	$501.00 \pm 2.04^e$	$132.66 \pm 0.66^d$	$91.07 \pm 0.35^e$
EX7	$499.93 \pm 1.53^e$	$135.83 \pm 0.55^c$	$98.52 \pm 0.23^c$
EX8	$563.73 \pm 2.62^a$	$134.70 \pm 0.94^c$	$101.70 \pm 1.01^b$

<sup>1)</sup>Values with in the same column with different letters are significantly different at  $p < 0.05$ . Each value is the mean  $\pm$  SD of three replicates.

<sup>2)</sup>Refer to extrusion conditions in Table 1.

temperature. Han et al. (12) reported that an increase was observed in the content of total sugar in extruded white ginsengs with the extrusion temperature increased from 110°C to 120°C.

The levels of both reducing sugars and amino acids decreased after extrusion processing. A similar tendency was observed by Kim et al. (33). Although reducing sugar was decreased with the increase in the extrusion temperature, this decrease was not significant. The amino acid content of raw red ginseng (103.53 mg/g) was obviously higher than those of extruded red ginseng samples (88.52~101.70 mg/g). The highest value of amino acid content of extrudate was 101.70 mg/g obtained from EX8 (feed moisture 30%, screw speed 250 rpm and temperature 130°C). Shivendra et al. (34) claim that during the drying process the reducing sugar generally decreases due to the browning reaction (Maillard reaction), since reducing sugars react with amino acids.

After extrusion, the highest contents of crude saponin, total sugar and amino acid were 71.80, 563.73 and 101.70 mg/g respectively, and obtained from EX8 (feed moisture 30%, screw speed 250 rpm and temperature 130°C). These results suggest that a high feed moisture, high screw speed, and high temperature extrusion condition may give a better chemical character to extruded red ginseng.

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