Effects of green tea contents on the quality and antioxidant properties of textured vegetable protein by extrusion-cooking

Xuelian Ma¹ · Gihyung Ryu¹

Received: 6 April 2018 / Revised: 5 June 2018 / Accepted: 12 July 2018 / Published online: 9 August 2018
© The Korean Society of Food Science and Technology and Springer Science+Business Media B.V., part of Springer Nature 2018

Abstract The aim of this study was to evaluate the effects of green tea contents (0, 5, 10, and 15%) on texturization and antioxidant properties of textured vegetable protein (TVP) by using a twin-screw extruder. Extrusion conditions were fixed at 140 °C barrel temperature, 50% moisture content, 100 g/min feed rate, and 200 rpm screw speed. The integrity index, hardness, and cutting strength of TVP significantly ($P < 0.05$) increased with the increase in green tea levels, while cohesiveness, springiness, water holding capacity, and nitrogen solubility index (NSI) significantly ($P < 0.05$) decreased. Increasing the amount of green tea resulted in better DPPH radical scavenging activity, higher total phenolic, total flavonoid, catechins, and caffeine contents. The (–)-epigallocatechin gallate, (–)-epicatechin, (–)-epigallocatechin, and (–)-epicatechin gallate contents of TVP significantly ($P < 0.05$) decreased, compared to that of raw materials. The incorporation of green tea in TVP can negatively affect expansion and NSI while positively affect texturization and antioxidant properties.

Keywords Textured vegetable protein · Extrusion · Green tea

Introduction

Extrusion cooking has been widely used in the food industry as a high temperature short time (HTST) process to produce commercially shelf stable products, because of

low cost, high productivity, energy efficiency and versatility (Angela, 2007). Extrusion offers continuous processing and could also maintain significant nutrient levels of ingredients (Guy, 2001). Physicochemical changes take place during the process which includes denaturation of protein, gelatinization of starch and Maillard reaction. In addition, the functional properties of the food ingredients are modified during the extrusion process (Yu, 2011).

Protein is an essential nutrition in the human diet (Macdonald et al., 2009). The direct consumption of vegetable proteins in food products has been increasing over the years because of animal related diseases, global shortage of animal protein, increasing demand for wholesome or religious food, and for economic reasons (Asgar et al., 2010). Soy protein is a source of high quality protein due to its relatively well-balanced composition of amino acids. It may further be processed into texturized vegetable protein (TVP) used in the manufacture of meat and poultry analogues. Soy protein isolate (SPI) is obtained by removing oil at low temperatures, which contains more than 90% protein (Angela, 2007). SPI is a mixture of 2 major fractions, 7S (β -conglycinin) and 11S (glycinin). 7S and 11S fractions, which make up 70% protein of soybean, were found to have influence on the texturization (Nishinari et al., 2014). An 11S/7S ratio of 1.5 in the formulation was reported to have the best texturization by Ning and Villota (1994). Wheat gluten (WG) is the most common ingredient to be texturized as vegetable protein from cereal sources, which is used in combination with soy-based ingredients, starch and other additives (Riaz and Texas, 2011). In recent years, vegetable protein made from combination of corn and other grains are getting more attention (Baskaran and Bhattacharya, 2004; Ghorpade et al., 1997; Yu, 2011; Yu and Ramaswamy, 2010; Yu et al., 2012).

✉ Gihyung Ryu
ghryu@kongju.ac.kr

¹ Department of Food Science and Technology, Kongju National University, Yesan, Chungnam 32439, South Korea

Green tea is one of the best sources of dietary fiber as well as polyphenols. Green tea contains more than 700 known compounds, including tea polyphenols (25–35%), tea polysaccharides (20–25%), protein (25–30%) and 26 kinds of amino acids, more than 50 kinds of mineral elements and vitamins, and other functional ingredients (Yuan, 2010). Furthermore, green tea has antioxidant, antibacterial, anticarcinogenic, antiviral, antiaging, and antimutagenic functions (Lu et al., 2010; Ramos, 2007).

Several studies have incorporated various plant proteins to enhance nutritional, textural, and functional characteristics of extrudate such as the mixture of corn, SPI, and WG (Ghorpade et al., 1997), soy-sweet potato (Iwo et al., 2004), SPI (Macdonald et al., 2009), whey protein concentrate (Manoi and Rizvi, 2009), and chickpea-barley (Aleksandar et al., 2017). However, studies that incorporate green tea in TVP are seldom found. The objectives of this research is to investigate the texturization properties of TVP with 0, 5, 10, and 15% green tea, and to study the effects of green tea contents on the antioxidant properties of TVP.

Materials and methods

Materials

Soy protein isolate (Wachsen Industry Co., Qingdao, China), wheat gluten (Roquette Freres, Lestrem, France), corn starch (Qone Co., Gwangyeoksi, South Korea), and green tea powder (Green tea institute, Hadong, South Korea) were purchased. The moisture contents of SPI, WG, corn starch, and green tea were 6.20, 6.20, 10.87, and 6.10%, respectively. The preformulation was constituted of 50% SPI, 40% WG, and 10% corn starch. Green tea partially replaced 0, 5, 10, and 15% of preformulation, respectively.

Extrusion process

The mixture was extruded with a co-rotating intermeshing twin-screw extruder (THK 31T, Incheon Machinery, South Korea) with a screw length of 690 mm and a screw diameter of 30 mm (L/D = 23:1). The extrusion parameters were fixed as follows: 140 °C barrel temperature, 50% feed moisture, 200 rpm screw speed, 100 g/min feed rate. The TVP was dried at 50 °C for 12 h and was cut to 2 ± 0.2 cm pellet to measure the physical properties. The dried sample was ground by grinder (SMKA-4000, PN Poong Nyun, Ansan, Korea) to pass 50–70 meshes sieve for chemical properties.

Proximate analysis

Moisture, crude protein, crude fat, and crude ash contents of TVP were determined by using the methods of AOAC (1990). Carbohydrate was calculated by removing moisture, crude protein, crude fat, and crude ash contents from 100. All experiments were done in triplicate.

Expansion properties

The expansion ratio was obtained by the area ratio of TVP (Park et al., 2017). The specific length was calculated as weight divided by length (Cho and Ryu, 2017). The piece density was determined by using millet displacement method (Shen et al., 2014). Expansion ratio and specific length were determined by ten repetitions. Piece density was averaged from triplicate.

Integrity index

Integrity index was determined by slightly modified method of Park et al. (2017). Around 5 g of dried samples were soaked in 100 mL distilled water for 30 min at 80 °C. The soaked samples were heated for 15 min at 121 °C in autoclave (DS-PAC 60, Lab house, Anyang, South Korea), then was washed with tap water for 15 s. The washed samples with 100 mL distilled water were homogenized at 14,450 rpm for 1 min. The samples were filtered by 20 meshes and dried at 105 °C until equilibration. The integrity index was recorded by dividing dry residue by sample weight, and multiplying it by 100.

Water holding capacity

Water holding capability (WHC) was determined by slightly modified method of Lin et al. (2002). The dried samples (5 g) were weighed and rehydrated in 100 mL distilled water for 12 h at 50 °C. The rehydrated samples were drained for 5 min. The WHC was calculated according to the following equation:

$$\text{WHC (\%)} = [(W_2 - W_1) / W_1] \times 100$$

where W_1 and W_2 are weights before and after rehydration, respectively.

Texture profile analysis and cutting strength

The texture profile analysis (TPA) of TVP was determined by a Rheo Meter (Sun Sci. Co., Compac-100 II, Tokyo, Japan). The cut TVP samples were rehydrated for 30 min at 80 °C and drained for 10 min in room temperature by using 20 meshes sieve. Hardness, cohesiveness, springiness, chewiness of TPA were recorded at 100 mm/min

travel speed and 10 kg load by using cylindrical probe with 25 mm diameter (Park et al., 2017). For cutting strength, a knife probe with 2 kg load and 100 mm/min were used to cut the rehydrated sample. Ten replications were measured.

Color

For color, the ground sample was measured by using a colorimeter (Minolta, CR-300, Osaka, Japan). The color parameters of the TVP with different green tea contents were expressed as *L* (lightness), *a* (redness) and *b* (yellowness) and the results were averaged from 3 replications.

Scanning electron microscopy

The microstructure of TVP with different green tea contents was scanned by using filed emission scanning electron microscopy (Tesan USA Inc., MIRA II LMH, Cranberry Township, PA). The results were obtained with an acceleration voltage of 10 kV at 1000 magnification.

Nitrogen solubility index

The soluble nitrogen was extracted from the ground sample (0.2 g) with 10 mL of 0.5% KOH. The mixture was stirred at 120 rpm for 20 min. A subsample was centrifuged at 2000×*g* for 10 min. The soluble nitrogen was analyzed by Ninhydrin method. Total nitrogen content was determined by the method of Barry (2001). Albumin was used as a standard. Nitrogen solubility index (NSI) was presented as soluble nitrogen content divided by total nitrogen content, and multiplied by 100.

Antioxidant properties

The ground samples (1 g) were extracted with 10 mL phosphate buffered saline solution at 200 rpm for 2 h at room temperature (Cho and Ryu, 2017). The mixtures were centrifuged at 3000×*g* for 30 min. The supernatant was filtered through Whatman No. 1 filter paper. The extracted samples were stored for total phenolic, total flavonoid contents and DPPH radical scavenging activity analysis which were measured by the method of Norajit et al. (2011).

Catechins and caffeine contents

The catechins and caffeine contents of TVP were determined according to the method of Shen et al. (2014) by using high performance liquid chromatography (Bionex Co., VM-3000, New Brunswick, USA) analysis. Catechins and caffeine contents were calculated on the basis of the calibration curve of each (–)-epigallocatechin (EGC), (+)-

catechin (C), (–)-epicatechin (EC), (–)-epigallocatechin gallate (EGCG), (–)-epicatechin gallate (ECG), and caffeine. The results were averaged from four replications.

Statistical analysis

The data was analyzed using one-way analysis of variance (ANOVA) by SPSS software (SPSS 20.0.0, IBM Corp., New York, USA). Duncan's least significant difference tests ($P < 0.05$) were used to analyze the difference between mean values of treatments.

Results and discussion

Proximate composition

Moisture, crude protein, crude fat, crude ash, and carbohydrate contents of TVP with differing levels of green tea are shown in Table 1. Crude protein showed a decreasing trend as the level of green tea got higher which might be due to the interaction between polyphenol–protein (Song and Yoo, 2017). In addition, less amount of protein was used in formulation since SPI and WG was replaced with green tea powder. The crude fat didn't show significant difference between TVPs. The highest crude ash content was found in TVP with 15% green tea level because green tea contains higher amount of minerals. The increasing green tea content resulted in higher carbohydrate content. The results of crude fat and ash content were in agreement with Lu et al. (2010), who reported crude fat content did not have significant difference with the increase in green tea content from 0 to 30% while crude ash content significantly increased due to the higher amount of green tea addition.

Physical properties

Expansion ratio of TVP with varying levels of green tea contents is shown in Table 2. Expansion ratio of TVP with 15% green tea was significantly ($P < 0.05$) lower than that of other samples while there was no significant difference among TVPs with 0, 5, and 10% green tea levels. The reduction of expansion ratio might be due to the higher amount of fiber addition (Norajit et al., 2011; Shen et al., 2014). Shen et al. (2014) claimed that expansion ratio decreased with increasing green tea content from 0 to 10% of puffed Yukwa. Non-significant change in specific length was observed with the increase in green tea proportion of TVP from 0 to 15%. Piece density was inversely related to the expansion ratio. The piece density of TVP with 15% green tea was significantly ($P < 0.05$) higher than that of other samples.

Table 1 Proximate composition of TVP with different green tea contents

GTC (%)	Moisture (%)	Protein (%)	Fat (%)	Ash (%)	Carbohydrate (%)
0	8.44 ± 0.09 ^a	76.56 ± 0.04 ^a	0.86 ± 0.02 ^a	2.86 ± 0.06 ^d	11.28
5	5.25 ± 0.01 ^c	75.68 ± 0.08 ^b	0.94 ± 0.01 ^a	2.97 ± 0.02 ^c	15.16
10	6.87 ± 0.08 ^b	73.25 ± 0.04 ^c	0.96 ± 0.01 ^a	3.09 ± 0.02 ^b	15.83
15	6.66 ± 0.09 ^b	72.10 ± 0.06 ^d	1.10 ± 0.01 ^a	3.21 ± 0.01 ^a	16.93

GTC Green tea content

Values of different letters in the same column are significantly different ($P < 0.05$)

Integrity index refers to the texture residues of meat analogue after the pellet sample was rehydrated, pressurized, dispersed, and dried. It is an important property that affects the quality of TVP. The integrity index of TVP with different green tea contents is shown in Table 2. The results of integrity index in TVP ranged from 48.25 to 63.96% and significantly ($P < 0.05$) increased with the increase in green tea contents. It indicated that the addition of green tea enhanced the degree of texturization during extrusion. Song and Yoo (2017) also observed that the adding the combination of polyphenol extract and protein isolate to rice noodles positively affects the cooking quality of rice noodles possibly due to the protein–polyphenol complex network.

As shown in Table 2, WHC varied from 259.02 to 200.09%. A decreasing trend of WHC was observed as green tea contents increased. The WHC of TVP was related to its texture after rehydration (Ning and Villota, 1994). Lin et al. (2002) reported that WHC had positive correlation with expansion as more water was absorbed by TVP during rehydration when more expansion occurred. WHC was mainly dependent on the size of the air cells and the porosity of the TVP (Lin et al., 2002; Ning, 1993).

Table 2 shows TPA and cutting strength of TVP with different green tea contents. Increasing the proportion of green tea content from 0 to 15% resulted in higher value in hardness and cutting strength. The increase in hardness at high green tea content may be due to the high density and hard extrudate caused by melt viscosity (Tucker et al., 2006). Ning et al. (2017) also reported that there was an increase in hardness with addition of more green tea. Cohesiveness quantifies the internal resistance of food structure. In other words, cohesiveness is a kind of ability of a material to stick to itself. Springiness measures elasticity by determining the extent of recovery between the first and second compression. The results showed that cohesiveness and springiness of TVP decreased with increasing levels of green tea. The chewiness of TVP was affected by the addition of green tea as there was significant decrease with the increase in green tea content from 5 to 10%, whereas it was significantly increased when green tea content changed from 10 to 15%. A few of studies have also demonstrated the potential of applying the protein–

polyphenol interaction to the food system in terms of enhancing textural properties (Lee et al., 2016; Li et al., 2012; Wu et al., 2007).

Color

The color is expressed by L , a , and b values. The color of TVP was significantly ($P < 0.05$) affected by the levels of green tea. TVP became darker, greener, and bluer with increasing green tea contents (Table 3). The color difference increased with addition of green tea. The color change might be due to the presence of polyphenol and pigments (Lu et al., 2010) or non-enzymatic browning by Maillard reaction between proteins and reducing sugars that occurred at high temperature (Petitot et al., 2009).

Scanning electron microscopy

Freeze dried samples were used for scanning electron microscopy imaging because preliminary experiment showed unclear picture when dried TVP was used. The microstructure of TVPs with different green tea contents were determined using scanning electron microscopy at magnifications of 1000 (Fig. 1). The cross-linking structure was obvious and all of the samples showed tightly fibrous structure. The layered and directional structure was easily seen, especially at 10% green tea addition. According to Kinsella and Franzen (1978), during extrusion process, the structure formation of extrudate was believe to result from a complete recombination of macromolecules into an oriented form, when then molten mass leaved the extruder die and the superheated water flashed off to make the polymeric material expand. Li and Lee (1996) claimed that all changes in microstructure of TVP might be a response to the changes in chemical compositions and protein–protein or protein–polyphenol interactions caused by varied concentrations of addition. Proper concentration of green tea improved the final structure of TVP.

Nitrogen solubility index

Table 4 shows the NSI of TVP with different green tea contents. Compared with raw materials, NSI of TVP

Table 2 Physical properties of TVP with different green tea contents

GTC (%)	Expansion ratio	Specific length (cm/g)	Piece density (g/cm ³)	Integrity index (%)	WAC (%)	Texture profile analysis			Cutting strength (g/cm ²)
						Hardness (g/cm ²)	Cohesiveness (%)	Springiness (%)	
0	1.37 ± 0.11 ^a	2.37 ± 0.10 ^a	0.56 ± 0.04 ^b	48.25 ± 0.22 ^c	259.02 ± 5.17 ^a	378.46 ± 54.24 ^b	71.84 ± 2.71 ^a	87.50 ± 2.55 ^a	378.89 ± 21.80 ^c
5	1.33 ± 0.06 ^a	2.44 ± 0.12 ^a	0.58 ± 0.04 ^b	60.32 ± 0.60 ^b	241.72 ± 1.74 ^b	411.60 ± 18.90 ^{ab}	61.57 ± 0.90 ^{bc}	77.65 ± 1.35 ^b	564.92 ± 22.00 ^b
10	1.38 ± 0.20 ^a	2.43 ± 0.08 ^a	0.56 ± 0.02 ^b	63.57 ± 1.17 ^a	223.42 ± 2.27 ^c	470.20 ± 27.39 ^{ab}	65.66 ± 1.25 ^b	78.97 ± 0.71 ^b	626.70 ± 16.49 ^a
15	1.12 ± 0.13 ^b	2.39 ± 0.09 ^a	0.69 ± 0.03 ^a	63.96 ± 1.08 ^a	200.09 ± 5.52 ^d	501.04 ± 31.05 ^a	60.20 ± 1.79 ^c	75.07 ± 2.11 ^b	652.98 ± 21.80 ^a

GTC Green tea contents, WHC water holding capacity

Values of different letters in the same column are significantly different ($P < 0.05$)

significantly ($P < 0.05$) decreased after extrusion which might be due to the loss of amino acid or Maillard reaction during extrusion. As green tea contents increased, the NSI of TVP significantly ($P < 0.05$) decreased as polyphenols crosslink with proteins such as lysine or methionine which makes them inactive during digestion or insoluble (Asgar et al., 2010).

Antioxidant properties

The antioxidant properties of TVP are shown in Table 4. Gallic acid was used as a standard for total phenolic content. Total phenolic varied from 9.85 to 57.49 mg/g. Total flavonoid ranged from 0.65 to 2.03 mg/g as quercetin equivalents. TVP with different green tea content had different total phenolic, total flavonoid contents, and DPPH radical-scavenging activities. Significantly ($P < 0.05$) enhanced antioxidant activity was observed in TVP with higher green tea contents. The improved antioxidant properties of adding green tea is due to the increase in phenolic compounds that possesses antioxidant activity (Shen et al., 2014). However, the phenolic and flavonoid content decreased in TVP, compared to that of raw material. The similar trend was found in the description of Korus (2007), who reported that the antioxidant activity of extrudate decreased due to thermal degradation of polyphenol by oxidation or polymerization during the extrusion.

Catechins and caffeine contents

The content of major catechins and caffeine in TVP with different green tea contents are shown in Table 5. A significantly higher content of catechins and caffeine was found in TVP with higher amount of green tea. There was a considerable loss of EC, EGCG, and ECG contents in the extrudate compared to that of raw materials. The C content significantly ($P < 0.05$) increased while EGC and caffeine content had no obvious changes in TVP compared to that of raw material. The loss of EC, EGCG, and ECG contents might be due to degradation, oxidation, epimerization and polymerization during food processing (Ananingsih et al., 2013).

In conclusion, effects of green tea contents on the texturization and antioxidant properties of TVP were investigated in this study. Higher amount of green tea level resulted in lower expansion, darker color, better texturization, lower NSI, and higher antioxidant properties. According to the structural studies and texture profile analysis, the TVP that had higher value of hardness or chewiness had a more orderly directional structure. Therefore, our results demonstrated that manufacture of

Table 3 Color of TVP with different green tea contents

GTC (%)	<i>L</i>	<i>a</i>	<i>b</i>	Color difference
Raw				
0	87.53 ± 0.19 ^a	− 1.61 ± 0.03 ^c	16.61 ± 0.18 ^g	–
5	80.33 ± 0.02 ^b	− 6.24 ± 0.01 ^d	20.26 ± 0.07 ^e	–
10	76.46 ± 0.08 ^c	− 7.87 ± 0.01 ^e	22.41 ± 0.05 ^c	–
15	74.23 ± 0.10 ^d	− 8.09 ± 0.04 ^f	23.21 ± 0.14 ^b	–
TVP				
0	67.86 ± 0.29 ^e	1.16 ± 0.08 ^a	25.94 ± 0.12 ^a	21.95
5	49.84 ± 0.20 ^f	− 1.27 ± 0.08 ^b	21.26 ± 0.11 ^d	30.91
10	45.35 ± 0.15 ^g	− 1.61 ± 0.03 ^c	18.43 ± 0.10 ^f	31.98
15	41.04 ± 0.17 ^h	− 1.32 ± 0.02 ^b	14.78 ± 0.06 ^h	34.91

GTC Green tea contents, *L* lightness, *a* redness, *b* yellowness

Values of different letters in the same column are significantly different ($P < 0.05$)

Fig. 1 Microstructure of TVP with different green tea contents

Table 4 Nitrogen solubility index and antioxidant properties of TVP with different green tea contents

GTC (%)	Nitrogen solubility index (%)	TPC (mg/g)	TFC (mg/g)	DPPH (%)
Raw				
0	52.43 ± 1.78 ^a	27.47 ± 0.84 ^e	10.36 ± 1.26 ^d	1.33 ± 0.04 ^d
5	49.30 ± 1.16 ^b	38.47 ± 0.90 ^c	30.75 ± 1.35 ^c	1.56 ± 0.01 ^c
10	46.23 ± 1.92 ^c	46.63 ± 1.47 ^b	42.99 ± 0.91 ^b	1.82 ± 0.05 ^b
15	40.18 ± 0.95 ^e	57.49 ± 0.46 ^a	54.98 ± 0.69 ^a	2.03 ± 0.02 ^a
TVP				
0	49.21 ± 0.63 ^b	9.85 ± 0.17 ^h	9.04 ± 1.01 ^d	0.65 ± 0.07 ^f
5	43.41 ± 0.78 ^d	15.22 ± 0.25 ^g	26.88 ± 1.02 ^c	0.87 ± 0.02 ^e
10	39.44 ± 0.93 ^e	25.34 ± 0.19 ^f	38.13 ± 1.17 ^b	1.41 ± 0.08 ^d
15	31.29 ± 1.60 ^f	31.60 ± 0.83 ^d	49.85 ± 2.20 ^a	1.61 ± 0.06 ^c

GTC Green tea contents, TPC total phenolic contents, TFC total flavonoid contents

Values of different letters in the same column are significantly different ($P < 0.05$)**Table 5** Catechins and caffeine contents of TVP with different green tea contents

GTC (%)	EGC (%)	C (%)	EC (%)	EGCG (%)	ECG (%)	Caffeine (%)
Raw						
100	1.780 ± 0.04 ^{1a}	0.071 ± 0.005 ^a	0.985 ± 0.022 ^a	3.951 ± 0.060 ^a	1.602 ± 0.013 ^a	1.724 ± 0.045 ^a
5	0.003 ± 0.001 ^d	0.005 ± 0.001 ^d	0.035 ± 0.003 ^d	0.025 ± 0.004 ^{de}	0.068 ± 0.005 ^{de}	0.085 ± 0.008 ^d
10	0.011 ± 0.002 ^{cd}	0.005 ± 0.001 ^d	0.074 ± 0.006 ^c	0.101 ± 0.013 ^{cd}	0.137 ± 0.011 ^c	0.172 ± 0.017 ^b
15	0.041 ± 0.010 ^b	0.009 ± 0.002 ^d	0.127 ± 0.005 ^b	0.237 ± 0.025 ^b	0.221 ± 0.008 ^b	0.260 ± 0.006 ^c
TVP						
5	0.001 ± 0.000 ^d	0.029 ± 0.002 ^c	0.017 ± 0.000 ^d	0.009 ± 0.005 ^e	0.050 ± 0.002 ^e	0.093 ± 0.006 ^d
10	0.005 ± 0.002 ^d	0.044 ± 0.005 ^b	0.033 ± 0.004 ^d	0.042 ± 0.014 ^{de}	0.087 ± 0.012 ^d	0.165 ± 0.020 ^b
15	0.028 ± 0.012 ^{bc}	0.062 ± 0.004 ^a	0.071 ± 0.005 ^c	0.153 ± 0.027 ^c	0.156 ± 0.005 ^c	0.268 ± 0.008 ^c

GTC Green tea contents, EGC (–)-epigallocatechin, C (+)-catechin, EC (–)-epicatechin, EGCG (–)-epigallocatechin gallate, ECG (–)-epicatechin gallate

Values of different letters in the same column are significantly different ($P < 0.05$)

TVP with incorporation green tea could have beneficial effects.

Acknowledgements This research was supported by Basic Science Research Program through the National Research Foundation (NRF) funded by the Ministry of Education, Science and Technology (2016H1C1A1035974).

Compliance with ethical standards

Conflict of interest The authors state no conflict of interest.

References

- Aleksandar Y, Andrea S, Shannon HN, Michael N. Influence of the extrusion parameters on the physical properties of chickpea and barley TVP. *Food Sci. Biotechnol.* 26: 393–399 (2017)
- Ananingsih VK, Amber S, Zhou WB. Green tea catechins during food processing and storage: A review on stability and detection. *Food Res. Int.* 50: 469–479 (2013)
- Angela C. Protein-protein interaction of soy protein isolate from extrusion processing. (2007) <http://hdl.handle.net/10355/5099>.
- AOAC. Official Method of Analysis of AOAC Intl. 15th ed. Association of Official Analytical Chemists, Arlington, VA, USA (1990).
- Asgar MA, Fazilah A, Huda N, Bhat R, Karim AA. Nonmeat protein alternatives as meat extenders and meat analogs. *Comp. Rev. Food Sci. Food Safety* 9: 513–529 (2010)
- Barry S. A Ninhydrin based assay to quantitate the total protein content of tissue samples. *Analyt. Biochem.* 292: 125–129 (2001)
- Baskaran V, Bhattacharya S. Nutritional status of the protein of corn-soy based extruded products evaluated by rat bioassay. *Plant Food Hum. Nut.* 59: 101–104 (2004)
- Cho SY, Ryu GH. Effects on quality characteristics of extruded meat analog by addition tuna sawdust. *J. Korean Soc. Food Sci. Nutr.* 46: 465–472 (2017)
- Ghorpade VM, Bhatnagar S, Hanna MA. Structural characteristics of corn starches extruded with soy protein isolate or wheat gluten. *Plant Food Hum. Nut.* 51: 109–123 (1997)
- Guy R. *Extrusion cooking: technologies and applications*. (1st ed.). USA. (2001)

- Iwo MO, Van ZDJ, Stolp W, Ngoddy PO. Effect of extrusion cooking of soy-sweet potato mixtures on available lysine content and browning index of extrudates. *J. Food Eng.* 62: 143–150 (2004)
- Korus, J, Gumul D, Czechowska K. Effect of extrusion on the phenolic composition and antioxidant activity of dry beans of *Phaseolus vulgaris* L. *Food Technol. Biotechnol.* 45: 139–146 (2007)
- Kinsella JE, Franzen KL. Texturized proteins: Frabrication, flavoring, and nutrition. *CRC Crit Rev Food Sci Nutr.* 10: 147–207 (1978)
- Lee DS, Kim Y, Song Y, Lee JH, Lee S, Yoo SH. Development of a gluten-free rice noodle by utilizing protein-polyphenol interaction between soyprotein isolate and extract of *Acanthopanax sessiliflorus*. *J Sci Food Agric.* 96: 1037–1043 (2016)
- Li M, Lee TC. Effect of extrusion temperature on solubility and molecular weight distribution of wheat proteins. *J Agric Food Chem.* 44: 763–768 (1996)
- Li M, Zhang JH, Zhu KX, Peng W, Zhang SK, Wang B, Zhou HM. Effect of superfine green tea powder on the thermodynamic, rheological and fresh noodle making properties of wheat flour. *LWT-Food Sci Tech.* 46: 23–28 (2012)
- Lin S, Huff HE, Hsieh F. Extrusion process parameters, sensory characteristics, and structural properties of a high moisture soy protein meat analog. *J. Food Sci.* 67: 1066–1072 (2002)
- Lu TM, Lee CC, Mau JL, Lin SD. Quality and antioxidant property of green tea sponge cake. *Food Chem.* 119: 1090–1095 (2010)
- Macdonald RS, Joseph P, Hsieh FH. Soy protein isolate extruded with high moisture retains high nutritional quality. *J. Agri. Food Chem.* 57: 3550–3555 (2009)
- Manoi K, Rizvi SSH. Physiochemical changes in whey protein concentrate texturized by reactive supercritical fluid extrusion. *J. Food Eng.* 95: 627–635 (2009)
- Ning JM, Hou GG, Sun JJ, Wan XC, Dubat A. Effect of green tea powder on the quality attributes and antioxidant activity of whole-wheat flour pan bread. *LWT - Food Sci. Technol.* 79, 342–348 (2017).
- Ning L. Texturization of soy protein via twin-screw extrusion. (1993) <http://hdl.handle.net/2142/21658>.
- Ning L, Villota R. Influence of 7S and 11S globulins on the extrusion performance of soy protein concentrates. *J. Food Process. Pres.* 18: 421–436 (1994)
- Nishinari K, Fang K, Guo S, Philips GO. Soy proteins: A review on composition, aggregation and emulsification. *Food Hydrocoll.* 39: 301–318 (2014)
- Norajit K, Gu BJ, Ryu GH. Effects of the addition of hemp powder on the physicochemical properties and energy bar qualities of extruded rice. *Food Chemistry* 129: 1919–1925 (2011)
- Park JH, Chatpaisarn A, Ryu GH. Effects of gluten and moisture contents on texturization of extruded soy protein isolate. *J. Korean Soc. Food Sci. Nutr.* 46: 473–480 (2017)
- Petitot M, Abecassis J, Micarda V. Structuring of pasta components during processing: impact on starch and protein digestibility and allergenicity. *Trends in Food Sci. Technol.* 20: 521–532 (2009)
- Ramos S. Effects of dietary flavonoids on apoptotic pathways related to cancer chemoprevention. *J. Nutr. Biochem.* 18: 427–442 (2007)
- Riaz MN, Texas A. *Handbook of food proteins.* (1st ed.). Woodhead Publishing (Chapter 15) (2011)
- Shen XJ, Han JY, Ryu GH. Effects of the addition of green tea powder on the quality and antioxidant properties of vacuum-puffed and deep-fried Yukwa. *LWT - Food Sci. Technol.* 55: 362–367 (2014)
- Song YW, Yoo SH. Quality improvement of a rice-substituted fried noodle by utilizing the protein-polyphenol interaction between a pea protein isolate and green tea (*Camellia sinensis*) extract. *Food chem.* 235: 181–187 (2017)
- Tucker G, Plunkett A, Ainsworth P, Ding QB, Marson H. The effect of extrusion conditions on the functional and physical properties of wheat-based expanded snacks. *J Food Eng.* 73: 142–148 (2006)
- Wu W, Clifford M, Howell NK. The effect of instant green tea on the foaming and rheological properties of egg albumen proteins. *J Sci Food Agric.* 87: 1810–1819 (2007)
- Yu L, Ramaswamy HS. Frying characteristics of protein-enriched snack food from extruded corn flour-soy protein isolate feed mix. Institute of Food Technologists Annual Meeting, Chicago, USA (2010)
- Yu L. Extrusion processing of protein rich food formulations. (2011) http://digitool.library.mcgill.ca/webclient/StreamGate?folder_id=0&dvs=1498366512390~165.
- Yu L, Ramaswamy HS, Boye J. Twin-screw extrusion of corn flour and soy protein isolate blends: a response surface analysis. *Food Bioprocess Technol.* 5: 485–497 (2012)
- Yuan HB. The study and application of tea dietary fiber. *Zhejiang Agri. Sci.* 5: 1010–1015 (2010)