Available online at www.sciencedirect.com
ScienceDirect
Food Chemistry 110 (2008) 1–13
FOOD CHEMISTRY
www.elsevier.com/locate/foodchem

Effect of soaking, boiling, and steaming on total phenolic content and antioxidant activities of cool season food legumes

Baojun Xu [a,b], Sam K.C. Chang [a,*]

[a] Department of Cereal and Food Sciences, North Dakota State University, Fargo, ND 58105, United States
[b] The Pharmaceutical Institute, Dalian University, Dalian 116622, China

Received 10 July 2007; received in revised form 21 January 2008; accepted 23 January 2008

Abstract

The effects of soaking, boiling and steaming processes on the total phenolic components and antioxidant activity in commonly consumed cool season food legumes (CSFL's), including green pea, yellow pea, chickpea and lentil were investigated. As compared to original unprocessed legumes, all processing steps caused significant ($p < 0.05$) decreases in total phenolic content (TPC), DPPH free radical scavenging activity (DPPH) in all tested CSFL's. All soaking and atmospheric boiling treatments caused significant ($p < 0.05$) decreases in oxygen radical absorbing capacity (ORAC). However, pressure boiling and pressure steaming caused significant ($p < 0.05$) increases in ORAC values. Steaming treatments resulted in a greater retention of TPC, DPPH, and ORAC values in all tested CSFL's as compared to boiling treatments. To obtain cooked legumes with similar palatability and firmness, pressure boiling shortened processing time as compared to atmospheric boiling, resulted in insignificant differences in TPC, DPPH for green and yellow pea. However, TPC and DPPH in cooked lentils differed significantly between atmospheric and pressure boiling. As compared to atmospheric processes, pressure processes significantly increased ORAC values in both boiled and steamed CSFL's. Greater TPC, DPPH and ORAC values were detected in boiling water than that in soaking and steaming water. Boiling also caused more solid loss than steaming. Steam processing exhibited several advantages in retaining the integrity of the legume appearance and texture of the cooked product, shortening process time, and greater retention of antioxidant components and activities.

Keywords: Cool season food legumes; Soaking; Boiling; Steaming; Phenolics; Antioxidant activity; ORAC; Peas and lentils; Legumes

1. Introduction

Experimental, epidemiological and clinical studies show correlations between the consumption of food legumes and decreasing incidence of several diseases, such as cancer, cardiovascular diseases, obesity and diabetes (Bhathena & Velasquez, 2002; Kris-Etherton et al., 2002; Kushi, Meyer, & Jacobs, 1999). A latest epidemiological study showed that among studied fruits and vegetables, only bean and lentil consumption was related to a lower incidence of breast cancer (Adebamowo et al., 2005). Antioxidant activities and phenolic compounds in raw legumes have been reported in several earlier communications (Amarowicz, Karamac, & Shahidi, 2003; Xu, Yuan, & Chang, 2007). Legumes must be cooked before consumption. However, how processing methods affect the health promoting phenolics and antioxidant activities have not been systematically studied.

Food processing not only improves flavor and palatability of foods but also increases the bioavailability of nutrients, by inactivating antinutritional factors, growth inhibitors and haemagglutinins (Chau, Cheung, & Wong, 1997). Cooking brings about a number of changes in physical characteristics and chemical compositions of dry legumes, which are commonly cooked by a boiling process before use. Pressure boiling and steaming can also be used. Prior to cooking, soaking is a preliminary step, it helps

* Corresponding author. Tel.: +1 701 231 7485; fax: +1 701 231 6536.
E-mail address: kow.chang@ndsu.edu (S.K.C. Chang).

0308-8146/$ - see front matter © 2008 Elsevier Ltd. All rights reserved.
doi:10.1016/j.foodchem.2008.01.045

soften texture and shorten the cooking time. High pressure processing technology may provide high quality of food products (flavor, color, biological active components) (Knorr, 1999).

US production of cool season food legumes, including green pea, yellow pea, lentil and chickpea, mainly in the states of North Dakota, Idaho, Washington and Montana, have increased significantly in recent years. Currently we do not know enough about the quality and quantity of the health promoting components in CSFL's as compared to soybean and common bean (Xu et al., 2007). In addition, very little information is available in the literature regarding the change of antioxidant components and antioxidant activity of the processed food legumes (Rocha-Guzmán, González-Laredo, Ibarra-Pérez, Nava-Berúmen, & Gallegos-Infante, 2007; Turkmen, Sari, & Velioglu, 2005). With the exception of germination processes (López-Amorós, Hernández, & Estrella, 2006), there are no other reports on the changes of antioxidant components and antioxidant activity of processed CSFL's. It is important to understand the effect of processing on functional components in CSFL's. Based on these considerations, the present study was undertaken to investigate the effects of soaking, boiling and steaming processes on the antioxidant phenolics and antioxidant activities of common consumed CSFL's.

2. Materials and methods

2.1. Chemicals and reagents

2,2-Diphenyl-1-picryhydrazyl radical (DPPH·), fluorescein disodium (FL), Folin-Ciocalteu reagent, gallic acid (GA), sodium carbonate, and 6-hydroxy-2,5,7,8-tetramethlchroman-2-carboxylic acid (Trolox) were obtained from Sigma Chemical Co. (St. Louis, MO). The 2,2′-azobis (2-amidino-propane) dihydrochloride (AAPH) was purchased from Wako Chemicals USA (Richmond, VA). All solvents used for extraction were purchased from VWR International (West Chester, PA), all other chemicals were of analytical grade.

2.2. Legume samples

The dry CSFL seeds used in current study were green pea (*Pisum sativum* L. cv. Stratus) supplied by Meridian Seed LLC. (West Fargo, ND), yellow pea (*P. sativum* L. cv. Golden) supplied by Steve Marman Pulse USA (Bismark, ND), chickpea (*Cicer arietinum* L. cv. Amits) and lentil (*Lens culinaris* cv. CDC Richlea) supplied by Agricare United (Ray, ND). Broken seeds, damaged seeds and foreign materials were hand-removed from the samples. Moisture content was determined by drying the sample in an air-circulated oven at 110 °C until a constant weight was obtained (AOAC, 2000). Results were reported on a dry weight basis.

2.3. Soaking and determination of hydration rate

CSFL samples (20 g) were rinsed in tap water and soaked in 60 mL of tap water in 8 oz Falcon specimen containers (Becton Dickinson Labware, Franklin Lakes, NJ) at ambient temperature for up to 24 h. Water absorption (moisture increase) of dry legumes during soaking was measured hourly for the initial 0–6 h, then measured every 2 h from 6 to 16 h and measured at 24 h for the last time. The soaked legumes were blotted with paper towel at appointed time to remove excess water, weighed and placed back into the soaking water. Moisture content of soaked legumes was calculated. Furthermore, water absorption curve was made by plotting the kinetic increase of moisture content with time. We defined the plateau phase (at 16 h) of water absorption curve as 100% hydration rate. Soaking time of CSFL's with desired hydration rate was calculated through quadratic fit equation of respective water absorption curve. For the following boiling and steaming experiments, legumes were soaked to the desired hydration rates by controlling soaking time. The soaked legumes were drained and boiled or steamed by the methods described below.

2.4. Boiling and determination of boiling time

Regular boiling (under atmospheric pressure) of lentil was conducted according to Mattson (1946) with slight modifications. The Mattson cooking apparatus was composed of 25 metal plungers (penetration rods) with 1/16 inch diameter and 90 g weight each, resting on the surface of 25 randomly picked pre-soaked lentils (with 50% hydration rate) retained in small metal cups. The entire apparatus, containing lentils with the rods resting on the top of the lentils, was immersed in boiling water open to the atmosphere. As boiling progressed, a lentil was considered cooked when the lentil became tender enough to be penetrated by the rod (90 g). The penetration times for all rods were manually recorded. We defined the time required for 100% of plungers to penetrate the seed as cooking time. After boiling, the lentils were drained and cooled to the room temperature for 1–2 h in covered plastic containers. Subsequently, boiled water was frozen and lentil solid samples were freeze-dried.

Regular boiling of green and yellow peas and chickpeas was conducted using a domestic atmospheric cooker. Briefly, pre-soaked peas (20 g in dry weight) with 100% hydration rate were immersed in 100 mL of boiling water. Determination of the cooking time for the regular boiling of these peas was conducted on Mattson apparatus in our preliminary experiments. Due to hard texture of seed hulls and individual difference of seed, long time durations (more than 2 h) were required for 100% of plungers to penetrate the seed. Therefore, the method for determining the cooking time of the regular boiling treatment of these legumes was conducted by a tactile method (Vindiola, Seib, & Hoseney, 1986), in which the cooked peas are squeezed

between the forefinger and thumb with moderate pressure. A seed was considered to be cooked when it could be squeezed by fingers easily. Cooking time was defined as the time duration (min) of at least 90% of seeds (submitted to the test) to be cooked. After boiling treatments, the peas were drained and cooled to the room temperature in covered plastic containers. Subsequently, cooked samples were freeze-dried.

Pressure boiling was performed by an M-0512-H Mirro pressure cooker (Mirro Co., Manitowoc, WI) with a 9898 Mirro pressure regulator. Five folds of tap water (100 mL) were added to pre-soaked peas and lentils (20 g in dry weight at 50% hydration for lentils, 100% hydration for peas and chickpeas) in a 250 mL Erlenmeyer flask which was then covered with aluminum foil. The contents of flask were brought quickly to boiling on a hot plate. The flask filled with legume samples and boiling water was placed into pre-heated pressure cooker with 2 L of boiling water, and the lid was locked in place and pressure regulator was set with desired pressure (5 or 15 psi). The cooking time was counted when steam spurted out from pressure regulator. Cooking time was selected from the preliminary experiments, in which cooking time was determined by the tactile method. When legumes were pressure-boiled to the desired cooking time, the pressure cooker was removed from the heat source and the pressure was released. Boiling water and cooked solid samples were cooled down to the room temperature, and freeze-dried.

2.5. Steaming and determination of steaming time and texture

Regular steaming was performed on an atmospheric steam cooker. The pre-soaked legume samples (100 g in dry weight) with 100% hydration rate were placed on a tray in the steam cooker covered with lid and steamed over 2 L of boiling water under the atmospheric pressure. Steaming time was selected according to preliminary experiments, in which steaming time was determined when the similar degrees of tenderness of each processed legume was achieved. After the steaming process, legumes were cooled down, frozen and freeze-dried. Pressure steaming was performed in the similar manner to pressure boiling, only difference was that the pre-soaked samples (100 g in dry weight) were placed on a tray in the pressure cooker and steamed over 2 L of boiling water under selected high pressures (5 or 15 psi).

Steamed legumes were placed in 8 oz covered plastic container and cooled at the room temperature for 1 h prior to texture analysis. The firmness values of 100 g of steamed legumes were measured using an Instron Universal Testing Machine (Model 1011, Instron Co., Canton, MA) equipped with a 500 kg weight beam and Kramer Compression-Shear cell. The crosshead speed was set at 20 mm/min. The force at the peak of the shearing process was taken to indicate the degree of firmness of the steamed legumes (Wang, Chang, & Grafton, 1988). Results were expressed as kg force/100 g steamed sample.

2.6. Extraction of unprocessed and processed legumes

For quantitative studies, original unprocessed legumes and freeze-dried processed legumes were ground to powder with an IKA® all basic mill (IKA Works Inc., Wilmington, NC) and to pass through a 60-mesh sieve. The legume sample powders (0.5 g each) were accurately weighed into a set of centrifuge tubes. Five milliliters of acetone/water (50:50, v/v) extraction solvent were added to the green pea, yellow pea, and chickpea, 5 mL of acetone/water/acetic acid (70:29.5:0.5, v/v/v) extraction solvent was added to lentil. The reason for selecting these specific solvents systems for the two respective legume groups was based on a preliminary study (Xu & Chang, 2007) that these respective solvents gave the best yields of phenolic contents and antioxidant activity. The tubes were capped and the mixtures were shaken at 300 rpm at room temperature on an orbital shaker for 3 h. The mixtures were extracted for another 12 h by setting in the dark. The extracts were centrifuged by an Allegra 21R Centrifuge (Beckman Coulter Ltd., Palo Alto, CA) at 3000 rpm for 10 min, and the supernatants were removed into new tubes. Residues were added with 5 mL of the respective extraction solvents. The above-mentioned extraction procedures were repeated. The two extracts were combined and stored at 4 °C in the dark for use. In addition, all soaking, boiling, steaming water were separated from the processed legume solids, and immediately frozen after processing, and stored in a freezer (−20 °C) for further determination of total phenolic content and antioxidant activity assay.

2.7. Determination of total phenolic content

The total phenolic content (TPC) was determined by a Folin-Ciocalteu assay (Singleton & Rossi, 1965) with slight modifications (Xu & Chang, 2007) using gallic acid (GA) as the standard. The original unprocessed or processed legume extract or processing water (50 μL), distilled water (3 mL), 250 μL of Folin-Ciocalteu's reagents solution, and 7% $NaCO_3$ (750 μL) were mixed in a tube and incubated for 8 min at the room temperature. Then a dose of 950 μL of distilled water was added. The mixture was allowed to stand for 2 h at the room temperature. The absorbance was measured at 765 nm against distilled water as a blank. The total phenolic content was expressed as gallic acid equivalents (mg of GAE/g sample) through the calibration curve of gallic acid. Linearity range of the calibration curve was 50–1000 μg/mL ($r = 0.99$).

2.8. DPPH free radical scavenging activity

DPPH free radical scavenging capacity of legume extracts was evaluated according to Chen and Ho (1995) with slight modifications (Xu & Chang, 2007). Basically,

0.2 mL of the raw or processed legume extract or processing water was added to 3.8 mL ethanol solution of DPPH radical (final concentration was 0.1 mM). The mixture was shaken vigorously for 1 min by vortexing and left to stand in the dark for 30 min at the room temperature. Thereafter, the absorbance for the sample (A_{sample}) was measured using a spectrophotometer (UV 160, Shimadzu, Japan) at 517 nm against ethanol blank. A negative control ($A_{control}$) was taken after adding DPPH solution to 0.2 mL of the respective extraction solvent. The percent of DPPH discoloration of the sample was calculated according to the equation % Discoloration $= [1-(A_{sample}/A_{control}] \times 100$. The free radical scavenging activity of legume extracts was expressed as mean micromole of Trolox equivalent per gram of legume (micromole TE/g legume) from triplicate extracts test using the calibration curve of Trolox. Linearity range of the calibration curve was 20–1000 μM ($r = 0.99$).

2.9. Oxygen radical absorbing capacity assay

Hydrophilic-oxygen radical absorbing capacity (ORAC) assays were carried out on a BMG Fluostar Optima Microplate Reader (Molecular Devices, Sunnyvale, CA), which was equipped with two auto injectors, an incubator and wavelength adjustable fluorescence filters. The temperature of the incubator was set to 37 °C, a fluorescence filter with an excitation wavelength of 485 nm and an emission wavelength of 520 nm was used. The procedures were based on the previous report by Prior et al. (2003) and Wu et al. (2004a) with slight modifications (Xu & Chang, 2007). Briefly, AAPH was used as peroxyl generator and Trolox as a standard. Twenty microliters of suitable diluted legume extract sample, blank and Trolox calibration solutions were loaded to clear flat bottom polystyrene 96-well microplates (Nalge Nunc International, NY) in triplicate based upon a set layout. The plate reader was programmed to record the fluorescence of FL on every cycle. Kinetic reading was recorded for 60 cycles with 40 s per cycle setting. For hydrophilic extracts from legumes, sample solutions were diluted with phosphate buffer to the proper concentration range for fitting the linearity range of the standard curve. Trolox standards were prepared with phosphate buffer and blank was phosphate buffer. After loading 20 μL of diluted sample, standard and blank, and 200 μL of the fluorescein solution into appointed wells according to layout, the microplate (sealed with film) was incubated for at least 30 min in plate reader, then 20 μL of peroxyl generator AAPH (3.2 μM) was adding to initiate oxidation reaction, kinetic fluorescence was recorded immediately by software SoftMax Pro (Molecular Devices, Sunnyvale, CA). The final ORAC values were calculated using a linear equation between the Trolox standards or sample concentration and net areas under the fluorescein decay curves. The data were analyzed using Microsoft Excel (Microsoft, Roselle, IL). The area under curve (AUC) was calculated as: $AUC = 0.5 + (R_2/R_1 + R_3/R_1 + R_3/R_1 + \cdots + 0.5R_n/R_1)$, where R_1 was the fluorescence reading at the initiation of the reaction and R_n was last measurement. The net AUC was obtained by subtracting the AUC of the blank from that of a sample or standard. The ORAC value was calculated and expressed as micromoles of Trolox equivalent per gram legume (μmol of TE/g legume) using the calibration curve of Trolox. Linearity range of the calibration curve was 5.0–50 μM ($r = 0.99$). For each specific sample, triplicate extractions were performed.

2.10. Statistical analysis

All soaking, boiling and steaming processes were performed in triplicate. The data were expressed as mean ± standard deviation. Statistical analysis was performed using 2005 SAS (Version 9.1, SAS institute Inc. Cary, NC). Analysis of variance (ANOVA) was conducted, and Duncan's multiple range tests were used to determine significant differences at $p < 0.05$.

3. Results and discussion

3.1. Water absorption, hydration rate and soaking time

Traditionally, dry legumes are soaked to hydrate prior to boiling, making them easier to cook. In fact, soaking legumes with water or aqueous salt solution prior to cooking has been used as a common strategy to soften texture and reduce cooking time. The water absorption curves of CSFL's, illustrated in Fig. 1, were characterized by an initial phase of rapid water imbibition followed by an equilibrium phase, during which the CSFL's approached their full soaking capacity. Hydration ratios were significantly different among CSFL's. Chickpea, green pea and yellow pea hydrated faster than lentil in the log phase of absorption curves. Chickpea and green pea were prone to saturation after soaking for 10 h and reached a plateau after 16 h. However, yellow pea and lentil went into a slow absorption period after 10 h and reached a plateau after 16 h. After

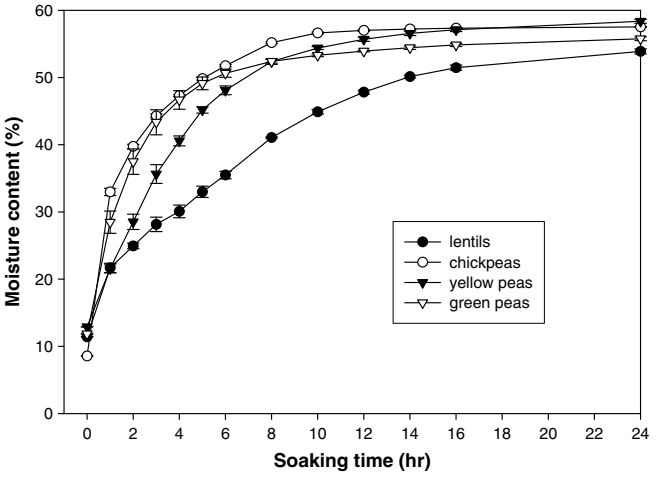

Fig. 1. The water absorption curves of dry cool season food legumes.

soaking for 16 h, all CSFL's were saturated with water, and chickpea, yellow pea and green pea possessed relatively higher moisture content (54.8%, 57.1%, 57.3%, respectively) than lentil (51.4%). In addition, soaking water was slightly colored in green and yellow pea trials, deeply yellow colored in chickpea trials, and the greatest colored in lentil trails as compared to others. This phenomenon indicated that some soluble constituents (might include some phenolic antioxidant constituents) of the CSFL's were leached into the soaking water. In order to decrease potential loss of antioxidant components, soaking treatment with various levels of hydration rates (50%, 70%, and 85%) and short soaking times were designed for further boiling and steaming treatments. To obtain the desired hydration rate, soaking times of CSFL's were calculated by calibrating through quadratic fit equations of the water absorption curves. In the consequent boiling and steaming experiments, green pea, yellow pea, chickpea, and lentil were soaked for 4.9 h, 6.4 h, 5 h, 9.49 h, respectively, to reach 85% hydration, soaked for 3 h, 4.3 h, 3.1 h, 6.2 h, respectively, to reach 70% hydration, while lentil was soaked for 2.7 h to reach 50% hydration.

3.2. Determination of boiling time

Cooking time as well as cooked texture, appearance and flavor are important cooking quality characteristics. The cooking time for producing palatable products is one of the main criteria used in evaluating cooking quality of dry legumes (Moscoso, Bourne, & Hood, 1984). Several methods for measuring the cooking time of legumes have been reported, however, no universally accepted methods exist so far. For regular boiling, we used both the Mattson (1946) and the tactile method (Vindiola et al., 1986) to evaluate the cooking time. For pressure boiling and steaming, the tactile method was used for all CSFL samples. There appears to be no clear definition for determination of cooking time by using the Mattson method. The times taken for 50%, 60%, 92%, and 100% of seeds to be penetrated had been defined as cooking time by different research groups (Wang & Daun, 2005). In the case of lentils, due to individual differences in terms of moisture content and seed size, the penetration time exhibited broad range difference (from 1 min for the first bean penetration to 30 min for the last penetration). Therefore, the time required for 100% of the plungers to penetrate the seed was taken as cooking time in this study. In the cases of the tactile method, we defined the cooking time when 90% of the beans could be squeezed easily with the forefinger and the thumb.

Owing to the texture properties of green pea, yellow pea and chickpea, it took a long time (more than 2 h) for the plunger rods to penetrate the seeds when using the Mattson method to determine cooking time. Alternatively, the tactile method was used to evaluate the cooking time of green pea, yellow pea and chickpea. The optimal cooking times for the different cooking condition were selected from our preliminary experiments for both regular and pressure cooking processes (results were not shown here). To prepare processed samples for further antioxidant assay, several optimal cooking times were performed to prepare samples. The selected optimal cooking times and pressure conditions are shown in Tables 1–3.

3.3. Determination of steaming time and texture

To overcome the subjectivity of tactile method, a combination of tactile method and instrumental textural test was used to decide the steaming time of both regular and pressure steaming processes, in which steaming time was determined when the similar degrees of tenderness or firmness of each steaming treatment was achieved. To prepare steamed samples for further antioxidant assay, several optimal cooking times were performed to prepare samples. The selected optimal cooking times and pressure conditions are shown in Tables 1–3.

Firmness or softness is one of the most important criteria used in determining the acceptability of processed legumes, usually the firmness less than 162 kg force/100 g is considered to be palatable or acceptable for cooked beans (Wang et al., 1988). Significant differences ($p < 0.05$) in firmness were found among different steaming conditions. Firmness (kg force/100 g) of CSFL's ranged from 104.67 to 149.33 for green pea, 98.33 to 158.00 for yellow pea, 105.33 to 142.00 for chickpea, 116.33 to 157.33 for lentil, respectively. According to our previous tactile evaluations and literatures (Su & Chang, 1995; Wang et al., 1988), all steaming treatments had firmness values in the palatable range. The firmnesses were lower in CSFL's processed by pressure steaming than those processed by regular steaming. The firmness was lower in CSFL's processed by a relatively high pressure (15 psi) than in those processed by a relatively low pressure (5 psi).

3.4. Effect of processing on total phenolic content of CSFL's

Total phenolic contents (TPC) of the extracts from soaked and processed CSFL's are presented in Table 1. Significant differences ($p < 0.05$) in TPC were found both in leached soaking or processing water and processed legumes among most processing treatments of yellow pea, green pea, chickpea and lentil. Significant differences ($p < 0.05$) existed among different soaking treatments of yellow pea and lentil, between 100% hydration treatment and the other hydration treatments of all tested CSFL's. No significant differences existed among the selected boiling treatments of green and yellow pea, but significant differences ($p < 0.05$) existed between regular and pressure boiling of chickpea and lentil. Significant differences ($p < 0.05$) existed between regular (atmospheric) and pressure steaming treatments of all tested CSFL's, and between the two pressure steaming treatments of all tested CSFL's.

After processing treatments, the TPC of processed CSFL's was significantly reduced as compared to the respective original unprocessed CSFL's, while steamed

CSFL's preserved slightly higher TPC as compared to boiled legumes. After soaking, about 2–12% of TPC in peas and chickpeas were lost, while about 9–38% of TPC in lentil were lost in soaking water. Meanwhile, the loss of TPC in peas and chickpeas decreased with increases in the hydration rate, while the loss of TPC in lentil increased with the increase in the hydration rate. These phenomena might be due to the differences on distribution and content of phenolic compounds in the seedcoat and cotyledon between lentil and peas, chickpea. In the case of peas and chickpeas, longer soaking times allowed the cotyledon to absorb phenolics in the water. While in the case of lentil, more phenolics lingered in the water than those diffused into the cotyledons.

Table 1
Effect of soaking, boiling and steaming on total phenolic content (mg gallic acid equivalents/g) of selected cool season food legumes

	Processing conditions	Green pea		Yellow pea		Chickpea		Lentil	
		TPC	Loss %[a]	TPC	Loss %	TPC	Loss %	TPC	Loss %
Raw	–	1.22 A		1.38 A		1.44 A		7.34 A	
Soaking water	50% hydration	–		–		–		0.31d	
	70% hydration	0.06b		0.06b		0.06c		0.58c	
	85% hydration	0.07b		0.08a		0.07b		1.14b	
	100% hydration	0.10a		0.09a		0.15a		1.55a	
Soaked legumes	50% hydration	–		–		–		6.64a B	9.5
	70% hydration	1.08b CD	11.5	1.22c B	11.6	1.31b D	9.0	6.41a B	12.6
	85% hydration	1.10b BC	9.8	1.31b A	5.1	1.31b D	9.0	5.76b C	21.5
	100% hydration	1.16a AB	4.9	1.35a A	2.2	1.40a B	2.77	4.56c D	37.8
Boiling water	RB, 30 min	–		–		–		1.25b	
	RB, 45 min	–		–		–		0.84c	
	RB, 60 min	–		–		–		0.84c	
	PB, 5 psi, 5 min	–		–		–		1.62a	
	PB, 15 psi, 5 min	–		–		–		1.18b	
	RB, 90 min	0.51b		0.56b		0.70b		–	
	RB, 120 min	0.55a		0.62a		0.75ab		–	
	RB, 150 min	0.55a		0.65a		0.78a		–	
	PB, 5 psi, 30 min	0.41c		0.49c		0.53c		–	
	PB, 15 psi, 15 min	0.41c		0.46c		0.48c		–	
Boiled legumes[b]	RB, 30 min	–		–		–		3.24b F	55.8
	RB, 45 min	–		–		–		3.66a E	50.1
	RB, 60 min	–		–		–		3.59a E	51.1
	PB, 5 psi, 5 min	–		–		–		2.35c H	67.9
	PB, 15 psi, 5 min	–		–		–		2.37c H	67.7
	RB, 90 min	0.61a G	50.0	0.75a E	45.6	0.96ab EF	33.3	–	
	RB, 120 min	0.60a G	50.8	0.76a E	44.9	0.92b F	36.1	–	
	RB, 150 min	0.63a G	48.4	0.76a E	44.9	0.90b F	37.5	–	
	PB, 5 psi, 30 min	0.61a G	50.0	0.74a E	46.4	0.98abEF	31.9	–	
	PB, 15 psi, 15 min	0.66a G	45.9	0.78a E	43.5	1.02a E	29.2	–	
Steaming water	RS, 15 min	–		–		–		0.09a	
	PS, 5 psi, 15 min	–		–		–		0.09a	
	PS, 15 psi, 15 min	–		–		–		0.09a	
	RS, 70 min	0.04b		0.13a		0.13a		–	
	PS, 5 psi, 70 min	0.03b		0.03a		0.04c		–	
	PS, 15 psi, 60 min	0.07a		0.05a		0.08b		–	
Steamed legumes[c]	RS, 15 min	–		–		–		3.49a EF	52.4
	PS, 5 psi, 15 min	–		–		–		3.21b F	56.3
	PS, 15 psi, 15 min	–		–		–		2.88c G	60.8
	RS, 70 min	1.05a D	13.9	1.25a C	9.4	1.40a B	2.8	–	
	PS, 5 psi, 70 min	0.88b E	27.9	0.96c D	30.4	1.33b CD	7.6	–	
	PS, 15 psi, 60 min	1.03a D	15.6	1.16b B	15.9	1.38a BC	4.3	–	

Values marked by the same small case letter within same group processing are not significantly different ($p < 0.05$), values marked by the same capital letter in same column are not significantly different ($p < 0.05$), $n = 3$.

[a] Loss % was calculated using original unprocessed beans as starting materials.

[b] Peas were pre-soaked based on 100% hydration rate, lentil was pre-soaked based on 50% hydration rate prior to boiling treatments.

[c] All samples were pre-soaked based on 70% hydration rate prior to steaming treatments. RB, regular boiling; PB, pressure boiling; RS, regular steaming; PS, pressure steaming.

Although there are hundreds of varieties of dry edible beans in the world, data on phenolics in cooked legumes are very limited. Bressani and Elias (1980) observed that about 30–40% of phenolics could be removed from common beans by cooking and discarding the cooking water. Data from Franke, Custer, Cerna, and Narala (1994) showed that an average 61.2% of flavonoids in the unprocessed beans lost after processing. However, in the present study, it was found that about 40–50% of phenolics were reduced in green pea, yellow pea and chickpea, and 50–68% of phenolics in lentil were leached (Table 1) into soaking and cooking water. Pressure cooking lost more TPC (about 68%) than regular cooking (about 50–56%) in lentil. These results are in accordance with those of Barroga, Laurena, and Mendoza (1985) who found that boiling and cooking reduced total phenolic content in Mung

Table 2
Effect of soaking, boiling and steaming on DPPH free radical scavenging capacity (μmol trolox equivalents/g) of selected cool season food legumes

	Processing conditions	Green pea		Yellow pea		Chickpea		Lentil	
		DPPH	Loss %[a]	DPPH	Loss %	DPPH	Loss %	DPPH	Loss %
Raw	–	2.77 A		3.68 A		2.94 A		19.72 A	
Soaking water	50% hydration	–		–		–		0.67c	
	70% hydration	ND		ND		ND		1.30a	
	85% hydration	0.05b		0.05a		ND		1.00b	
	100% hydration	0.16a		0.10a		ND		0.58d	
Soaked legumes	50% hydration	–		–		–		18.21a B	7.6
	70% hydration	2.34b C	15.5	3.27b C	11.1	1.91c D	35.0	18.01a B	8.7
	85% hydration	2.53a B	8.6	3.46a B	5.9	2.34b C	20.4	17.94a B	9.0
	100% hydration	2.28b C	17.6	3.18b D	13.6	2.63a B	10.5	17.86a B	9.4
Boiling water	RB, 30 min	–		–		–		2.80b	
	RB, 45 min	–		–		–		1.34c	
	RB, 60 min	–		–		–		1.31c	
	PB, 5 psi, 5 min	–		–		–		3.18a	
	PB, 15 psi, 5 min	–		–		–		2.85b	
	RB, 90 min	0.49c		1.05b		0.15d		–	
	RB, 120 min	0.61b		0.67c		0.29bc		–	
	RB, 150 min	0.69b		1.08b		0.38a		–	
	PB, 5 psi, 30 min	0.93a		1.07b		0.31b		–	
	PB, 15 psi, 15 min	0.85a		1.19a		0.27c		–	
Boiled legumes[b]	RB, 30 min	–		–		–		17.83a B	9.6
	RB, 45 min	–		–		–		18.07a B	8.4
	RB, 60 min	–		–		–		17.89a B	9.3
	PB, 5 psi, 5 min	–		–		–		13.91c F	29.5
	PB, 15 psi, 5 min	–		–		–		14.57b E	26.1
	RB, 90 min	1.05a E	62.1	1.73a E	52.9	0.34b G	88.4	–	
	RB, 120 min	0.91b F	67.1	1.72ab E	53.3	0.28c G	90.5	–	
	RB, 150 min	0.85b F	69.3	1.62ab E	55.9	0.10d H	96.6	–	
	PB, 5 psi, 30 min	1.06a E	61.7	1.54b EF	58.2	0.33b G	88.8	–	
	PB, 15 psi, 15 min	1.15a E	58.5	1.66ab E	54.8	0.44a F	85.0	–	
Steaming water	RS, 15 min	–		–		–		ND	
	PS, 5 psi, 15 min	–		–		–		ND	
	PS, 15 psi, 15 min	–		–		–		ND	
	RS, 70 min	ND		ND		ND		–	
	PS, 5 psi, 70 min	ND		ND		ND		–	
	PS, 15 psi, 60 min	ND		ND		ND		–	
Steamed legumes[c]	RS, 15 min	–		–		–		16.97a C	13.9
	PS, 5 psi, 15 min	–		–		–		15.06b D	23.6
	PS, 15 psi, 15 min	–		–		–		14.54c E	26.3
	RS, 70 min	1.31a D	52.7	1.88a E	48.9	1.99a D	83.3	–	
	PS, 5 psi, 70 min	0.92b F	66.7	1.20c F	67.4	1.66b E	43.5	–	
	PS, 15 psi, 60 min	1.34a D	51.6	1.56b EF	57.6	1.95a D	33.6	–	

Values marked by the same small case letter within same group processing are not significantly different ($p < 0.05$), values marked by the same capital letter in same column are not significantly different ($p < 0.05$), $n = 3$.

[a] Loss % was calculated using original unprocessed beans as starting materials.

[b] Peas were pre-soaked based on 100% hydration rate, lentil was pre-soaked based on 50% hydration rate prior to boiling treatments.

[c] All samples were pre-soaked based on 70% hydration rate prior to steaming treatments. RB, regular boiling; PB, pressure boiling; RS, regular steaming; PS, pressure steaming.

bean by 73%. Pressure steaming lost less TPC in green, yellow pea and chickpea, while lost more TPC in lentil as compared to regular steaming. Our results on variation of TPC by processing are also in good agreement with those reported by Ismail, Marjan, and Foong (2004), who found that thermal treatment decreased the total phenolic content in all vegetables. Large amount of the loss of phenolic components could be due to leaching of phenols into soaking and cooking water, as well as breakdown of phenolics during processing. Significant levels of TPC could be detected in soaking, boiling and steaming water leached from processed CSFL's as shown in Table 1. Almost half of TPC was detected in boiling water, these results showed the fate of TPC in processed CSFL's. Especially, in the cases of boiling and steaming, the sum of TPC was far less than original unprocessed CSFL's. The

Table 3
Effect of soaking, boiling and steaming on oxygen radical absorbing capacity (ORAC, μmol trolox equivalents/g) of selected cool season food legumes

	Processing conditions	Green pea		Yellow pea		Chickpea		Lentil	
		ORAC	Loss %[a]	ORAC	Loss %	ORAC	Loss %	ORAC	Loss %
Raw	–	9.75 E		12.06 ED		18.66 E		94.90 B	
Soaking water	50% hydration	–		–		–		10.77d	
	70% hydration	0.27c		0.28c		0.24b		15.81c	
	85% hydration	0.74b		0.60b		0.30b		20.12b	
	100% hydration	1.08a		1.06a		1.63a		23.74a	
Soaked legumes	50% hydration	–		–		–		72.31a D	23.8
	70% hydration	4.71a FG	51.7	5.75b G	52.3	12.57b F	32.6	64.39a E	32.1
	85% hydration	5.55a F	43.1	8.89a F	26.3	16.66a E	10.7	56.88a F	40.1
	100% hydration	7.85a F	58.5	9.92a EF	17.7	17.92a E	3.9	29.36b I	69.1
Boiling water	RB, 30 min	–		–		–		6.36b	
	RB, 45 min	–		–		–		6.29b	
	RB, 60 min	–		–		–		6.17b	
	PB, 5 psi, 5 min	–		–		–		20.40a	
	PB, 15 psi, 5 min	–		–		–		21.63a	
	RB, 90 min	2.90d		3.31e		7.11c		–	
	RB, 120 min	3.50cd		5.34d		8.99b		–	
	RB, 150 min	4.63bc		6.48c		10.69a		–	
	PB, 5 psi, 30 min	5.99ab		9.18a		9.33b		–	
	PB, 15 psi, 15 min	6.17a		7.70b		6.56c		–	
Boiled legumes[b]	RB, 30 min	–		–		–		35.72d H	62.3
	RB, 45 min	–		–		–		39.55d GH	58.3
	RB, 60 min	–		–		–		43.96c G	53.6
	PB, 5 psi, 5 min	–		–		–		84.36a C	11.1
	PB, 15 psi, 5 min	–		–		–		79.78b C	15.9
	RB, 90 min	2.59d H	73.4	5.10c G	57.7	8.24c G	55.8	–	
	RB, 120 min	4.12c G	57.7	5.85c G	51.5	6.07d G	67.5	–	
	RB, 150 min	2.27d H	76.7	5.66c G	53.1	5.76d G	69.1	–	
	PB, 5 psi, 30 min	12.41b D	−27.3	13.55b D	−12.3	23.25b D	−24.6	–	
	PB, 15 psi, 15 min	20.89a B	−114.2	20.08a C	−66.5	26.16a C	−40.2	–	
Steaming water	RS, 15 min	–		–		–		ND	
	PS, 5 psi, 15 min	–		–		–		ND	
	PS, 15 psi, 15 min	–		–		–		ND	
	RS, 70 min	ND		ND		ND		–	
	PS, 5 psi, 70 min	ND		ND		ND		–	
	PS, 15 psi, 60 min	ND		ND		ND		–	
Steamed legumes[c]	RS, 15 min	–		–		–		93.59a B	1.4
	PS, 5 psi, 15 min	–		–		–		99.61a B	−4.9
	PS, 15 psi, 15 min	–		–		–		106.99a A	−12.7
	RS, 70 min	9.48c E	2.7	10.98c DEF	8.9	17.29c E	7.3	–	
	PS, 5 psi, 70 min	16.43b C	−68.5	23.98b B	−98.8	34.29b B	−83.7	–	
	PS, 15 psi, 60 min	26.80a A	−174.8	30.53a A	−153.1	41.40a A	−121.8	–	

Values marked by the same small case letter within same group processing are not significantly different ($p < 0.05$), values marked by the same capital letter in same column are not significantly different ($p < 0.05$), $n = 3$.

[a] Loss % was calculated using original unprocessed beans as starting materials.

[b] Peas were pre-soaked based on 100% hydration rate, lentil was pre-soaked based on 50% hydration rate prior to boiling treatments.

[c] All samples were pre-soaked based on 70% hydration rate prior to steaming treatments. RB, regular boiling; PB, pressure boiling; RS, regular steaming; PS, pressure steaming.

exact chemical nature of these reductions in TPC is not fully understood, however, could be attributed to chemical transformation, decomposition of phenolics, and formation of phenolic-protein complex under thermal and pressure conditions.

3.5. Effect of processing on DPPH free radical scavenging capacity of CSFL's

DPPH free radical scavenging capacities (DPPH) of the extracts from processed CSFL's are presented in Table 2. Significant differences ($p < 0.05$) in DPPH values were found both in leached processing water and processed legumes among most processing treatments of yellow pea, green pea, chickpea and lentil. Significant differences ($p < 0.05$) existed among different soaking treatments of yellow pea and chickpea, no significant differences were found among different hydration soaking treatments in the case of lentil. No significant differences existed among the multiple boiling treatments of green, yellow pea and lentil, but significant differences ($p < 0.05$) existed between two pressure treatments, and between regular (atmospheric) and pressure boiling of all processed CSFL's. Significant differences ($p < 0.05$) existed between regular and pressure steaming treatments of all processed CSFL's, and between two the pressure steaming treatments of all tested CSFL's.

After processing, the DPPH free radical scavenging capacities (DPPH values) of processed CSFL's were significantly reduced as compared to the respective original unprocessed CSFL's, while green pea and chickpea preserved relatively high radical scavenging capacities, and yellow pea and lentil preserved relatively low radical scavenging capacities at the overall level in steamed legumes as compared to boiled legumes. DPPH free radical scavenging capacities were lost about 9–18% in green pea, 6–14% in yellow pea, 10–35% in chickpea, and about 8–10% in lentil after soaking by removing soaking water. Meanwhile, loss of free radical scavenging capacities in chickpea exhibited a decreasing tendency, while the loss of free radical scavenging capacities in lentil exhibited an increasing tendency with the increasing of hydration rate.

After boiling, free radical scavenging capacities of CSFL's were reduced by about 60–70% in green pea, 50–60% in yellow pea, 85–95% in chickpea, and 9–30% in lentil (Table 2). Pressure boiling lost more free radical scavenging capacities (about 26–30%) than regular boiling (8–10%) in lentil.

After steaming, free radical scavenging capacities of CSFL's were reduced by 51–67% in green pea, 49–67% in yellow pea, 33–83% in chickpea, and 14–26% in lentil (Table 2). Pressure steaming lost less free radical scavenging capacities in chickpea, while lost more free radical scavenging capacities in lentil as compared to regular steaming. In general, the loss of DPPH was partly due to soluble antioxidants in leached water and heat effect.

3.6. Effect of processing on oxygen radical absorbing capacity of CSFL's

The oxygen radical absorbance capacity (ORAC) is the only method so far that combined both inhibition time and degree of inhibition into a single quantity (Prior et al., 2003). Comparing to DPPH method, ORAC utilizes different antioxidant reaction mechanism: ORAC reactions involves hydrogen atom transfer (HAT) mechanism, while DPPH involves single electron transfer (SET) mechanism (Prior, Wu, & Schaich, 2005). The presence of antioxidants results in an inhibition in the free radical damage to the fluorescent compounds. The ORAC assay has been used to study the antioxidant capacity of many compounds and food samples (Prior et al., 2003; Wu et al., 2004a, 2004b). The ORAC values of the antioxidant extracts from processed legume solids are presented in Table 3. Significant differences ($p < 0.05$) in ORAC values were found both in leached processing water and processed legume solids among most processing treatments of yellow pea, green pea, chickpea and lentil. Significant differences ($p < 0.05$) existed among different soaking treatments of green, yellow pea, chickpea, and lentil. No significant differences existed among the multiple boiling treatments of yellow pea and chickpea, but significant differences ($p < 0.05$) existed between the two pressure treatments in the cases of green, yellow pea and chickpea, and between regular and pressure boiling of all processed CSFL's. Significant differences ($p < 0.05$) existed between regular and pressure steaming treatments of all processed CSFL's, and between the two pressure steaming treatments of all tested CSFL's.

After processing, the oxygen radical absorbance capacities of processed CSFL's were significantly reduced in the cases of soaked legumes, regular boiled legume as compared to the respective original unprocessed CSFL's. However, the oxygen radical absorbance capacities of processed CSFL's were significantly increased in the cases of pressure boiling and pressure steaming as compared to the respective original unprocessed CSFL's. After soaking, the oxygen radical absorbance capacity were decreased by 43–59% in green pea, 18–52% in yellow pea, 4–33% in chickpea, and about 24–70% in lentil. Meanwhile, the loss of oxygen radical absorbance capacity in yellow pea and chickpea decreased, while the loss of oxygen radical absorbance capacity in lentil increased with the increase of hydration rate.

Boiling is generally regarded as being destructive to antioxidant compositions. Recent research showed that boiling significantly influenced antioxidant capacity of vegetables, and the effects were not consistent in different foods (Wu et al., 2004a, 2004b). In our studies, oxygen radical absorbance capacity of regular boiled legumes were reduced by 58–77% in green pea, 53–58% in yellow pea, 56–69% in chickpea, and 54–62% in lentil (Table 3). The losses of oxygen radical absorbance capacity in chickpea exhibited an increasing tendency with the extension of cooking time, while the losses of oxygen radical absorbance capacity in

lentil exhibited a decreasing tendency. Oxygen radical absorbance capacities were increased by about 27–114% in green pea, 12–67% in yellow pea, 25–40% in chickpea as compared to respective raw legume after pressure boiling. However, oxygen radical absorbance capacities were decreased by about 11–16% in lentil after pressure boiling.

Oxygen radical absorbance capacity of regular steamed legumes was reduced by 2.7% in green pea, 8.9% in yellow pea, 7.3% in chickpea, and 1.4% in lentil (Table 3) by removing soaking and steaming water. After pressure steaming, oxygen radical absorbance capacities were increased by 69–175% in green pea, 99–153% in yellow pea, 84–122% in chickpea, and 5–13% in lentil as compared to respective original unprocessed legume. In addition, we found that the oxygen radical absorbance capacities were increased with the increase of pressure in both pressure boiling and pressure steaming treatments. TPC and DPPH were not parallel with ORAC in cases of pressure boiling and pressure steaming treatments. This phenomenon could be attributed to the increases or the formation (after high pressure heat treatments) of specific compounds, which could provide more hydrogen atom during oxidation–reduction reaction. ORAC utilizes different antioxidant reaction mechanism from DPPH: ORAC reactions involve hydrogen atom transfer mechanism, while DPPH involves single electron transfer mechanism. Different classes of compounds may have different contributions to TPC, DPPH and ORAC values, respectively. Positive heat effects

Table 4
Losses of total phenolic content and antioxidant activities caused by thermal processing

	Processing conditions	TPC loss %[a]		DPPH loss %		ORAC loss %	
		Loss in water[d]	Thermal degradation[e]	Loss in water	Thermal degradation	Loss in water	Thermal degradation
Boiled green pea[b]	RB, 90 min	43.9	3.4	21.5	32.5	36.9	30.1
	RB, 120 min	47.4	0.86	26.8	33.3	44.6	2.9
	RB, 150 min	47.4	0.86	30.3	32.5	58.9	12.1
	PB, 5 psi, 30 min	35.3	12.1	40.8	12.7	76.3	−134.4
	PB, 15 psi, 15 min	35.3	7.8	37.3	12.3	78.6	−244.7
Boiled yellow pea[b]	RB, 90 min	41.5	3.0	33.0	12.6	33.4	15.2
	RB, 120 min	45.9	−2.2	21.1	24.8	53.8	−12.8
	RB, 150 min	48.1	−4.4	33.9	15.1	65.3	−22.4
	PB, 5 psi, 30 min	36.3	8.9	33.6	17.9	92.5	−129.1
	PB, 15 psi, 15 min	34.1	8.1	37.4	10.4	77.6	−180.0
Boiled chickpea[b]	RB, 90 min	50	−18.6	5.7	81.4	39.7	14.3
	RB, 120 min	53.6	−19.3	11.0	78.3	50.2	15.9
	RB, 150 min	55.7	−20.0	14.4	81.6	59.6	8.2
	PB, 5 psi, 30 min	37.8	−7.9	11.8	75.7	52.1	−81.8
	PB, 15 psi, 15 min	34.3	−7.1	10.3	73	36.6	−82.6
Boiled Lentil[b]	RB, 30 min	18.8	32.4	15.4	−13.3	8.8	41.8
	RB, 45 min	12.7	32.2	7.4	−6.6	8.7	36.6
	RB, 60 min	12.7	33.3	7.2	−5.4	8.5	30.7
	PB, 5 psi, 5 min	24.4	40.2	17.5	6.2	28.2	−44.9
	PB, 15 psi, 5 min	17.9	46.5	15.7	4.3	29.9	−40.2
Steamed green pea[c]	RS, 70 min	3.4	6.0	0	44.0	0	−101.3
	PS, 5 psi, 70 min	2.6	21.6	0	60.7	0	−248.8
	PS, 15 psi, 60 min	6.0	5.2	0	42.7	0	−469.0
Steamed yellow pea[c]	RS, 70 min	9.6	−2.2	0	42.5	0	−90.9
	PS, 5 psi, 70 min	2.2	26.7	0	63.3	0	−317.0
	PS, 15 psi, 60 min	3.7	10.4	0	52.3	0	−430.9
Steamed chickpea[c]	RS, 70 min	9.3	−9.3	0	−4.2	0	−37.5
	PS, 5 psi, 70 min	2.8	2.1	0	13.1	0	−172.8
	PS, 15 psi, 60 min	5.7	−4.3	0	−2.1	0	−229.4
Steamed lentil[c]	RS, 15 min	1.4	46.1	0	5.8	0	−45.3
	PS, 5 psi, 15 min	1.4	50.3	0	16.4	0	−54.7
	PS, 15 psi, 15 min	1.4	55.3	0	19.3	0	−66.2

[a] Loss % was calculated using respective soaked legumes as starting materials.
[b] Peas were pre-soaked based on 100% hydration rate, lentil was pre-soaked based on 50% hydration rate prior to boiling treatments.
[c] All samples were pre-soaked based on 70% hydration rate prior to steaming treatments.
[d] The values lost to the cooking water.
[e] The values due to possible thermal degradation (the rest values when lost values subtracted the values lost into cooking water). RB, regular boiling; PB, pressure boiling; RS, regular steaming; PS, pressure steaming.

were found in pasteurization of tea extracts (Manzocco, Anese, & Nicoli, 1998), which caused an increase in antioxidant activity of teas.

Previous research on fruits and vegetables indicated that processing caused no changes in antioxidant potential or increased it due to improvement of antioxidant properties of naturally occurring compounds or formation of novel compounds such as Maillard reaction products, which have antioxidant activity (Manzocco, Calligaris, Masrrocola, Nicoli, & Lerici, 2001; Nicoli, Anese, & Parpinel, 1999). During the processing of CSFL's, it was observed that pressure boiling and pressure steaming yielded darker color products than regular cooking and steaming. These darker color products might be from the Maillard reactions and might have contributed partly to the increases of antioxidant capacity. In addition, thermal treatments also could break the glucosides of flavonoids to form alglycones which possess higher antioxidant properties.

The changes in the antioxidant properties of cooked CSFL's could be attributed to the two major factors, one

Table 5
Mass balance of cool season food legumes during processing

Legumes	Processing condition	Before processing (g)[a]	After processing (g)[a]	Solid loss (%)[a]
Green pea	Soaking, 70%	17.95 ± 0.06 a	17.55 ± 0.07 b	2.26 ± 0.11
	Soaking, 85%	17.89 ± 0.12 a	17.40 ± 0.13 b	2.72 ± 0.07
	Soaking, 100%	17.85 ± 0.10 a	17.81 ± 0.12 a	0.26 ± 0.12
	RB, 90 min	17.73 ± 0.04 a	15.53 ± 0.26 b	12.39 ± 1.44
	RB, 120 min	17.69 ± 0.04 a	15.45 ± 0.13 b	12.67 ± 0.56
	RB, 150 min	17.75 ± 0.02 a	15.45 ± 0.05 b	12.95 ± 0.26
	PB, 5 psi, 30 min	18.22 ± 0.04 a	16.28 ± 0.11 b	10.69 ± 0.53
	PB, 15 psi, 15 min	18.04 ± 0.08 a	15.94 ± 0.02 b	11.67 ± 0.31
	RS, 70 min	88.37 ± 0.09 a	82.34 ± 1.41 b	6.82 ± 1.55
	PS, 5 psi, 70 min	88.58 ± 0.05 a	85.21 ± 1.32 b	3.81 ± 1.51
	PS, 15 psi, 60 min	88.55 ± 0.12 a	83.90 ± 1.07 b	5.26 ± 1.10
Yellow pea	Soaking, 70%	17.68 ± 0.12 a	17.31 ± 0.10 b	2.09 ± 0.10
	Soaking, 85%	17.72 ± 0.07 a	17.29 ± 0.06 b	2.41 ± 0.25
	Soaking, 100%	17.63 ± 0.08 a	17.60 ± 0.08 a	0.16 ± 0.13
	RB, 90 min	17.48 ± 0.02 a	15.41 ± 0.06 b	11.85 ± 0.38
	RB, 120 min	17.49 ± 0.01 a	15.10 ± 0.09 b	13.65 ± 0.50
	RB, 150 min	17.53 ± 0.01 a	15.10 ± 0.09 b	13.83 ± 0.48
	PB, 5 psi, 30 min	17.83 ± 0.07 a	15.72 ± 0.22 b	11.80 ± 1.38
	PB, 15 psi, 15 min	17.77 ± 0.04 a	15.69 ± 0.07 b	11.72 ± 0.29
	RS, 70 min	87.17 ± 0.04 a	82.58 ± 2.39 b	5.28 ± 2.75
	PS, 5 psi, 70 min	87.42 ± 0.05 a	82.37 ± 0.43 b	5.78 ± 0.55
	PS, 15 psi, 60 min	87.56 ± 0.04 a	83.30 ± 1.83 b	4.86 ± 2.06
Chickpea	Soaking, 70%	18.48 ± 0.04 a	17.96 ± 0.05 b	2.80 ± 0.52
	Soaking, 85%	18.44 ± 0.05 a	18.14 ± 0.06 b	1.62 ± 0.24
	Soaking, 100%	18.54 ± 0.08 a	18.39 ± 0.04 b	0.81 ± 0.29
	RB, 90 min	18.32 ± 0.02 a	16.31 ± 0.06 b	10.95 ± 0.20
	RB, 120 min	18.38 ± 0.03 a	16.17 ± 0.22 b	12.02 ± 1.09
	RB, 150 min	18.35 ± 0.03 a	15.98 ± 0.09 b	12.95 ± 0.39
	PB, 5 psi, 30 min	18.63 ± 0.07 a	16.96 ± 0.10 b	8.93 ± 0.29
	PB, 15 psi, 15 min	18.66 ± 0.07 a	17.13 ± 0.04 b	8.19 ± 0.56
	RS, 70 min	91.54 ± 0.09 a	88.60 ± 2.13 a	3.22 ± 2.31
	PS, 5 psi, 70 min	91.85 ± 0.09 a	89.47 ± 0.95 a	2.59 ± 1.10
	PS, 15 psi, 60 min	91.86 ± 0.05 a	88.79 ± 0.77 b	3.34 ± 0.78
Lentil	Soaking, 50%	17.76 ± 0.02 a	17.68 ± 0.03 b	0.41 ± 0.09
	Soaking, 70%	17.89 ± 0.05 a	17.79 ± 0.04 a	0.54 ± 0.06
	Soaking, 85%	17.92 ± 0.07 a	17.80 ± 0.05 b	0.66 ± 0.23
	Soaking, 100%	17.88 ± 0.04 a	17.75 ± 0.06 b	0.75 ± 0.15
	RB, 30 min	17.76 ± 0.02 a	16.98 ± 0.09 b	4.39 ± 0.48
	RB, 45 min	17.77 ± 0.00 a	16.94 ± 0.12 b	4.67 ± 0.67
	RB, 60 min	17.79 ± 0.00 a	16.95 ± 0.16 b	4.71 ± 0.89
	PB, 5 psi, 5 min	18.21 ± 0.04 a	17.26 ± 0.01 b	5.21 ± 0.27
	PB, 15 psi, 5 min	18.10 ± 0.02 a	16.77 ± 0.13 b	7.32 ± 0.73
	RS, 15 min	88.72 ± 0.02 a	87.74 ± 1.31 a	1.10 ± 1.47
	PS, 5 psi, 15 min	88.76 ± 0.03 a	87.66 ± 0.76 a	1.24 ± 0.83
	PS, 15 psi, 15 min	88.76 ± 0.05 a	86.92 ± 0.66 b	2.07 ± 0.78

Values marked by the same letter in same row are not significantly different ($p < 0.05$), $n = 3$. RB, regular boiling; PB, pressure boiling; RS, regular steaming; PS, pressure steaming.

[a] Dry weigh basis.

is the leaching of phenolic compounds, which was lost into the cooking water; the other is the degradation or formation of new compounds (not limited to phenolic compounds). The losses of total phenolics, DPPH free radical scavenging capacities, and oxygen radical absorbance capacities of cooked CSFL's were summarized in Table 4, in which the loss % was calculated using soaked legumes as starting materials, and the losses were differentiated into two aspects: the losses to the cooking water, the losses due to possible degradation.

3.7. Mass balance analysis

Mass balance analyses on processing treatments of CSFL's are shown in Table 5. Significant differences ($p < 0.05$) in solid weight existed between before and after processing in most processing treatments of CSFL's except 100% hydration soaking treatments of green, yellow pea and lentil and regular steaming treatments of chickpea and lentil. The 100% hydration soaking treatment caused minimum solid loss as compared to other soaking treatments in the cases of green pea (0.26%), yellow pea (0.16%), chickpea (0.81%), while caused maximum solid loss in the case of lentil (0.75%). These phenomena could be attributed to the different types of the seed structures and different water-soluble composition content (such as phenolics, fiber and starch, etc.). Water-soluble compositions reached a kinetic equilibration in soaking water and seeds after 100% hydration. For the case of peas and chickpeas, more leached water-soluble compositions were absorbed back into seeds, while more leached water-soluble compositions lingered in soaking water for the case of lentils. Boiling caused more dry solid loss than steaming in all styles of CSFL's. Solid losses exhibited an increasing tendency with the extension of the cooking time in all CSFL's. Regular boiling treatments caused 11–14% of solid losses, pressure boiling treatments caused 8.2–11.8% of solid losses for green pea, yellow pea, and chickpea, while caused 4.4–7.4% of solid losses for lentil. Steaming caused 4–7% of solid losses for the cases of green pea, yellow pea, and chickpea, while caused 1–2% of solid losses for the cases of lentil. The significant solid losses by soaking, boiling and steaming CSFL's could be attributed to the diffusion of water-soluble components, into soaking, cooking, and steaming water.

4. Conclusion

In summary, soaking, boiling, steaming processes significantly affected the total phenolic contents and antioxidant activities in all CSFL's. The changes depended on the type of legume and processing conditions. These changes affected the antioxidant properties of the CSFL's. From our results, boiled or steamed CSFL's still contained substantial amounts of antioxidants. However, steaming processes caused smaller losses in TPC, antioxidant activities and solid mass than the boiling processes. Therefore, steaming is recommended for CSFL's preparation in domestic and industrial processes, not only for preserving of antioxidant components, but also for decreasing cooking time. The changes in the overall antioxidant properties of processed CSFL's could be attributed to the synergistic combinations or counteracting of several types of factors, including oxidative reaction, leaching of water-soluble antioxidant compositions, formation or breakdown of antioxidant compositions, and solid losses during processing.

Acknowledgements

This work was supported by a Grant (No. FAR100773) from USDA-CSREES Cool Season Legumes Programs administered through the University of Idaho. The authors thank Mrs. Marsha Kapphahn for her assistance on freeze-drying of processed samples. We also thank Eric Bartch of North Dakota Pea & Lentil Association, and mentioned companies in providing legume samples for this study.

References

Adebamowo, C. A., Cho, E. Y., Sampson, L., Katan, M. B., Spiegelman, D., Willett, W. C., et al. (2005). Dietary flavonols and flavonol-rich foods intake and the risk of breast cancer. *International Journal of Cancer, 114*, 628–633.

Amarowicz, R., Karamac, M., & Shahidi, F. (2003). Antioxidant activity of phenolic fractions of lentils (*Lens culinaris*). *Journal of Food Lipids, 10*, 1–10.

Association of Official Analytical Chemists. (2000). AOAC method no. 925.10 (Air Oven Method) for moisture in flour. In *Official methods of analysis* (17th ed.). Gaithersburg, MD.

Barroga, F. C., Laurena, A. C., & Mendoza, E. M. T. (1985). Polyphenols in Mung bean (*Vigna radiata* (L.) Wilczek): Determination and removal. *Journal of Agriculture and Food Chemistry, 33*, 1006–1009.

Bhathena, S. J., & Velasquez, M. T. (2002). Beneficial role of dietary phytoestrogens in obesity and diabetes. *American Journal of Clinical Nutrition, 76*, 1191–1201.

Bressani, A., & Elias, L. G. (1980). The nutritional role of polyphenols in beans. In J. H. Hulse (Ed.), *Polyphenols in cereal and legumes* (pp. 61–68). Ottawa, Canada: International Development Research Center.

Chau, C. F., Cheung, P. C., & Wong, Y. S. (1997). Effect of cooking on content of amino acids and antinutrients in three Chinese indigenous legume seeds. *Journal of the Science of Food and Agriculture, 75*, 447–452.

Chen, C. W., & Ho, C. T. (1995). Antioxidant properties of polyphenols extracted from green and black teas. *Journal of Food Lipids, 2*, 35–46.

Franke, A. A., Custer, L. J., Cerna, C. M., & Narala, K. K. (1994). Quantitation of phytoestrogens in legumes by HPLC. *Journal of Agriculture and Food Chemistry, 42*, 1905–1913.

Ismail, A., Marjan, Z. M., & Foong, C. W. (2004). Total antioxidant activity and phenolic content in selected vegetables. *Food Chemistry, 87*, 581–586.

Knorr, D. (1999). Process assessment of high-pressure processing of foods: An overview. In F. A. R. Oliveira & J. C. Oliveira (Eds.), *Processing foods. Quality optimization and process assessment* (pp. 249–267). Boca Raton, FL: CRC Press.

Kris-Etherton, P. M., Hecker, K. D., Bonanome, A., Coval, S. M., Binkoski, A. E., & Hilpert, K. F. (2002). Bioactive compounds in foods: their role in the prevention of cardiovascular disease and cancer. *The American Journal of Medicine, 113*(Suppl. 9B), 71S–88S.

Kushi, L. H., Meyer, K. A., & Jacobs, D. R. Jr., (1999). Cereal, legumes, and chronic disease risk reduction: Evidence from epidemiologic studies. *American Journal of Clinical Nutrition, 70*(Suppl.), 451S–458S.

López-Amorós, M. L., Hernández, T., & Estrella, I. (2006). Effect of germination on legume phenolic compounds and their antioxidant activity. *Journal of Food Composition and Analysis, 19*, 277–283.

Manzocco, L., Anese, M., & Nicoli, M. (1998). Antioxidant properties of tea extracts as affected by processing. *LWT-Food Science and Technology, 31*, 694–698.

Manzocco, L., Calligaris, S., Masrrocola, D., Nicoli, M., & Lerici, C. R. (2001). Review of non-enzymatic browning and antioxidant capacity in processed foods. *Trends in Food Science & Technology, 11*, 340–346.

Mattson, S. (1946). The cookability of yellow peas. A colloid-chemical and biochemical study. *Acta Agronomica Suecana, 2*, 185–231.

Moscoso, W., Bourne, M. C., & Hood, L. F. (1984). Relationship between the hard-to-cook phenomenon in red kidney beans and water absorption, puncture force, pectin, phytic acid, and minerals. *Journal of Food Science, 49*, 1577–1583.

Nicoli, M. C., Anese, M., & Parpinel, M. (1999). Influence of processing on the antioxidant properties of fruits and vegetables. *Trends in Food Science & Technology, 10*, 94–100.

Prior, R. L., Hoang, H., Gu, L. W., Wu, X. L., Bacchiocca, M., Howard, L., et al. (2003). Assay for hydrophilic and lipophilic antioxidant capacity (oxygen radical absorbance capacity ($ORAC_{FL}$)) of plasma and other biological and food samples. *Journal of Agriculture and Food Chemistry, 51*, 3273–3279.

Prior, R. L., Wu, X. L., & Schaich, K. (2005). Standardized methods for the determination of antioxidant capacity and phenolics in food and dietary supplements. *Journal of Agriculture and Food Chemistry, 53*, 4290–4302.

Rocha-Guzmán, N. E., González-Laredo, R. F., Ibarra-Pérez, F. J., Nava-Berúmen, C. A., & Gallegos-Infante, J. A. (2007). Effect of pressure cooking on the antioxidant activity of extracts from three common bean (*Phaseolus vulgaris* L.) cultivars. *Food Chemistry, 100*, 31–35.

Singleton, V. L., & Rossi, J. A. (1965). Colorimetry of total phenolic with phosphomolybdic–phosphotungstic acid reagents. *American Journal of Enology and Viticulture, 16*, 144–158.

Su, H. L., & Chang, K. C. (1995). Dehydrated precooked pinto bean quality as affected by cultivar and coating biopolymers. *Journal of Food Science, 60*, 1330–1332.

Turkmen, N., Sari, F., & Velioglu, S. (2005). The effect of cooking methods on total phenolics and antioxidant activity of selected green vegetables. *Food Chemistry, 93*, 713–718.

Vindiola, O. L., Seib, P. A., & Hoseney, R. C. (1986). Accelerated development of the hard-to-cook state in beans. *Cereal Foods World, 31*, 538–552.

Wang, C. R., Chang, K. C., & Grafton, K. (1988). Canning quality evaluation of pinto and navy beans. *Journal of Food Science, 53*, 772–776.

Wang, N., & Daun, J. K. (2005). Determination of cooking time of pulses using an automated Mattson cooker apparatus. *Journal of the Science of Food and Agriculture, 85*, 1631–1635.

Wu, X. L., Beecher, G. R., Holden, J. M., Haytowitz, D. B., Gebhardt, S. E., & Prior, R. L. (2004a). Lipophilic and hydrophilic antioxidant capacities of common foods in the United States. *Journal of Agriculture and Food Chemistry, 52*, 4026–4037.

Wu, X. L., Gu, L. W., Holden, J., Haytowitz, D. B., Gebhardt, S. E., Beecher, G., et al. (2004b). Development of a database for total antioxidant capacity in foods: A preliminary study. *Journal of Food Composition and Analysis, 17*, 407–422.

Xu, B. J., & Chang, S. K. C. (2007). A comparative study on phenolic profiles and antioxidant activities of legumes as affected by extraction solvents. *Journal of Food Science, 72*, S159–S166.

Xu, B. J., Yuan, S. H., & Chang, S. K. C. (2007). Comparative analyses of phenolic composition, antioxidant capacity, and color of cool season legumes and other selected food legumes. *Journal of Food Science, 72*, S167–S177.