TITLE:

Review on utilization and composition of coffee silverskin

AUTHORS:

Yusaku Narita[‡] and Kuniyo Inouye[*, †]

AFFILIATION AND ADDRESS:

[†]Division of Food Science and Biotechnology, Graduate School of Agriculture, Kyoto University, Sakyo-ku, Kyoto 606-8502, Japan [‡]R&D Center, UCC Ueshima Coffee Co., Ltd., 3-1-4 Zushi, Takatsuki-shi, Osaka 569-0036, Japan

AUTHOR EMAIL ADDRESS:

inouye@kais.kais.kyoto-u.ac.jp

yuusaku-narita@ucc.co.jp

CORRESPONDING AUTHOR FOOTNOTE:

*To whom correspondence should be addressed. Tel: +81-75-753-6266, Fax: +81-75-753-6265, Email: inouye@kais.kyoto-u.ac.jp

Abstract

Coffee is one of the most frequently consumed drinks in the world. Coffee silverskin (CS) is the only by-product produced during the coffee beans roasting process, and large amounts of CS are produced by roasters in coffee-consuming countries. However, methods for the effective utilization of CS have not been developed. Reuse of CS, which is the primary residue from the coffee industry, is important for the environment and economy. Recently, there have been some attempts to reuse CS for biological materials and as a nutrient source for solid-state fermentation. The purpose of this review is to provide an overview about CS, its chemical composition, biological activity, and attempts at its reuse.

Keywords: Coffee; Coffee silverskin; By-product; Composition; Review.

List of abbreviations

CS	Coffee silverskin
CGAs	Chlorogenic acids
5-CQA	5-Caffeoylquinic acid
5-HMF	5-(Hydroxymethyl)-2-furfural

1. Introduction

1.1. Coffee

Coffee is one of the most frequently consumed drinks in the world. Approximately 7 million tons of green coffee beans were produced globally in 2010 (Food and Agricultural Organization). With the increase in the number of coffee consumers in both importing and exporting countries, annual coffee production has increased. Coffee is grown primarily in the area between the 25°N latitude and the 25°S latitude, known as "the coffee belt". More than 60 countries produce green coffee beans (Lashermes, Andrade, & Etienne, 2008; Vieira, 2008). Brazil is the global leader in production of green coffee beans, followed by Vietnam, Indonesia, Colombia, and India (United States Department of Agriculture; Bacon, 2005).

Coffee plants belong to the botanical family Rubiaceae, which includes approximately 80 species. Two major coffee species are cultivated for drinking. *Coffea arabica*, known as arabica coffee, accounts for approximately 75% of global coffee production and *C. canephora*, known as robusta coffee, accounts for approximately 24% of global coffee production (van Boxtel, Berthouly, Carasco, Dufour, & Eskes, 1995; Casal, Oliveira, Alves, & Ferreira, 2000; Bertrand, Ramirez, Topart, & Anthony, 2002). Coffee beans are roasted using dry heat at temperatures between 200°C and 300°C with constant agitation to ensure even heating. During roasting, the color of green coffee beans shifts to yellow, then to a suntan-like light brown, and later to a dark, oily brown color. Some of the natural sugars in the beans are

transformed into CO_2 gas, and others are caramelized into the complex flavor essences that contribute to good taste and color. Chlorogenic acid lactones produced from chlorogenic acids (CGAs) by roasting green coffee beans has contributed to the bitter taste of brewed coffee (Farah, de Pulis, Trugo, & Martin, 2005; Farah, de Paulis, Moreira, Trugo, & Martin, 2006). In recent years, in addition to studies of taste and flavor, attention has been focused on the biological activities of coffee ingredient. In particular, it has been reported that CGAs have various bioactivities, such as antioxidant activity (Iwai, Kishimoto, Kakino, Mochida, & Fujita, 2004), α-amylase inhibition (Narita & Inouye, 2009, 2011), lipase inhibition (Narita, Iwai, Fukunaga, & Nakagiri, 2012), antihyperglycemic effects (Iwai et al. 2012), and other activities.

1.2. Coffee silverskin

Figure 1 shows the structure of the fruit (coffee cherry) of the coffee tree (Saenger, Hartge, Werther, Ogada, & Siagi, 2001). The coffee cherry is oval and approximately 10 mm in size. Green coffee beans exist inward in the coffee cherry and are covered by a thin seed skin known as coffee silverskin (CS), an endocarp called the parchment, a pectic adhesive layer, pulp, and epicarp (outer skin) in the order (Saenger, Hartge, Werther, Ogada, & Siagi, 2001). Green coffee beans are generally produced via two processes, purification and thresh process (Casal et al., 2004; Bytof, Knopp, Schieberle, Teutsch, & Selmar, 2005; Knopp, Bytof, & Selmer, 2006; Bytof et al., 2007). For the purification process, two methods generally are used. One is the

“washed” or “wet” method and the other is “unwashed”, “natural” or “dry” method. In general, more CS is obtained from green coffee beans purified by the dry method than from those purified by the wet method. The outer skin, pulp, pectic adhesive layer, and parchment are completely removed from the green coffee beans in these two processes. However, a portion of CS remains with the green coffee beans after their treatment. The green coffee beans with attached CS are exported to consuming countries from producing countries, and the beans are roasted by suppliers in the consuming countries. Thus, CS is the only by-product produced in the roasting process, and large amounts of CS are produced by large-scale coffee roasters in consuming countries.

Many research groups are focusing on the utilization of coffee wastes that are by-products of the coffee brewing process as source of sugars, minerals and fibers; as alternative renewable energy sources (bio-diesel oil and bio-ethanol); and as electrode materials (Mussatto, Carneiro, Silva, Roberto, & Teixeira, 2011; Al-Hamamre, Foerster, Hartmann, Kroger, & Kaltschmitt, 2012; Kondamudi, Mohapatra, & Misra, 2008; Rufford, Hulicova-Jurcakova, Zhu, & Lu, 2008). Studies on the utilization of coffee waste have advanced worldwide (Mussatto, Machado, Martins & Teixeira, 2011; Esquivel & Jimenez, 2012; Murthy & Madhava Naidu, 2012), but methods for the effective utilization of CS have not been developed. Thus, most CS is disposed of as industrial waste. CS is the only by-product of the coffee bean roasting process, and CS can only be collected in large amounts from roasting factories. Therefore, CS is a resource that may be

136 easy to reuse, and it can be regarded as biomass that is expected
137 to be utilized in the future.
138
139
140 **2. Chemical composition of CS**
141
142 ***2.1.*** **Dietary fiber in CS**
143 CS ingredients and the amounts thus far reported are
144 summarized into Table 1. Dietary fiber is important for nutrition
145 and health and is used as a therapeutic material for physiological
146 problem such as diabetes and hyperlipidemia (Saura-Calixto,
147 Garcia-Alonso, Goni, & Bravo, 2000). It is thought that dietary
148 fiber will help in preventing cardiovascular disorders by
149 arteriosclerosis or the serious complications of diabetes, because
150 this controls the absorption of cholesterol and fat into the body
151 by adsorbing them. CS has a high dietary fiber (50−60%), which
152 includes 15% soluble dietary fiber and 85% insoluble dietary
153 fiber (Borrelli, Esposito, Napolitano, Ritieni, & Fogliano, 2004;
154 Napolitano et al., 2006; Pourfarzad, Mahdavian-Mehr, &
155 Sedaghat, 2013; Napolitano, Fogliano, Tafuri, & Ritieni, 2007).
156 Napolitano et al. (2007) investigated CS dietary fiber obtained
157 from four types of *C. arabic*a samples from Ethiopia, Santos,
158 India, and Costa Rica, and three types of *C. canephora* samples
159 from Ivory Coast, Vietnam, and Cameroon. They reported that
160 there were no significant differences in the dietary fiber and
161 soluble dietary fiber contents between all samples tested. The
162 dietary fiber content of CS is higher than that of dietary plant
163 foods such as apple (28.43%), Broccoli (28.94%), cabbage

(22.41%), carrot (28.4%), wheat bran (41.97%), oat bran (28.60%), and potato (2.85%) (Southgate, 1978; Anderson & Bridges, 1988; Chen, Rubenthaler, Leung, & Baranowski, 1988). It has been reported that insoluble dietary fiber shortens intestinal transit, thereby allowing less time for carbohydrates to be absorbed (Montonen, Knekt, Jarvinen, Aromaa, & Reunanen, 2003). Insoluble dietary fiber is considered effective for prevention and remedial treatment of diabetes by controlling the carbohydrate absorption time (Hayashi et al., 2010; van de Laar et al., 2005). Therefore, CS consumption may be effective for the prevention and treatment of diabetes. However, this is the possibility suggested from the results obtained from an in vitro experiment, and in vivo experiment is necessary in order to confirm the presence or absence of the effects. Before that, it is necessary to confirm that there is no toxicity from intake of CS for humans. Recently, *Lang et al.* reported that 2-*O*-β-D-glucopyranosyl-carboxyatractyligenin, which is a kind of aminoglycoside and inhibits ATP-production in isolated mitochondria by blockage of adenine nucleotide translocase, was found in raw coffee bean (Lang, Fromme, Beusch, Wahi, Klingenspor, & Hofmann, 2013).

In general, plant dietary fiber consists of hemicelluloses, cellulose, lignin, oligosaccharides, polysaccharides, pectins, gums, and waxes (Lecumberri et al., 2007; Harris & Smith, 2006; Rodriguez, Jimenez, Bolanos, Guillen, & Heredia, 2006). It is reported that 34.6–80.5% of carbohydrates are included in CS (Borrelli et al., 2004; Napolitano et al., 2006; Pourfarzad et al., 2013; Napolitano et al., 2007). CS contains approximately 30%

lignin, and the polysaccharides in CS are 17.8% glucan, 4.7% xylan, 2% arabinan, 3.8% galactan, and 2.6% mannan (Mussatto, Machado, Carneiro, & Teixeira, 2012). It is suggested that CS has little monosaccharide contents because the contents of reducing sugars was low (Borrelli et al., 2004; Napolitano et al., 2006).

2.2. Protein, fat, and ash in CS

CS contains protein, fat, and ash, at 16.2–19.0%, 1.56–3.28%, and 7%, respectively (Borrelli et al., 2004; Napolitano et al., 2006; Pourfarzad et al., 2013; Napolitano et al., 2007). The total mineral contents of green coffee beans are approximately 4% (w/w dry matter) (Grembecka, Malinowska, & Szefer, 2007; Clarke & Walker, 1974). It is reported that mineral contents of roasted coffee beans are 4–5% (Franca, Oliveira, Mendonca, & Silva, 2005; Tawfik & El Bader, 2005; Oliveira, Franca, Mendonca, & Barros-Junior, 2006). The main component of mineral in green coffee beans is potassium, and its contents are approximately 40% of the amounts of total mineral (Clarke & Walker, 1974). The compositions of minerals CS have not been clarified so far. De Assuncao et al. (2012) reported that the contents of calcium are higher than potassium in coffee husk. CS has approximately 0.81–1.37% caffeine (Napolitano et al., 2007). Coffee beans contain 1–3% (w/w dry matter) caffeine (Alonso-Salces, Serra, Reniero, & Heberger, 2009; Belay, 2011; Ky et al., 2001). Thus, the caffeine contents of CS are lower than that of coffee beans. Napolitano et al. (2007) investigated seven types of CS from different growing areas and species that differ

in their protein, fat, carbohydrate, reducing sugar, caffeine, total dietary fiber, insoluble dietary fiber, and soluble dietary fiber contents. They showed that there were no significant correlations between geographic variety and growth conditions in which CS was produced and the chemical composition of CS.

2.3. Summary of chapter 2

This brief overview describes the CS constituents, and in particular, those that may promote health. There is a possibility that it can be used as a source of dietary fiber and minerals as CS has high contents of these. CS is the major by-product of the roasting process, and easily peels off from roasted coffee beans in the roasting process of green coffee beans. Therefore, it is considered that the amounts of CS ingredients vary with the degree of roasting, because the ingredient contents of roasted coffee beans varies with the degree of roasting (Farah, et al., 2005; Somporn, Kamtuo, Theerakulpisut, & Siriamornpun, 2011). We expect to learn more in the future about CS constituents, such as flavor, pigments, and organic acids, and the variety of CS ingredient that differ according to the degree of roasting and the species of green coffee beans.

In the case of using CS to liquid processed products such as beverages and detergents, CS water extracts are more convenient than CS of solid matter. For example, CS has high amounts of dietary fiber of about 50–60 g/100 g (Table 1). However, when the amounts of soluble and insoluble fractions of the dietary fiber in CS are compared, the former is about 1/10 of the latter (Table 1). Then, we summarized CS water extracts in next

248 subject.

249

250 **3. CS water extracts**

251

252 ***3.1.*** **Yields of soluble solid from CS**

253 It has been reported that yields of soluble solid obtained from
254 CS by water extraction change with the extraction temperature
255 (Furusawa, Narita, Iwai, Fukunaga, & Nakagiri, 2011; Narita &
256 Inouye, 2012). The yields with extraction at 25^{o}C and 80^{o}C were
257 16% (w/w dry matter) and 19% (w/w dry matter), respectively
258 (Furusawa et al., 2011; Narita & Inouye, 2012). Furusawa et al.
259 (2011) reported that the amounts of total sugars in CS water
260 extracts were 29.5% (w/w dry matter) and that the extracts
261 contained acidic polysaccharides. It has been suggested that
262 these polysaccharides are pectic substances because they have a
263 high uronic acid content (Furusawa et al. 2011).

264 Water maintained in the liquid state with pressure at
265 temperatures ranging between 100^{o}C and 374^{o}C is called
266 subcritical water. The specific inductive capacity or dielectric
267 constant of water decreases remarkably with increasing
268 temperature (Miller & Hawthorne, 1998). Moreover, subcritical
269 water functions as an acid or alkali catalyst because the ionic
270 product of subcritical water is higher than water under normal
271 temperature and pressure conditions. Recently, Subcritical water
272 has been used extensively for research on extracting ingredients
273 from food waste such as okara (Wakita et al., 2004), wheat bran
274 (Kataoka, Wiboonsirikul, Kimura, & Adachi, 2008), and defatted
275 rice bran (Wiboonsirikul et al., 2007). The yields of CS extracts

from water treatment increased with extraction temperature from 25°C to 210°C and decreased in a temperature-dependent manner in the temperature range of 210–270°C (Table 2). The highest yields (29%, w/w dry matter) of CS extracts by water treatment were obtained at an extraction temperature of 210°C and were 1.8-fold higher than that obtained at 25°C (Narita & Inouye, 2012). We summarized in Table 2 about the chemical composition such as proteins, carbohydrates, caffeine, and total phenolics of the CS water extracts. Table 2 shows that their chemical composition of CS water extracts changes by difference of extraction temperature.

3.2. Yields of proteins, carbohydrates, caffeine, and total phenolics from CS

We converted the yields of proteins, carbohydrates, caffeine, and total phenolics obtained from CS of solid by water extraction using the amounts of each component of CS water extracts and the yields of soluble solids (Table 3). The amounts of protein extracted from CS by the water treatment at 25–80°C are about 20% of the protein contents in the CS of solid from values in Tables 1 and 3. It is roughly estimated that the proteins nearly 80% was insoluble from this result. The amounts of protein of approximately 80% in CS of solid were extracted by subcritical water treatment at 240°C. These results indicate that part of the insoluble proteins in CS of solid was hydrolyzed and solubilized. The soluble proteins produced by subcritical water treatment from CS may be used as nutrients or food additives in food, drinks and supplements for human. However, composition of the

304 proteins extracted from CS by subcritical water treatment has not
305 been reported until now. As undermentioned, it has been reported
306 that CS water extracts have antioxidant activities (Narita &
307 Inouye, 2012). It is reported that proteins produced by
308 subcritical water treatment from deoiled rice bran, which is an
309 agro-industrial residue of the rice milling process, showed high
310 antioxidant activity and were proven to be useful for application
311 as a culture medium for yeast growth (Sereewatthanawut,
312 Prapintip, Watchiraruji, Goto, Sasaki, & Shotipruk, 2008). It is
313 reported that the peptides produced by the decomposition of
314 soybean protein and wheat gluten have high antioxidant activity
315 (Park, Morimae, Matsumura, Nakamura, & Sato, 2008). Proteins
316 or peptides produced by subcritical water treatment from CS
317 might have antioxidant activity. The yields of caffeine from CS
318 were almost constant at 0.4% (w/w dry matter) at extraction
319 temperatures in the range of 25–270^{o}C (Narita & Inouye, 2012).
320 Total phenolic contents of the CS extracts obtained by water
321 treatment increased with increasing extraction temperature from
322 25^{o}C to 240^{o}C (Narita & Inouye, 2012). Subcritical water
323 treatment was effective for the extraction of phenolic
324 components (Narita & Inouye, 2012). 5-Caffeoylquinic acid
325 (5-CQA) was extracted at 0.1–0.2% (w/w dry matter) from CS in
326 the temperature range of 25–180^{o}C, but It was not extracted in
327 the temperature range of 210–270^{o}C (Narita & Inouye, 2012). It
328 was considered that 5-CQA in CS was not detected with heat
329 treatment because it was reported that 5-CQA decreased with
330 increasing temperature (de Maria, Trugo, de Mariz e Miranda, &
331 Salvador, 1998) and under alkaline conditions (Narita & Inouye,

2013). Bresciani et al. reported that CS extract, which is prepared using acidified water (1% aqueous formic acid) at 70°C for 1 h, are included 3-CQA, 4-CQA, 5-CQA, 4-feruloylquinic acid (4-FQA), 5-FQA, 3-coumaroylquinic acid (3-CoA), and 5-CoA (Bresciani, Calani, Bruni, Brighenti, & Del Rio, 2013). The content of 3-CQA, 4-CQA, 5-CQA, total of 4-FQA and 5-FQA, 3-CoA, and 5-CoA are 147.8 mg/100 g, 84.9 mg/100 g, 198.9 mg/100 g, 121.6 mg/100 g, 2.4 mg/100 g, and 5.7 mg/100 g, respectively (Bresciani, et al., 2013).

The amounts of 5-(hydroxymethyl)-2-furfural (5-HMF) extracted from CS were increased with subcritical water treatment (Narita & Inouye, 2012). 5-HMF is considered a main degradation product formed by dehydration of hexoses through hydrothermolysis (Khajavi, Kimura, Oomori, Matsuno, & Adachi, 2005; Usuki, Kimura, & Adachi, 2008).

3.3. Summary of chapter 3

This brief overview of CS extracts sheds light on the extraction of active ingredients from CS. In particular, it is considered that subcritical water treatment is effective for the extraction of active ingredients such as proteins and phenolic components. The extraction of active ingredients from CS using subcritical water without organic solvents and other catalysts is expected to be environment friendly. We expect more investigational advances in the future on the composition of CS and effective methods for extraction of active ingredients from CS.

About utilization of CS, two usages are suggested. One is the

use as bioactive substance, and another is solid-state fermentation using CS. We summarized it in a following subject about the study on these usages.

4. Bioactivity of CS

4.1. Antioxidant effect of CS

Antioxidants exert important effects for human health by reducing oxidative stress because the stress is a factor in the development of various diseases such as cancer (Lambert & Yang, 2003), cardiovascular disease (Diaz, Frei, Vita, & Keaney, 1997), type 2 diabetes (Takayanagi, Inoguchi, & Ohnaka, 2011), alzheimer's disease (Christen, 2000), and Parkinson's disease (Lang & Lozano, 1998). Borrelli et al. (2004) reported that CS methanol extracts have an antioxidant activity evaluated with ABTS [(2,2'-azobis(3-ethylbenzothiazoline-6-sulfonic acid)) radical scavenging ability similar to that of wheat bran, which is known to have very high antioxidant activity (Andlauer & Furst, 1998). It was reported that CS extracts obtained by water treatment at several temperatures also have antioxidant activity (Narita & Inouye, 2012). The antioxidant activity of CS water extracts were evaluated using H-ORAC assay and DPPH assay (Narita & Inouye, 2012). The H-ORAC and DPPH values of CS extracts obtained after water treatment at 25–270^{o}C increased remarkably with increasing extraction temperatures (Table 2). The highest H-ORAC and DPPH values of CS extracts were observed at 270^{o}C, and were 379 μmol TE/g of CS extract and 2629 μmol TE/g of CS extract, respectively (Table 2). In regard

388 to the factors H-ORAC values of CS extracts has increased
389 remarkably with increasing extraction temperatures, Narita &
390 Inouye (2012) have mentioned two possibilities. One is the
391 possibility of the phenolic components that the CS water extracts
392 may contribute, another is the possibility that peptides produced
393 by hydrolysing the proteins in CS by subcritical water treatment
394 in the temperature range of 180–270°C have a high antioxidant
395 activity (Narita & Inouye, 2012). It is reported that the peptides
396 produced by the decomposition of soybean protein and wheat
397 gluten have high antioxidant activity (Park, Morimae, Matsumura,
398 Nakamura, & Sato, 2008). H-ORAC values of fruits such as
399 blueberry, plum, raspberry, apple, and orange, and vegetables
400 such as carrot, green pepper, and spinach are in the range of 5–70
401 μmol TE/g (Wu, Beecher, Holden, Haytowitz, Gebhardt, & Prior,
402 2004). Even the H-ORAC value (354 μmol TE/g of CS extracts)
403 of CS extracts by treatment water at 25°C showed that it was
404 higher than that of the above mentioned fruits and vegetables.
405 However, this is the possibility suggested from the results
406 obtained from an in vitro experiment, and in vivo experiment is
407 necessary in order to confirm the presence or absence of the
408 effects. A study to confirm an antioxidant effect of CS will be
409 necessary in vivo experiment in future. Furthermore,
410 Identification of ingredients contributing to the antioxidant
411 effect of CS is necessary in in vitro experiments.
412
413 ***4.2.*** **Prebiotic effect and inhibitory activity on hyaluronidase**
414 **by CS**
415 It has been reported that CS has prebiotic properties and

supports the growth of bifidobacteria (Borrelli et al., 2004). However, CS has also found proliferative activity of coliforms weaker than the increase effect of bifidobacteria (Borrelli et al., 2004). These results are evaluated after 24 h of fermentation. It seems that a detailed study on growth time and species of bacteria is more necessary. Hyaluronidase inhibitors appear to be effective in suppressing allergies and inflammations (Kakegawa, Matsumoto, & Satoh, 1992). Furusawa et al. (2011) reported that the inhibitory effects of CS extracts against hyalurodidase are similar to those of disodium cromoglycate, which is a potent antiallergen.

4.3. Summary of chapter 4

As noted above, Antioxidant, prebiotic substance, and hyaluronidase inhibitor are considered as a utilization method of the CS as a bioactive substance. In particular, there is a possibility that CS could be used as a good source of antioxidants. However, there are very few reports about the bioactivity of CS. Moreover, the contributions of CS ingredients to the physiological functions of CS have not been reported, and it appears that further future research is required.

5. Solid-state fermentation using CS

Solid-state fermentation is one of the effective methods for producing or extracting useful ingredients from food and agricultural waste products（Gombert, Pinto, Castilho, & Freire, 1999; Rodriguez Couto & Sanroman, 2005, 2006）. Food waste

used as biomass is easy to corrupt because microbe growth tends to increase in it. Therefore, food waste can change to materials with various functions by suitable fermentation processing for promoting propagation of microbes. Murthy, Naidu, and Srinivas (2009) reported that α-amylase production by *Neurospora crassa* CFR 308 with CS as a substrate is possible under solid-state fermentation conditions. Fructooligosaccharides (FOS) are produced commercially via enzymatic synthesis from sucrose by β-fructofuranosidase (EC.3.2.1.26) or fructosyltransferase (EC.2.4.1.9) from fungi such as *Aspergillus*, *Aureobasidum*, and *Penicillium* (Balasubramaniem, Nagarajan, & Paramasamy, 2001; Chien, Lee, & Lin, 2001; Mussatto & Teixeira, 2010). Mussatto and Teixeirra (2010) reported that high production of fructooligosaccharides by *A. japonicus* under solid-state fermentation was obtained when CS was used as a nutrient source. Machado, Rodriguez-Jasso, Teixeira, and Mussatto (2012) reported that seven fungal strains, including *A. ustus* PSS, *A. niger* AA20, *A. niger* GH1, *A. niger* PSH, *Mucor* Sp. 3P, *N. crassa* ATCC10337, and *Penicillium purpurogenum* GH2 could grow on CS under solid-state conditions. Moreover, *P. purpurogenum* GH2, *N. crassa* ATCC10337, *and Mucor* Sp. 3P were able to release phenolic compounds from CS (Machado, Rodriguez-Jasso, Teixeira, & Mussatto, 2012). CS is transformed into value-added products by fermentation under solid-state conditions using various fungi.

SSF is very useful as effective use of industrial waste and excels in environmental, economic, and safety aspect, because it requires only minimum quantity of water. Therefore, a seemingly

effective utilization method of CS is to use it as a substrate of SSF. FOS is producible by *A. japonicus* under SSF when CS was used as a nutrient source (Mussatto & Teixeira, 2010), and has been shown to beneficially modulate the composition of intestinal bacterial flora and notably to increase bifidobacteria and lactobacilli in vivo (Orrhage, Sjostedt, & Nord, 2000). As mentioned above, it has been reported that CS has prebiotic properties and supports the growth of bifidobacteria (Borrelli et al., 2004). However, the active ingredients in CS are not clear for both production of FOS by SSF with CS and *A. japonicus* and for prebiotic effects of CS. Identification of these active ingredients of CS is necessary in the future.

6. Conclusion

Coffee is one of the most frequently consumed drinks in the world. CS is the only by-product produced in the coffee bean roasting process, and large amounts of CS are produced by roasters in consuming countries. Therefore, establishment of effective use of CS is important. Two suggestions are shown for a direction of the utilization of CS. One is the use of CS as a bioactive substance or the source thereof. It is reported that CS has hyaluronidase inhibition, prebiotic properties, and antioxidant activity. Another is the use of CS as a substrate of SSF. It is necessary to identify the active substance in CS against the above-mentioned effects, bioactive activity in particular, in the future. Feasibility will be high if these effects are proved by subsequent experiments such as a large-scale experiment for

industrialization and a clinical trial in the future, because there are economic benefits in order that these uses help decrease the cost of disposal of CS.

In order to achieve high utilization of CS as biomass resources, active substances are collected gradually, and the construction of the systematized development system that can finally use it for feed, fertilizer, microbial fermentation materials for biorefinery, and recovery of the energy by combustion is important. In the future, further study on the components of CS and their functionality is not only required, but construction of databases that can share their information is also important.

7. References

Al-Hamamre, Z., Foerster, S., Hartmann, F., Kroger, M., & Kaltschmitt, M. (2012). Oil extracted from spent coffee grounds as a renewable source for fatty acid methyl ester manufacturing. *Fuel, 96,* 70–76.

Alonso-Salces, R. M., Serra, F., Reniero, F., & Heberger, K. (2009). Botanical and geographical characterization of green coffee (*Coffea arabica* and *Coffea canephora*): chemometric evaluation of phenolic and methylxanthine contents. *Journal of Agricultural and Food Chemistry, 57,* 4224–4235.

Anderson, J. W., & Bridges, S. R. (1988). Dietary fiber content of selected foods. *The American Journal of Clinical Nutrition. 47,* 440–447.

Andlauer, W., & Furst, P. (1998). Antioxidative power of phytochemicals with special reference to cereals. *Cereal Food World, 43,* 356–360.

Bacon, C. (2005). Confronting the coffee crisis: can fair trade, organic, and specialty coffees reduce small-scale farmer vulnerability in Northern Nicaragua? *World Development, 33,* 497–511.

Balasubramaniem, A. K., Nagarajan, K. V., & Paramasamy, G. (2001). Optimization of media for β-fructofuranosidase production by *Aspergillus niger* in submerged and solid state fermentation. *Process Biochemistry, 36,* 1241–1247.

Belay, A. (2011). Some biochemical compounds in coffee beans and methods developed for their analysis. *International Journal of the Physical Sciences, 6,* 6373–6378.

539 Bertrand, B., Ramirez, G., Topart, P., & Anthony, F. (2002).
540 Resistance of cultivated coffee (*Coffea Arabica* and *C.*
541 *canephora*) trees to corky-root by *Meloidogyne arabicida* and
542 *Fusarium oxysporum*, under controlled and field conditions. *Crop*
543 *Protection, 21*, 713–719.
544 Borrelli, R. C., Esposito, F., Napolitano, A., Ritieni, A., &
545 Fogliano, V. (2004). Characterization of a new potential
546 functional ingredient: coffee silverskin. *Journal of Agricultural*
547 *and Food Chemistry, 52*, 1338–1343.
548 Bresciani, L., Calani, L., Bruni, R., Brighenti, F., & Del Rio, D.
549 (2013). Phenolic composition , caffeine content and antioxidant
550 capacity of coffee silverskin. *Food Research International*, in
551 press, DOI: 10.1016/j.foodres.2013.10.047.
552 Bytof, G., Knopp, S.-E., Schieberle, P., Teutsch, I., & Selmar, D.
553 (2005). Influence of processing on the generation of
554 γ-aminobutyric acid in green coffee beans. *European Food*
555 *Research and Technology, 220*, 245–250.
556 Bytof, G., Knopp, S.-E., Kramer, D., Breitenstein, B., Bergervoet,
557 J. H. W., Groot, S. P. C., & Selmar, D. (2007). Transient
558 occurrence of seed germination processes during coffee
559 post-harvest treatment. *Annals of Botany, 100*, 61–66.
560 Casal, S., Oliveira, M. B. P. P., Alves, M. R., & Ferreira, M. A.
561 (2000). Discriminate analysis of roasted coffee varieties for
562 trigonelline, nicotinic acid, and caffeine content. *Journal of*
563 *Agricultural and Food Chemistry*, *48*, 3420–3424.
564 Casal, S., Mendes, E., Alves, M. R., Alves, R. C., Beatriz, M.,
565 Oliveira, P. P., & Ferreira, M. A. (2004). Free and conjugated
566 biogenic amines in green and roasted coffee beans. *Journal of*

Agricultural and Food Chemistry, 52, 6188–6192.

Chien, C.-S., Lee, W.-C., & Lin, T.-J. (2001). Immobilization of *Aspergillus japonicus* by entrapping cells in gluten for production of fructooligosaccharides. *Enzyme and Microbial Technology, 29*, 252–257.

Chen, H., Rubenthaler, G. L., Leung, H. K., & Baranowski, J. D. (1988). Chemical, physical, and baking properties of apple fiber compared with wheat and oat bran. *Cereal Chemistry, 65*, 244–247.

Christen, Y. (2000). Oxidative stress and Alzheimer disease. *The American Journal of Clinical Nutrition, 71*, 621S–629S.

Clarke, R. J., & Walker, L. J. (1974). Potassium and other mineral contents of green, roasted and instant coffees. *Journal of the Science of Food Agriculture, 25*, 1389–1404.

de Assuncao, L. S., da Luz, J. M. R., da Silva, M. C. S., Viera, P. A. F., Bazzolli, D. M. S., Vanetti, M. C. D., & Kasuya, M. C. M. (2012). Enrichment of mushrooms: an interesting strategy for the acquisition of lithium. Food Chemistry, 134, 1123–1127.

de Maria, C. A.B., Trugo, L. C., de Mariz e Miranda, L. S., & Salvador, E. (1998). Stability of 5-caffeoylquinic acid under different conditions of heating. *Food Research International, 31*, 6–7.

Diaz, M. N., Frei, B., Vita, J. A., & Keaney, J. F. Jr. (1997). Antioxidants and atherosclerotic heart disease. *New England Journal of Medicine, 337*, 408–416.

Esquivel, P., & Jimenez, V. M. (2012). Functional properties of coffee and coffee by-products. *Food Research International, 46*, 488–495.

595 Farah, A., de Paulis, T., Trugo, L. C., & Martin, P. R. (2005).
596 Effect of roasting on the formation of chlorogenic acid lactones
597 in coffee. *Journal of Agricultural and Food Chemistry, 53*,
598 1505–1513.
599 Farah, A., de Paulis, T., Moreira, D. P., Trugo, L. C., & Martin, P.
600 R. (2006). Chlorogenic acids and lactones in regular and
601 water-decaffeinated arabica coffees. *Journal of Agricultural and*
602 *Food Chemistry, 54*, 374–381.
603 Food and Agricultural Organization. Food balance sheets
604 [http://www.fao.org/].
605 Franca, A. S., Oliveira, L. S., Mendonca, J. C. F., & Silva, X. A.
606 (2005). Physical and chemical attributes of defective crude and
607 roasted coffee beans. *Food Chemistry, 90*, 89–94.
608 Furusawa, M., Narita, Y., Iwai, K., Fukunaga, T., & Nakagiri, O.
609 (2011). Inhibitory effect of a hot water extract of coffee
610 “silverskin” on hyaluronidase. *Bioscience, Biotechnology, and*
611 *Biochemistry, 75*, 1205–1207.
612 Gombert, A. K., Pinto, A. L., Castilho, L. R., & Freire, D. M. G.
613 (1999). Lipase production by *Penicillium restrictium* in
614 solid-state fermentation using babassu oil cake as substrate.
615 *Process Biochemistry, 35*, 85–90.
616 Grembecka, M., Malinowska, E., & Szefer, P. (2007).
617 Differentiation of market coffee and its infusions in view of their
618 mineral composition. *Science of the Total Environment, 383*,
619 59–69.
620 Harris, P. J., & Smith, B. G. (2006). Plant cell walls and
621 cell-wall polysaccharides: structures, properties and uses in food
622 products. *International Journal of Food Science and Technology,*

623 *41*, 129–143.
624 Hayashi, N., Iida, T., Yamada, T., Okuma, K., Takehara, I.,
625 Yamamoto, T., Yamada, K., & Tokuda, M. (2010). Study on the
626 postprandial blood glucose suppression effect of D-psicose in
627 borderline diabetes and the safety of long-term ingestion by
628 normal human subjects. *Bioscience, Biotechnology, and*
629 *Biochemistry, 74*, 510–519.
630 Iwai, K., Kishimoto, N., Kakino, Y., Mochida, K., & Fujita, T.
631 (2004). In vitro antioxidative effects and tyrosinase inhibitory
632 activities of seven hydroxycinnamoyl derivatives in green coffee
633 beans. *Journal of Agricultural and Food Chemistry, 52,*
634 4893–4898.
635 Iwai, K., Narita, Y., Fukunaga, T., Nakagiri, O., Kamiya, T.,
636 Ikeguchi, M., & Kikuchi, Y. (2012). Study on the postprandial
637 glucose responses to a chlorogenic acid-rich extract of
638 decaffeinated green coffee beans in rats and healthy human
639 subjects. *Food Science and Technology Research, 18*, 849–860.
640 Kakegawa, H., Matsumoto, H., & Satoh, T. (1992). Inhibitory
641 effects of some natural products on the activation of
642 hyaluronidase and their antiallergic actions. *Chemical and*
643 *Pharmaceutical Bulletin, 40*, 1439–1442.
644 Kataoka, M., Wiboonsirikul, J., Kimura, Y., & Adachi, S. (2008).
645 Properties of extracts from wheat bran by subcritical water
646 treatment. *Food Science and Technology Research, 14*, 553–556.
647 Khajavi, S. H., Kimura, Y., Oomori, T., Matsuno, R., & Adachi, S.
648 (2005). Degradation kinetics of monosaccharides in subcritical
649 water. *Journal of Food Engineering, 68*, 309–313.
650 Knopp, S., Bytof, G., & Selmar, D. (2006). Influence of

processing on the content of sugars in green Arabica coffee beans. *European Food Research and Technology, 223*, 195–201.

Kondamudi, N., Mohapatra, S. K., & Misra, M. (2008). Spent coffee grounds as a versatile source of green energy. *Journal of Agricultural and Food Chemistry, 56*, 11757–11760.

Ky, C.-L., Louarn, J., Dussert, S., Guyot, B., Hamon, S., & Noirot, M. (2001). Caffeine, trigonelline, chlorogenic acids and sucrose diversity in wild *Coffea arabica* L. and *C. canephora* P. accessions. *Food Chemistry, 75*, 223–230.

Lambert, J. D., & Yang, C. S. (2003). Mechanisms of cancer prevention by tea constituents. *Journal of Nutrition, 133*, 3262S–3267S.

Lang, A. E., & Lozano, A.M. (1998). Parkinson's disease. First of two parts. *New England Journal of Medicine, 339*, 1044–1053.

Lang, R., Fromme, T., Beusch, A., Wahi, A., Klingenspor, M., & Hofmann, T. (2013). 2-*O*-β-D-Glucopyranosyl-carboxyatractyligenin from *Coffea* L. inhibits adenine nucleotide translocase in isolated mitochondria but is quantitatively degraded during coffee roasting. *Phytochemistry, 93*, 124–135.

Lashermes, P., Andrade, A. C., & Etienne, H. (2008). Genomics of coffee, one of the world's largest traded commodities. In P. H. Moore, & R. Ming (Eds.), Genomics of tropical crop plants (pp. 203–225). New York: Springer.

Lecumberri, E., Mateos, R., Izquierdo-Pulido, M., Ruperez, P., Goya, L., & Bravo, L. (2007). Dietary fibre composition, antioxidant capacity and physico-chemical properties of a fibre-rich product from cocoa (*Theobroma cacao* L.) *Food*

679 *Chemistry, 104*, 948–954.
680 Machado, E. M. S., Rodriguez-Jasso, R. M., Teixeira, J. A., &
681 Mussatto, S. I. (2012). Growth of fungal strains on coffee
682 industry residues with removal of polyphenolic compounds.
683 *Biochemical Engineering Journal, 60*, 87–90.
684 Miller, D. J. & Hawthorne, S. B. (1998). Method for determining
685 the solubilities of hydrophobic organics in subcritical water.
686 *Analytical Chemistry, 70*, 1618–1621.
687 Montonen, J., Knekt, P., Jarvinen, R., Aromaa, A., & Reunanen,
688 A. (2003). Whole-grain and fiber intake and the incidence of
689 type 2 diabetes. *The American Journal of Clinical Nutrition, 77*,
690 622–629.
691 Murthy, P. S., Naidu, M. M., & Srinivas, P. (2009). Production of
692 α-amylase under solid−state fermentation utilizing coffee waste.
693 *Journal of Chemical Technology and Biotechnology, 84*,
694 1246–1249.
695 Murthy, P. S., & Naidu, M. M. (2012). Sustainable management
696 of coffee industry by-products and value addition–a review.
697 *Resources, Conservation and Recycling, 66*, 45–58.
698 Mussatto, S. I. & Teixeira, J. A. (2010). Increase in the
699 fructooligosaccharides yield and productively by solid-state
700 fermentation with *Aspergillus japonicus* using agro-industrial
701 residues as support and nutrient source. *Biochemical*
702 *Engineering Journal, 53*, 154–157.
703 Mussatto, S. I., Carneiro, L. M., Silva, J. P. A., Roberto, I. C., &
704 Teixeira, J. A. (2011). A study on chemical constituents and
705 sugars extraction from spent coffee grounds. *Carbohydrate*
706 *Polymers, 83*, 368–374.

Mussatto, S. I., Machado, E. M. S., Martins, S., & Teixeira, J. A. (2011). Production, composition, and application of coffee and its industrial residues. *Food Bioprocess Technology, 4*, 661–672.

Mussatto, S. I., Machado, E. M. S., Carneiro, L. M., & Teixeira, J. A. (2012). Sugars metabolism and ethanol production by different yeast strains from coffee industry wastes hydrolysates. *Applied Energy, 92*, 763–768.

Napolitano, A., Lanzuise, S., Ruocco, M., Arlotti, G., Ranieri, R., Knutsen, S. H., Lorito, M., & Fogliano, V. (2006). Treatment of cereal products with a tailored preparation of *Trichoderma* enzymes increases the amount of soluble dietary fiber. *Journal of Agricultural and Food Chemistry, 54*, 7863–7869.

Napolitano, A., Fogliano, V., Tafuri, A., & Ritieni, A. (2007). Natural occurrence of ochratoxin A and antioxidant activities of green and roasted coffees and corresponding byproducts. *Journal of Agricultural and Food Chemistry, 55*, 10499–10504.

Narita, Y., & Inouye, K. (2009). Kinetic analysis and mechanism on the inhibition of chlorogenic acid and its components against porcine pancreas α-amylase isozymes I and II. *Journal of Agricultural and Food Chemistry, 57*, 9218–9225.

Narita, Y., & Inouye, K. (2011). Inhibitory effects of chlorogenic acids from green coffee beans and cinnamate derivatives on the activity of porcine pancreas α-amylase isozyme I. *Food Chemistry, 127*, 1532–1539.

Narita, Y., & Inouye, K. (2012). High antioxidant activity of coffee silverskin extracts obtained by the treatment of coffee silverskin with subcritical water. *Food Chemistry, 135*, 943–949.

Narita, Y., Iwai, K., Fukunaga, T., & Nakagiri, O. (2012).

735 Inhibitory activity of chlorogenic acids in decaffeinated green
736 coffee beans against porcine pancreas lipase and effect of a
737 decaffeinated green coffee bean extract on an emulsion of olive
738 oil. *Bioscience, Biotechnology, and Biochemistry, 76*,
739 2329–2331.
740 Narita, Y., & Inouye, K. (2013). Degradation kinetics of
741 chlorogenic acid at various pH values and effects of ascorbic
742 acid and epigallocatechin gallate on its stability under alkaline
743 conditions. *Journal of Agricultural and Food Chemistry, 61*,
744 966–972.
745 Oliveira, L. S., Franca, A. S., Mendonca, J. C. F., &
746 Barros-Junior, M. C. (2006). Proximate composition and fatty
747 acids profile of green and roasted defective coffee beans.
748 *LWT-Food Science and Technology, 39*, 235–239.
749 Orrhage, K., Sjostedt, S., & Nord, C. E. (2000). Effect of
750 supplements with lactic acid bacteria and oligofructose on the
751 intestinal microflora during administration of cefpodoxime
752 proxetil. *Journal of Antimicrobial Chemotherapy, 46*, 603–611.
753 Park, E. Y., Morimae, M., Matsumura, Y., Nakamura, Y., & Sato,
754 K. (2008). Antioxidant activity of some protein hydrolysates and
755 their fractions with different isoelectric points. *Journal of*
756 *Agricultural and Food Chemistry, 56*, 9246–9251.
757 Pourfarzad, A., Mahdavian-Mehr, H., & Sedaghat, N. (2013).
758 Coffee silverskin as a source of dietary fiber in bread-making:
759 optimization of chemical treatment using response surface
760 methodology. *LWT-Food Science and Technology, 50*, 599–7606.
761 Rodriguez, R., Jimenez, A., Bolanos, J. F., Guillen., R, &
762 Heredia, A. (2006). Dietary fibre from vegetable products as

763 source of functional ingredients. *Trends in Food Science &*
764 *Technology, 17*, 3–15.
765 Rodriguez Couto, S., & Sanroman, M. A. (2005). Application of
766 solid-state fermentation to ligninolytic enzyme production.
767 *Biochemical Engineering Journal, 22*, 211–219.
768 Rodriguez Couto, S., & Sanroman, M. A. (2006). Application of
769 solid-state fermentation to food industry–A review. *Journal of*
770 *Food Engineering, 76*, 291–302.
771 Rufford, T. E., Hulicova-Jurcakova, D., Zhu, Z., & Lu, G. Q.
772 (2008). Nanoporous carbon electrode from waste coffee beans for
773 high performance supercapacitors. *Electrochemistry*
774 *Communications, 10*, 1594–1597.
775 Saenger, M., Hartge, E.-U., Werther, J., Ogada, T., & Siagi, Z.
776 (2001). Combustion of coffee husks. *Renewable Energy, 23*,
777 103–121.
778 Saura-Calixto, F., Garcia-Alonso, A., Goni, I., & Bravo, L.
779 (2000). In vitro determination of the indigestible fraction in
780 foods: an alternative to dietary fiber analysis. *Journal of*
781 *Agricultural and Food Chemistry, 48*, 3342–3347.
782 Sereewatthanawut, I., Prapintip, S., Watchiraruji, K., Goto, M.,
783 Sasaki, M., & Shotipruk, A. (2008). Extraction of protein and
784 amino acids from deoiled rice bran by subcritical water
785 hydrolysis. *Bioresource Technology, 99*, 555–561.
786 Somporn, C., Kamtuo, A., Theerakulpisut, P., & Siriamornpun, S.
787 (2011). Effects of roasting degree on radical scavenging activity,
788 phenolics and volatile compounds of Arabica coffee beans
789 (*Coffea arabica L. cv.* Catimor). *International Journals of Food*
790 *Science & Technology, 46*, 2287–2296.

Southgate, D. A. T. (1978). Dietary fiber: analysis and food sources. *The American Journal of Clinical Nutrition, 31*, S107–S110.

Takayanagi, R., Inoguchi, T., & Ohnaka, K. (2011). Clinical and experimental evidence for oxidative stress as an exacerbating factor of diabetes mellitus. *Journal of Clinical Biochemistry and Nutrition, 48*, 72–77.

Tawfik, M. S., & El Bader, N. A. (2005). Chemical characterization of harar and berry coffee beans with special reference to roasting effect. *Journal of Food Technology, 3*, 601–604.

United States Department of Agriculture. Coffee: World Markets and Trade [http://www.usda.gov/wps/portal/usda/usdahome].

Usuki, C., Kimura, Y., & Adachi, S. (2008). Degradation of pentaoses and hexouronic acids in subcritical water. *Chemical Engineering and Technology, 31*, 133–137.

van Boxtel, J., Berthouly, M., Carasco, C., Dufour, M., & Eskes, A. (1995). Transient expression of b-glucuronidase following biolistic delivery of foreign DNA into coffee tissues. *Plant Cell Reports, 14*, 748–752.

van de Laar, F. A., Lucassen, P. L., Akkermans, R. P., van de Lisdonk, E. H., Rutten, G. E., & van Weel, C. (2005). α-Glucosidase inhibitors for patients with type 2 diabetes. *Diabetes Care, 28*, 154–163.

Vieira, H. D. (2008). Coffee: The plant and its cultivation. In M. Souza (Ed.), Plant-parasitic nematodes of coffee (pp. 3–18). Dordrecht: Springer.

Wakita, Y., Harada, O., Kuwata, M., Fujimura, T., Yamada, T.,

819 Suzuki, M., & Tsuji, K. (2004). Preparation of subcritical
820 water-treated okara and its effect on blood pressure in
821 spontaneously hypertensive rats. *Food Science and Technology*
822 *Research, 10*, 164–167.
823 Wiboonsirikul, J., Kimura, Y., Kadota, M., Morita, H., Tsuno, T.,
824 & Adachi, S. (2007). Properties of extracts from defatted rice
825 bran by its subcritical water treatment. *Journal of Agricultural*
826 *and Food Chemistry, 55*, 8759–8765.
827 Wu, X., Beecher, G. R., Holden, J. M., Haytowitz, D. B.,
828 Gebhardt, S. E., & Prior, R. L. (2004). Lipophilic and
829 hydrophilic antioxidant capacities of common foods in the
830 United States. *Journal of Agricultural and Food Chemistry, 52*,
831 4026–4037.
832

Figure captions

Figure 1. Typical section of a coffee cherry

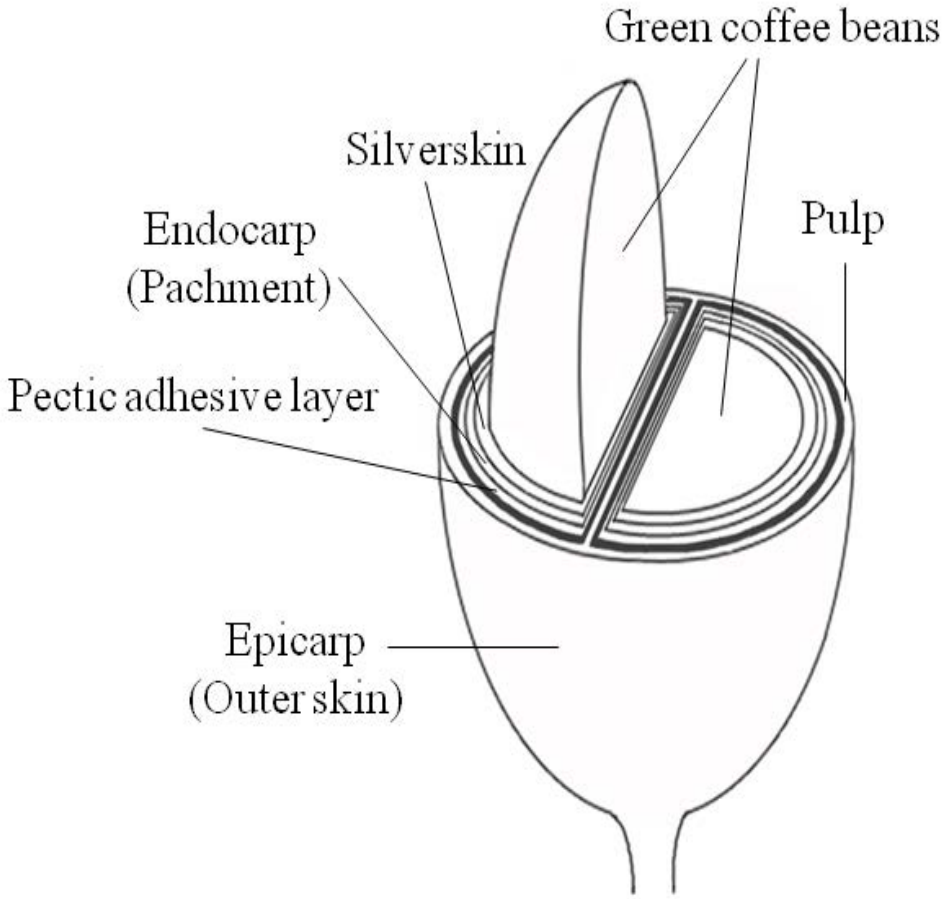

Table 1. Coffee silverskin nutritional composition (g per 100g)

Component	CS				
	–	from Arabica	from Canephora	from Arabica	–
Proteins	18.6 ± 0.6	18.6 ± 0.3	17.9–19.0	18.4–19.0	16.2
Fats	2.2 ± 0.1	2.2 ± 0.5	2.50–2.92	1.56–3.28	N. A.
Carbohydrates	62.1 ± 1.6	65.1 ± 1.2	47.0–80.5	34.6–52.0	N. A.
Reducing sugars	0.2 ± 0.01	N. A.	N. D.[b]	N. D.	N. A.
Moisture	7.3 ± 0.4	7.1 ± 0.2	N. A.	N. A.	4.7
Ashes	7.0 ± 0.2	7.0 ± 0.2	N. A.	N. A.	N. A.
Caffeine	N. A.[a]	N. A.	0.81–1.37	0.83–1.16	N. A.
Ochratoxin A	4 <	N. A.	N. A.	N. A.	N. A.
Total dietary fiber	62.4 ± 0.6	62.4 ± 0.5	53.4–69.2	56.4–65.9	N. A.
Insoluble dietary fiber	53.7 ± 0.2	53.7 ± 0.4	48.5–64.2	50.1–60.7	N. A.
Soluble dietary fiber	8.8 ± 0.4	8.8 ± 0.6	4.9–9.3	5.0–6.3	N. A.
Glucan	N. A.	N. A.	N. A.	N. A.	17.8
Xylan	N. A.	N. A.	N. A.	N. A.	4.7
Arabinan	N. A.	N. A.	N. A.	N. A.	2.0
Galactan	N. A.	N. A.	N. A.	N. A.	3.8
Mannan	N. A.	N. A.	N. A.	N. A.	2.6
Lignin	N. A.	N. A.	N. A.	N. A.	30.2
Acetyl groups	N. A.	N. A.	N. A.	N. A.	3.0
Extractives	N. A.	N. A.	N. A.	N. A.	15.0
References	A	B	C	C	D

from Borrelli et al. (2004) and Napolitano et al. (2006) (A), Pourfarzad et al. (2013) (B), Napolitano et al. (2007) (C), and Mussatto et al. (2012) (D).

[a] Not analyzed

[b] Not detected

Table 2. Yields of soluble solid from CS of solid and each component and antioxidant activity of CS water extraction[a]

Extraction Temperature (°C)	Yields of soluble solid (g/100 g)	Proteins (g/100 g)	Carbohydrates (g/100 g)	Caffeine (g/100 g)	Total phenolics (g/100 g)	H-ORAC (μmol TE/g of CS extracts)	DPPH (μmol TE/g of CS extracts)
25	16 ± 1	21.2 ± 1.8	36.6 ± 2.1	2.6 ± 0.0	3.6 ± 0.3	354 ± 44	74 ± 13
80	19 ± 1	23.6 ± 1.2	40.5 ± 3.0	2.3 ± 0.0	3.5 ± 0.1	384 ± 58	75 ± 18
180	25 ± 1	37.8 ± 2.0	47.7 ± 2.9	1.6 ± 0.0	8.5 ± 0.5	1223 ± 65	184 ± 28
210	29 ± 1	53.5 ± 1.4	22.8 ± 5.0	1.4 ± 0.0	12.4 ± 0.9	2321 ± 169	323 ± 39
240	27 ± 1	58.2 ± 1.0	8.6 ± 1.0	1.6 ± 0.0	13.0 ± 0.6	2611 ± 150	371 ± 33
270	23 ± 1	54.4 ± 1.1	7.1 ± 0.6	1.8 ± 0.0	12.3 ± 0.9	2629 ± 193	379 ± 36

[a] from Narita & Inouye (2012).

Table 3. Yields of each component obtained from CS of solid by water extraction[a]

Extraction Temperature (°C)	Proteins (g/100 g)	Carbohydrates (g/100 g)	Caffeine (g/100 g)	Total phenolics (g/100 g)
25	3.3 ± 0.2	5.7 ± 0.2	0.4 ± 0.0	0.6 ± 0.0
80	4.5 ± 0.3	7.7 ± 0.9	0.4 ± 0.0	0.7 ± 0.0
180	9.5 ± 5.0	12.1 ± 0.9	0.4 ± 0.0	2.2 ± 0.1
210	15.7 ± 0.4	6.7 ± 0.3	0.4 ± 0.0	3.6 ± 0.3
240	15.5 ± 0.7	2.3 ± 0.1	0.4 ± 0.0	3.5 ± 0.2
270	12.5 ± 0.4	1.6 ± 0.1	0.4 ± 0.0	2.8 ± 0.1

[a] from Narita & Inouye (2012).

Figure 1