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 easy to reuse, and it can be regarded as biomass that is expected to be utilized in the future.

2. Chemical composition of CS

2.1. Dietary fiber in CS

CS ingredients and the amounts thus far reported are summarized into Table 1. Dietary fiber is important for nutrition and health and is used as a therapeutic material for physiological problem such as diabetes and hyperlipidemia (Saura-Calixto, Garcia-Alonso, Goni, & Bravo, 2000). It is thought that dietary fiber will help in preventing cardiovascular disorders by arteriosclerosis or the serious complications of diabetes, because this controls the absorption of cholesterol and fat into the body by adsorbing them. CS has a high dietary fiber (50−60%), which includes 15% soluble dietary fiber and 85% insoluble dietary fiber (Borrelli, Esposito, Napolitano, Ritieni, & Fogliano, 2004; Napolitano et al., 2006; Pourfarzad, Mahdavian-Mehr, & Sedaghat, 2013; Napolitano, Fogliano, Tafuri, & Ritieni, 2007). Napolitano et al. (2007) investigated CS dietary fiber obtained from four types of *C. arabic*a samples from Ethiopia, Santos, India, and Costa Rica, and three types of *C. canephora* samples from Ivory Coast, Vietnam, and Cameroon. They reported that there were no significant differences in the dietary fiber and soluble dietary fiber contents between all samples tested. The dietary fiber content of CS is higher than that of dietary plant 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 subject.

3. CS water extracts

3.1. Yields of soluble solid from CS

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

Water maintained in the liquid state with pressure at temperatures ranging between 100^{o}C and 374^{o}C is called subcritical water. The specific inductive capacity or dielectric constant of water decreases remarkably with increasing temperature (Miller & Hawthorne, 1998). Moreover, subcritical water functions as an acid or alkali catalyst because the ionic product of subcritical water is higher than water under normal temperature and pressure conditions. Recently, Subcritical water has been used extensively for research on extracting ingredients from food waste such as okara (Wakita et al., 2004), wheat bran (Kataoka, Wiboonsirikul, Kimura, & Adachi, 2008), and defatted 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 proteins extracted from CS by subcritical water treatment has not been reported until now. As undermentioned, it has been reported that CS water extracts have antioxidant activities (Narita & Inouye, 2012). It is reported that proteins produced by subcritical water treatment from deoiled rice bran, which is an agro-industrial residue of the rice milling process, showed high antioxidant activity and were proven to be useful for application as a culture medium for yeast growth (Sereewatthanawut, Prapintip, Watchiraruji, Goto, Sasaki, & Shotipruk, 2008). It is reported that the peptides produced by the decomposition of soybean protein and wheat gluten have high antioxidant activity (Park, Morimae, Matsumura, Nakamura, & Sato, 2008). Proteins or peptides produced by subcritical water treatment from CS might have antioxidant activity. The yields of caffeine from CS were almost constant at 0.4% (w/w dry matter) at extraction temperatures in the range of 25–270°C (Narita & Inouye, 2012). Total phenolic contents of the CS extracts obtained by water treatment increased with increasing extraction temperature from 25°C to 240°C (Narita & Inouye, 2012). Subcritical water treatment was effective for the extraction of phenolic components (Narita & Inouye, 2012). 5-Caffeoylquinic acid (5-CQA) was extracted at 0.1–0.2% (w/w dry matter) from CS in the temperature range of 25–180°C, but It was not extracted in the temperature range of 210–270°C (Narita & Inouye, 2012). It was considered that 5-CQA in CS was not detected with heat treatment because it was reported that 5-CQA decreased with increasing temperature (de Maria, Trugo, de Mariz e Miranda, & 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 to the factors H-ORAC values of CS extracts has increased remarkably with increasing extraction temperatures, Narita & Inouye (2012) have mentioned two possibilities. One is the possibility of the phenolic components that the CS water extracts may contribute, another is the possibility that peptides produced by hydrolysing the proteins in CS by subcritical water treatment in the temperature range of 180–270^{o}C have a high antioxidant activity (Narita & Inouye, 2012). It is reported that the peptides produced by the decomposition of soybean protein and wheat gluten have high antioxidant activity (Park, Morimae, Matsumura, Nakamura, & Sato, 2008). H-ORAC values of fruits such as blueberry, plum, raspberry, apple, and orange, and vegetables such as carrot, green pepper, and spinach are in the range of 5–70 μmol TE/g (Wu, Beecher, Holden, Haytowitz, Gebhardt, & Prior, 2004). Even the H-ORAC value (354 μmol TE/g of CS extracts) of CS extracts by treatment water at 25^{o}C showed that it was higher than that of the above mentioned fruits and vegetables. 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. A study to confirm an antioxidant effect of CS will be necessary in vivo experiment in future. Furthermore, Identification of ingredients contributing to the antioxidant effect of CS is necessary in in vitro experiments.

4.2. Prebiotic effect and inhibitory activity on hyaluronidase by CS

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

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Figure captions

Figure 1. Typical section of a coffee cherry

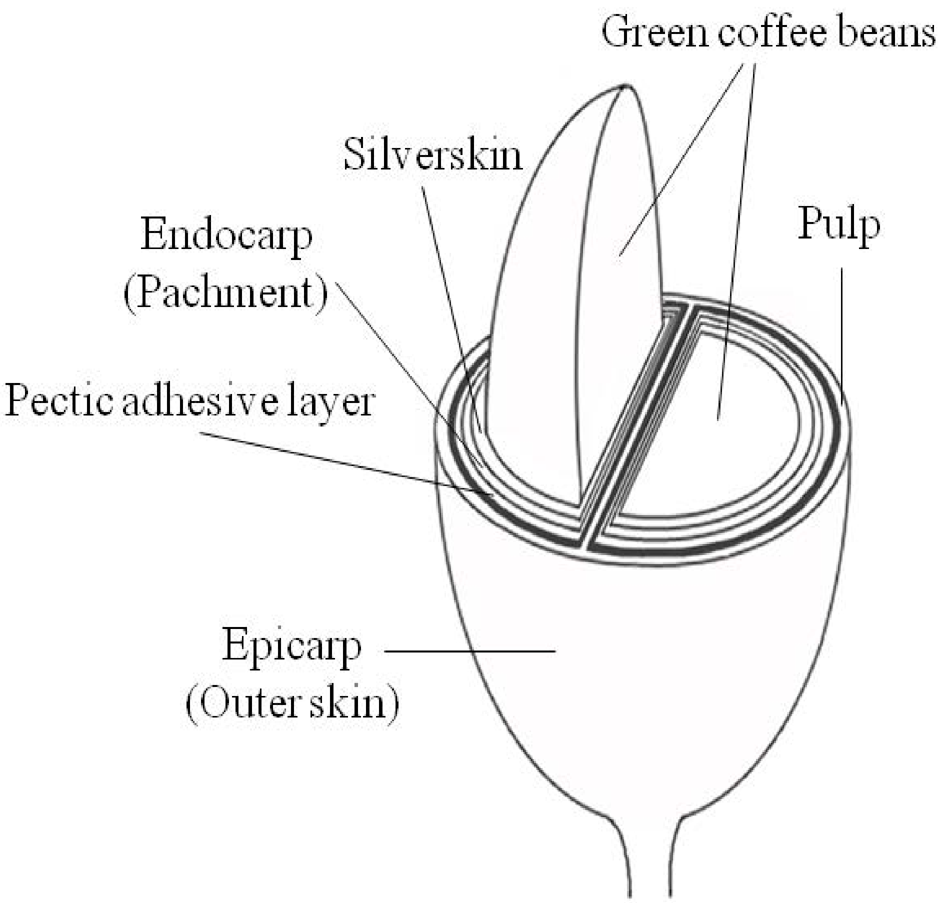

Table 1. Coffee silverskin nutritional composition (g per 100g)

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