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MINI-REVIEW

Spent coffee ground: transformation from environmental burden into valuable bioactive metabolites

Tanim Arpit Singh · Namrata Pal · Poonam Sharma · Ajit Kumar Passari

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Abstract Spent coffee ground (SCG) is a primary by-product obtained during soluble coffee processing and could be used for high-value products due to its protein content. The SCG is a rich source of cellulose, hemicellulose, lignin, lipids and proteins. The bioactive peptide obtained after protein hydrolysis has great potential as an antioxidant, antimicrobial, and anti-mutagenic agent and a better understanding is a prerequisite for proper utilization of the natural and renewable source of protein to attain a sustainable approach. Moreover, by utilizing SCG-derived peptides we can reduce the contamination of these residues at an agronomical scale. In this review, we discussed the spent coffee ground protein-based peptides and also high-lightened the properties of these valuable bioactive peptides in addition to other industrially important metabolites. Conclusively, the SCG peptides can be an interesting substitute to plant protein with functional properties in food industries, and at the same time utilization of SCG would reduce the bio-waste burden.

Tanim Arpit Singh, Namrata Pal and Poonam Sharma have contributed equally.

T. A. Singh
Maharaja Ranjit Singh College of Professional Sciences, Indore, M.P., India

N. Pal · P. Sharma
National Institute for Research in Environmental Health, Bhopal, M.P., India

A. K. Passari (✉)
Instituto de Investigaciones Biomédicas, Universidad Nacional Autónoma de México (UNAM), 04510 Ciudad de México, México
e-mail: ajit.passari22@gmail.com; ajit.passari22@iibiomedicas.unam.mx

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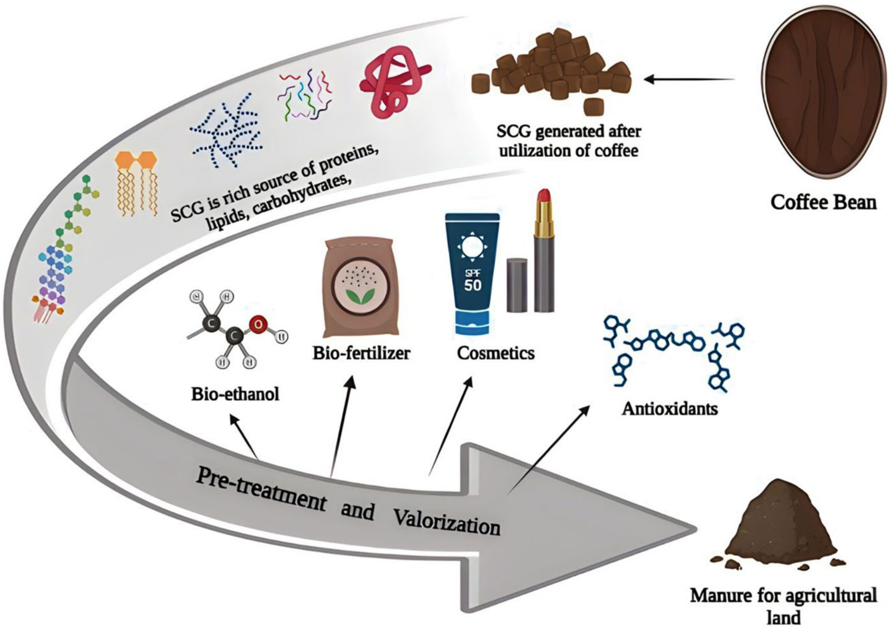
Graphical abstract



Keywords Spent coffee ground · Protein · Peptide · Bioactivity

1 Introduction

Coffee is one of the most valuable primary products in the world trade and holds a major part in the food industry. Its production and consumption across the world reached 169.34 million bags of 60 kg and 198.39 million bags, respectively, in the year 2019–2020 resulting in a surplus of 952,000 bags on the estimate (Fig. 1a). The trend of general coffee consumption has been continuously increasing, for instance, in 2018–19, the annual global production of coffee in the fiscal year 1990–1991, 2000–2001, and 2010–2011 raised by 83.35%, 50%, and 20%, respectively (Atabani et al. 2022). Brazil is the largest producer of coffee throughout the world followed by Vietnam and Colombia. These three coffees producing countries are responsible for producing and exporting almost 60% of the global coffee throughout the world (Fig. 1b). According to the International Coffee Organization, Brazil on an average produce approximately 40 million bags coffee with 60 kg in each bag (Mussatto et al. 2011). The climate of Brazil is perfectly suitable for coffee farming and the coffee plantations spread in an area of around 27,000 square kilometers. The major coffee producing areas in Brazil include Minas Gerais, Sao Paulo and Parana. However, coffee production generates a lot of coffee wastes and by-products, which, on the one hand, could be used for more applications such as the removal of heavy metals and dyes from aqueous solutions, production of bio-fuels, composting material, production of reusable cups, a substrate for mushroom production, source of natural phenolic antioxidants, and even in construction material (McNutt and He 2018). On the other hand, it could be a source of severe contamination posing a serious environmental problem. Conventional methods for eradicating SCGs were either incinerated as a solid fuel or dumped, ignoring its valuable organic contents. SCG incineration has been reported to cause major environmental pollution (Vítezová et al. 2019) due to the excessive emissions of toxic gases such as carbon monoxide (CO) and nitrogen oxides (NO_x). This result in air pollution and significantly contributes to augmenting global warming. Additionally, landfilling needs large areas with a potential pollution risk and also contributes to groundwater contamination (Leow et al. 2021; Kueh 2021; Atabani et al. 2022). These methods are

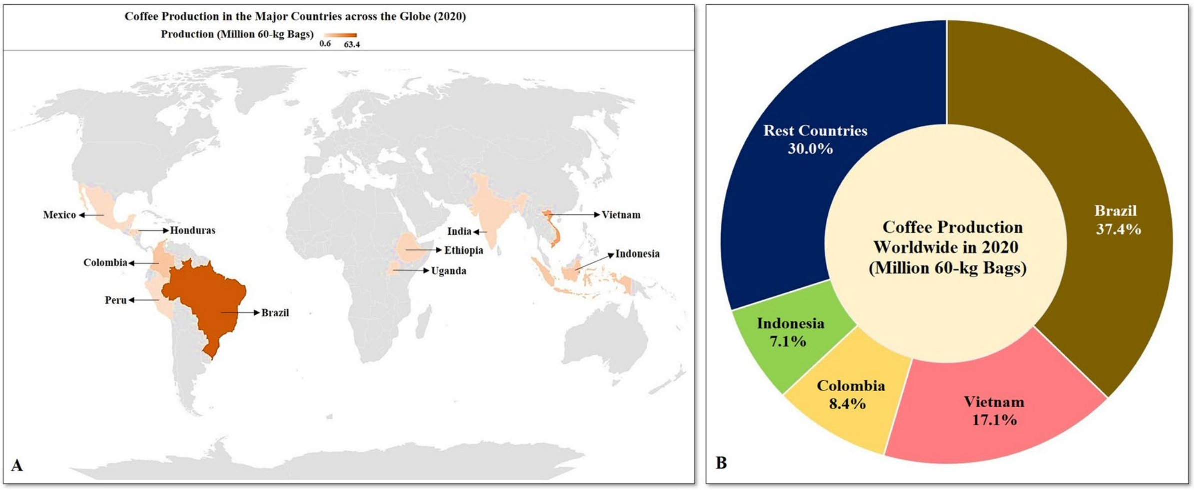


Fig. 1 Statistics on Coffee. Annual production of Coffee by the **a** major countries across the world, and **b** Market share of top coffee-producing countries (Deshmukh 2021; Shahbandeh 2022)

highly destructive to the environment and thus, to handle these contaminants consistent waste management strategies should be framed and implemented with existing national regulations (Costa et al. 2022). For instance, Nestlé, the world's largest food company pledged to alleviate such waste in Europe by 2020 by utilizing it as a source of renewable energy source in more than 20 Nescafé factories (Campos-Vega et al. 2015).

SCGs are the residues obtained from brewing coffee. Coffee brews are typically prepared from *Arabica* coffee or *Arabica/Robusta* blends, and are available to consumers as roasted beans, whole or ground, or as instant/soluble coffee. The term "spent coffee grounds" can therefore be used to refer to both those produced after brewing at home or in cafeterias as well as those received from the soluble coffee industry. In contrast to wasted coffee obtained after brewing from cafeterias/household contexts, industrial spent coffee ingredients are significantly more successfully removed, resulting in more chemically depleted remnants (Bomfim et al. 2022).

SCG are majorly comprised of cellulose, hemicellulose, lignin and proteins. Apart from these major constituents it also contains value added compounds like fatty acids, cafestol, vitamins and lipids (Battista et al. 2021). These compounds, by using different extraction methods can be isolated and utilized commercially in different commercial sectors like cosmetics, food and pharmaceuticals. The presence of carbohydrates and polysaccharides in SCG makes it an adequate substrate for the production of biodiesel, biochemicals and other phenolic compounds (He et al. 2020). The valorisation of SCG for production of commercially valuable compounds is still underexplored and is needed to be evaluated for better production of different value-based products. Besides extraction process, pre-treatment is also an important method that is required to taken into consideration while utilizing SCG waste. Pre-treatment of SCG by-products with N-methyl morpholine N-oxide (NMMO) enhanced the bioconversion of lignocellulosic components of waste into methane and other important compounds (Oliva et al. 2022).

Around 9.5 million tonnes of coffee were produced globally in 2018, and for every 1 g of ground coffee, 0.91 g of SCG is generated (Tan et al. 2020; Barrios et al. 2022). Protein content in SCG is 12–17% (Fig. 2) which is relatively higher than the roasted coffee which is 3.1% (w/w). The chemical composition of coffee brews depends on extraction efficiency, which is attributed to varied factors, including the coffee species, roasting temperature, grinding grade, coffee/water ratio, water quality, temperature, pressure, and percolation time (Olechno et al. 2021). Therefore, different extraction processes will lead to chemically diverse brews and so as the SCGs.

With the estimated increase of coffee production and consumption in the upcoming years, there is an imperative need for proper utilization, along with a

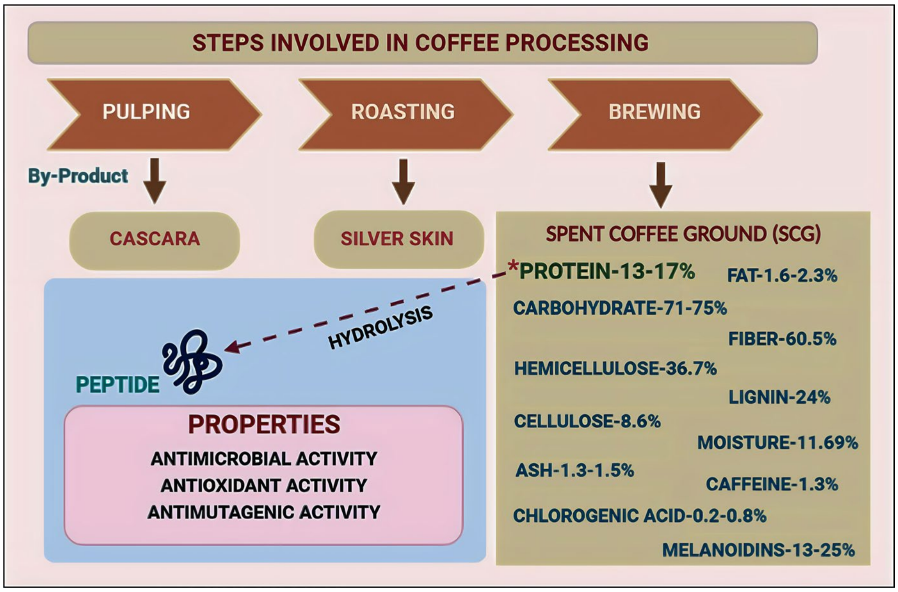


Fig. 2 Step involved in coffee processing, origin, and composition of SCGs and their biological properties (Iriondo-DeHond et al. 2021)

novel industrial application. Recently, more attention has been paid to recycling spent coffee for the development of healthier products. Thus, in this review, we tried to collate the existing knowledge available regarding SCG-based valuable metabolites mainly focusing on the SCG-derived peptides. Since the world is fast running out of new therapeutic options, potential bioactive peptides would be needed to save mankind, thus future studies should emphasize SCG-based peptides to unravel the SCG treasure house. Nevertheless, it shall offer a preliminary overview of some of the efforts of the scientific community to furnish SCG, coffee by-products with valuable traits, that can be exploited at the industrial level to synthesize valuable compounds for the prevention of diseases.

2 Composition of spent coffee ground

SCG comprises cellulose (12.4%), hemicellulose (39.1%), lignin (23.9%), fat (2.29%), protein (13–17%), and total dietary fibres (60.46%) and micronutrients such as potassium, calcium, magnesium, sulfur, phosphorus, iron, manganese, boron, and copper, thus making them intriguing sources of raw materials for various applications at industrial scale (Fig. 2) (Saratale et al. 2020). Though, the extraction technique plays an important role in the recovery of functional metabolites from SCG. Conventional methods such as probiotic fermentation, enzymatic hydrolysis (Roukas and Kotzekidou 2022), solvent extraction, and microwave-assisted extraction have been reported to date for the extraction of SCGs metabolites as per the available literature (Wu et al. 2019).

2.1 Microwave-assisted extraction (MAE)

MAE has been proven to be one of the most potent techniques and considered is the advanced and best alternative to conventional and other extraction techniques. The efficient and rapid heating released by MAE is associated with the dielectric properties of the samples. Dielectric heating quickly raises the temperature of the sample matrices, consequently, reduces the heating time. Being a closed system, MAE controls the temperature and pressure conditions and also prevents the loss of volatile materials and extraction solvent, contrary to the open system. Despite this, numerous factors affect the efficiency of the MAE process such as the nature of the matrix, power of microwave irradiation, temperature and extraction time, solvent choice, and solvent/solid ratio, though the impact of the latter can be curtailed by providing agitation during the extraction process (Coelho et al. 2021).

2.2 Supercritical fluid extraction (SCFE)

Zetzel had previously described the supercritical extraction unit, which was used to obtain the wasted coffee grounds and coffee husk extracts (Zetzel et al. 2003). The extraction process, moisture content, particle size, type and volume of solvent, and extraction time all affect the product yield. Several other parameters including pressure, temperature, and time could affect the SCF extraction efficiency (Sharma et al. 2021). Soxhlet solvent extraction has been the baseline method employed in several previous studies investigating lipid extraction from SCGs, with n-hexane observed as the most effective solvent in studies that considered a range of solvents (Efthymiopoulos et al. 2019). The Advanced SCFE technique is an eco-friendly and green-based approach that employed solvents such as CO_2 under supercritical conditions for the extraction of different valuable substances such as oil, polyphenols, or pigments. This method possesses several advantages such as safe, non-mutagenic, non-flammable, readily available, and economically owned to CO_2 usage.

2.3 Probiotic fermentation

Given the nutritional makeup of SCG and the existence of insoluble components, these by-products ought to have an intriguing effect on the gut flora. Since it was found that SCG increased the levels of *Lactobacillus spp.* and *Bifidobacterium spp.* under in vitro fermentation, Panzella et al. (2017) examined the impact of microbial fermentation on hydrolyzed spent coffee grounds by monitoring changes in microbial composition and the synthesis of short-chain fatty acids, which are known to have beneficial features.

Liu et al. (2021a) evaluated the effects of yeast extracts (0% and 0.25%, w/v) on the non-volatile and volatile compounds derived from SCG hydrolysates fermented with single-cultures of two non-Saccharomyces wine yeasts, *Torulaspora delbrueckii*, and *Pichia kluyveri*. The result showed that the addition of yeast extracts significantly improved the growth of both *T. delbrueckii* and *P. kluyveri*, especially *P. kluyveri*, resulting in higher ethanol production. Another study conducted by his group also demonstrated that the addition of yeast extracts affected the metabolism of both *S. cerevisiae* and *L. thermotolerans* during SCG hydrolysate fermentation thus, subsequently increasing the production of succinic acid, acetic acid, and volatile compounds (Liu et al. 2021b).

2.4 Enzymatic hydrolysis

Jooste et al. (2013) thought that using an enzyme cocktail (mannanase, endo-glucanase, exo-glucanase, xylanase, and pectinase) to hydrolyze residual particles could boost the output of soluble solids in instant coffee or serve as a raw material for the manufacturing of bioethanol and food additives (mannitol). Enzymatic hydrolysis has advantages over chemical pre-treatment, including a better yield of fermentable sugar, softer working conditions, higher selectivity, and lower energy expenditures.

SCG on an average contains 13.6% w/w of proteins. The total amount of proteins even during the roasting stage is found to be in range of 8.5–13.6%. This shows that the protein and other nitrogenous compounds in the SCG remains stable even after different treatment procedures (Belitz 2004). The crude protein content reported by Cruz et al. (2012) in espresso coffee residues varies from 12.8 to 16.9%. The higher protein content in SCG than in the coffee bean is due to the concentration of the non-extracted components during instant coffee preparation. Due to other nitrogen-containing substances like caffeine, trigonelline, free amines, and amino acids, the protein content in SCG might be overestimated (Gao et al. 2019). However, similar protein contents, varying between 6.7% and 9.9% and up to 14% have been reported by many authors (Franca and Oliveira 2022; Bevilacqua et al. 2023). The 11 S protein, a storage protein, makes up about 45% of the total proteins in the coffee endosperm, or 5–7% of the dry bean weight. Two-dimensional profiles of green coffee proteins recognized that the 11 S storage protein consists of high 32 kDa α- and low 22 kDa β- molecular subunits (Acuna et al. 2002).

The SCG protein has a high lysine/arginine ratio, which indicates that it may contribute to physiological effects that are hypercholesterolemic and atherogenic. The three amino acids arginine, glutamine, and histidine, which are known to have a significant impact on the body's immune system, are also abundant in SCG protein. Some SCG proteins' high levels of cysteine and methionine can raise the antioxidant levels in the body stabilizing DNA during cell division and lowering the chance of developing certain types of colon cancer (Campos-Vega et al. 2013, 2015).

SCG protein has a greater concentration of branched-chain amino acids (BCAA) and a higher Fischer ratio except for some. Proteins with high BCAA, Fischer ratio, and low content of aromatic amino acids can be looked for in the production of physiologically functional foods for specific needs, such as in patients with malnutrition associated with cancers, burns, trauma, and liver failure, as well as for the nutritional support of children with chronic or acute diarrhea or milk protein allergies (Master et al. 2021; Campos-Vega et al. 2015). The SCG protein can be used for the formulation of food products with multiple human health benefits during liver diseases, oxidative stress, and hypertension. Patients with hepatic encephalopathy have received treatment with proteins that have a Fischer ratio higher than 20 and aromatic amino acids (AAA) that are less than 2% (Campos-Vega et al. 2015; Bhattarai et al. 2022).

2.5 Ultrasound assisted extraction (UAE)

UAE is a rapid and low-cost method that is employed for the extraction of valuable phenolic compounds from the SCG waste (Tiwari 2015). This process is versatile in terms of solvents that are employed and requires low investment when compared with other techniques like supercritical fluid extraction (SFE) or pressurised solvent extraction. UAE allows the use of different solvents and neither have restrictions on the polarity of compound nor towards the moisture of matrix (Rastogi 2011). The UAE can be effectively utilised in enhancing the mass transfer during solid-liquid extraction process to obtain commercially important products like biodiesel and phenolics from SCG. This effectiveness of this method is due to the cavitation effect that is generated by the ultrasonic waves (Rabelo et al. 2016). Like majority of conventional methods, UAE also has one disadvantage, that we do not obtain solvent-free extracts and to overcome this an additional concentration step is requisite after extraction (Ghitescu et al. 2015).

Ultrasonic-assisted extraction, used as a pre-treatment to conventional extraction, was used to study the protein from spent coffee grounds. According to Samsalee and Sothornvit (2021), the greatest antioxidant activity (933.92-976.03 mM Trolox eq/g protein extract) and total phenolic content (267.66-304.81 mg GAE/g protein extract) were obtained after a 20-minute extraction time. The primary phenolic compound in SCGs, chlorogenic acid, was recovered using environmentally friendly UAE extraction methods (Okur et al. 2021). The maximum concentration of chlorogenic acid found was 85.0 0.6 mg/kg Fresh Weight using UAE at 60% amplitude for 15 min. Furthermore, using ultrasonic-autoclave-assisted extraction at 40% amplitude for 10 min, the total sugar and reduced sugar contents of the SCG sugar extracts were detected to be 529.25 mg glucose/g extract and 361.25 mg mannose/g extract, respectively (Samsalee and Sothornvit 2021). The hydrolysate of spent coffee ground was found to contain 2016.4 milligrams per litre of reducing sugars (464.2 milligrams per litre of mannose, 947.1 milligrams per litre of glucose, and 256.3 milligrams per litre of galactose), with a 401.70 milligram per litre of total phenolic content. Additionally, the hydrolysate demonstrated antioxidant activity with an antioxidant content of 564.3 milligrams per liter of ascorbic acid equivalent (Ho et al. 2022).

3 SCGs: sources of bioactive peptides

SCGs-derived protein ranges from 12 to 17% and thus could serve as a rich source of peptides. In a study conducted by Valdés et al., the peptide content (OPA assay), the antioxidant activity, and the in vitro ACE-inhibitory activity of SCG protein hydrolysates were determined. The result showed that the highest protein content is obtained from espresso SCG, and possesses antioxidant and ACE-inhibitory activities (Valdés et al. 2020). Another research conducted by Samsalee and Sothornvit reported 15.97% total protein content derived from SCGs, which also suggested that varying protein content corresponded to the variety and brewing conditions used during the process (Samsalee and Sothornvit 2021).

Ribeiro et al. evaluated the bioactive potential of protein extracted from green and roasted coffee beans and SCGs. They observed that both green coffee bean and spent coffee ground protein showed high ACE inhibition efficiency, and hence possess high antihypertensive potentials. This can be related to the low molecular mass peptides released after digestion. Moreover, the high antioxidant activity can be ascribed to the interactions occurring between the proteins and melanoidins during roasting. It was observed that antihypertensive and antioxidant potentials were evident in the protein fraction of spent coffee grounds. Therefore, the usage of this protein in nutrition might be an important strategy for both glycemic and hypertensive cases and even can be explored for the prevention of the oxidative damage produced by metabolic disorders (Ribeiro et al. 2021). Febrianto has extracted the protein and antioxidative metabolites from spent coffee grounds through the hydrolysis of protein utilizing papain. The research showed a promising result with 67.38% protein extraction and its hydrolysate also exhibits high antioxidant activity. The finding showed that the use of crude papain has proven to be effective to hydrolyze the SCG with its optimum concentration of 6%- and 2-hours incubation time (Febrianto 2018).

3.1 Bacterial fermentation of SCG induces the release of potentially bioactive peptides

A natural alternative method for producing protein hydrolysates is fermentation. Proteins in food are hydrolyzed by microbial proteolytic systems to release peptides and amino acids. This technique has been employed in recent years to make food-plant protein hydrolysates, which have other health advantages and function as inhibitors of an enzyme involved in the etiology of metabolic syndromes.

SCGs are a rich source of peptides. Protein hydrolyses during bacterial fermentation of SCG can produce bioactive peptides; however, this has not been reported yet. As a substitute for obtaining potentially beneficial compounds for the prevention of chronic diseases, Ramirez and his colleagues have stimulated the release of peptides from digested protein hydrolysates of SCG fermented by *Bacillus clausii*, identified them, and evaluated their bioactivity potential by in silico analysis of their peptide sequences. The fermentation procedure raised total proteins, soluble proteins, and protein hydrolysates by 2.7, 2.2, and 1.2-fold, respectively. Seven peptides with possible antioxidant properties, angiotensin-converting enzyme (ACE), and dipeptidyl peptidase-IV (DPP-IV) inhibitory action were more prevalent in fermented SCG samples. Each peptide's likelihood of being bioactive was predicted by PeptideRanker with YGF and GMCC peptide sequences presenting a higher score (0.97), followed by the YWRYDCQ (0.65) and RMYRY (0.60) peptides (Table 1) (Ramirez et al. 2021).

3.2 Melanoidins: another valuable bioactive metabolite derived from SCG

During roasting, coffee's protein composition changes when the proteins are broken down, polymerized, and incorporated into melanoidins. *Arabica* roast and brew have total amino acid contents of 10.1 and 6.4% dry weight, respectively, indicating that SCG has a 3.7% dry weight of amino acids (Ginz et al. 2000).

Table 1 Bioactive potential of peptides identified after digestion with pepsin/pancreatin of spent coffee grounds proteins predicted by the BIOPEP database (Ramirez et al. 2021: Ribeiro et al. 2021)

Bioactive fractions of SCG-peptides	Activity
RY, YW, YRY	Antioxidant
SH, SL, QL, IN, AL, TN, DN, YS, YQ, QH, RM, YR, QT, WRY, WR, YD, YW	DPP-IV inhibitor
GR, GK, QK, IF, AR, GM, RY	ACE-Inhibitor
AQL, PH, VPK, GW, GL, EY, VAF, VF, PL, YG, GF	DPP-IV inhibitor; ACE-inhibitor
GF	DPP-III inhibitor; DPP-IV inhibitor; ACE-inhibitor
VL	Stimulant; DPP-IV inhibitor
IL	Stimulant; DPP-IV inhibitor; ACE-inhibitor
TY	Antioxidant; DPP-IV inhibitor
AH, MY	Antioxidant; DPP-IV inhibitor; ACE-inhibitor
VY	Antioxidant; DPP-III inhibitor; DPP-IV inhibitor; ACE-inhibitor

Melanoidins are large molecular weight, brown-colored nitrogenous compounds with a small amount (<6%) of amino acids; glutamic acid, and glycine being primarily generated by acid hydrolysis. Coffee melanoidins possess multi-health-promoting properties and have been linked to several biological actions, including anti-oxidative, antibacterial, anti-cariogenic, anti-inflammatory, antihypertensive, and antiglycative ones (Iriondo-DeHond et al. 2021). The metal-chelating capabilities of melanoidins have been found to mediate the antibacterial action of melanoidins against several bacterial strains in three different ways. At low concentrations, they show bacteriostatic activity via iron chelation from the culture medium, however, the possibility of sequestering additional vital cations cannot be ruled out. Additionally, it has been shown that melanoidins can chelate the siderophore-Fe^{3+} complex for bacterial strains that can manufacture siderophores for iron acquisition, thus reducing the virulence of such harmful bacteria. Finally, at high concentrations, melanoidins promote cell membrane disruption through the elimination of Mg^{2+} cations from the outer membrane resulting in the leakage of intracellular molecules (Rufian-Henares and Cueva 2009).

4 Applications of SCG in various sectors

Apart from bioactive peptides, spent coffee grounds can potentially be used in several other sectors. It has been significantly used as, not limited to, distillates, nutraceuticals, animal feed, energy sources, fertilizers, insecticides, biofuel, construction materials (Ramalakshmi et al. 2008) (Fig. 3). In the food industry, SCGs could be used as a dietary fibre source as well as in the production of alcoholic distillates. “Coffee flour” which is produced after drying the SCG, followed by the extraction of coffee oil is highly fibrous, protein-rich, and gluten-free. It is for use as a novel food ingredient in sweet recipes, baked items, snacks, and ready-to-eat products (Klingel et al. 2020).

SCG can also be used to produce a spirit involving three processing steps. Aroma compounds are extracted out of SCG through hydrothermal treatment which is then supplemented with sucrose and fermented to ethanol, the resulting fermented broth is then distilled. The chemical analysis determined that SCG spiricet had an organoleptic quality that was suitable for human consumption (Sampaio et al. 2013).

Green coffee beans possess numerous nutraceutical benefits and so do their waste by-product SCG. Chlorogenic acids (CGAs) including caffeoylquinic

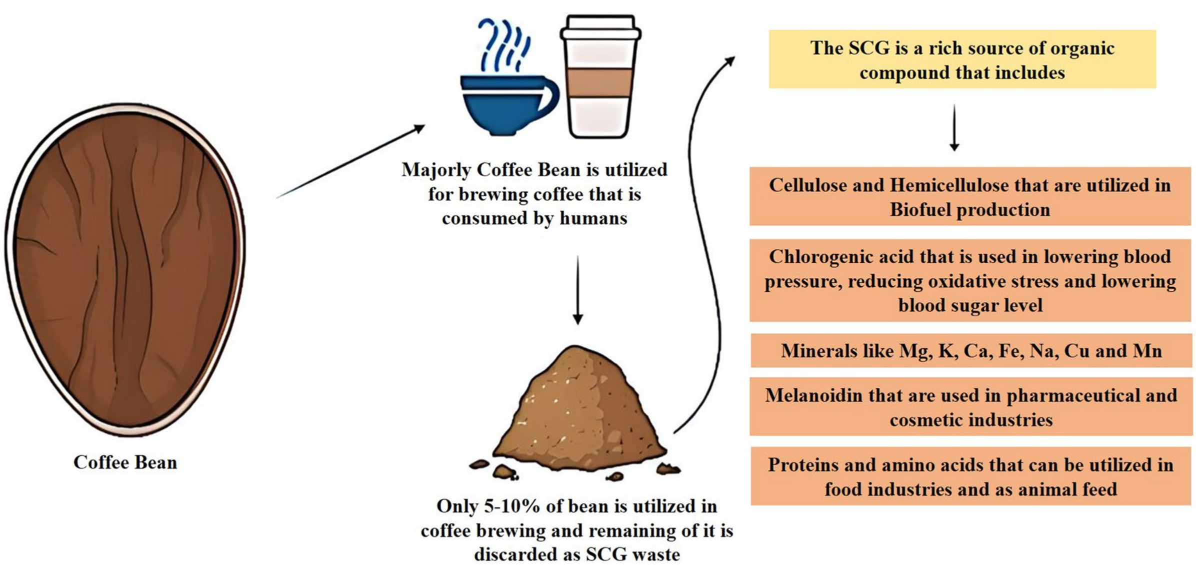


Fig. 3 A general overview of the production of Spent coffee grounds (SCG) after the coffee bean has been used for brewing. The figure further elaborated on SCG with its possible commercial applications

acids are the most studied among such molecules with nutraceutical properties (Fanali et al. 2020). Such wastes can also be a rich dietary source of hydrophilic bioactive antioxidants. Almost all SCGs, generated either from the filter, plunger, or espresso-type coffeemakers, contain a significant amount of total caffeoylquinic acids, mainly di-caffeoylquinic acids which is about 4–7 times more than the brews. Moreover, the observed antitumor and anti-allergenic action shown by the extract of SCG have paved new opportunities in the pharmaceutical application (Valdés et al. 2020).

SCG which is an environmental bothering, can be profitable as an energy source if dealt with appropriately. Considering the energy source, SCG has successfully been converted into biodiesel, bioethanol, bio-ethers, bio-oil and biochar, and biogas (Tun et al. 2020a). SCGs were also used to produce adsorptive filters during the process of wet co-granulation which could then be utilized for the elimination of anionic as well as cationic dyes. A few research have also suggested the cosmetic benefits of SCG for instance, Choi et al., have conducted an experiment on UVB-induced photoaging in hairless mice. They topically applied the oil fraction (OSCG) and ethanol extract (ESCG) of SCG that protected the skin of studied mice by down-regulating matrix metalloproteinases (MMP2, 9, and 13), signifying the potential of SCG extracts as an anti-photoaging agent (Choi et al. 2016). Due to their availability and nutritional richness, SCG has also been added to the feed rations of animal feedstock (San Martin et al. 2021; Rasool et al. 2023).

The modularity, stability, and strength of SCGs' husks made them an ideal candidate for different applications in civil engineering. For example, the great similarity in physical properties of SCGs with that of sand reflects its suitability for road subgrades (Saberian et al. 2021).

With the growing demand for bio-insecticides, a methanol extract of SCGs were successfully investigated by Hussein et al. (2022) for its insecticidal activity against the major pests of green beans namely, *Spodoptera littoralis*, *Agrotis ipsilon*, *Bemisia tabaci*, *Empoasca fabae*, and *Aphis craccivora* (Hussein et al. 2022). SCG compost (SCGC) has been alternatively evaluated instead of commercial peat (CP) and fertilizers. A proportion of 40% SCGC has influenced the dry weight and foliar parameters, thereby improving the general plant stand (Ronga et al. 2016).

5 Conclusion

Driven by rising consciousness on the continual depletion of irreplaceable natural resources, emerging creative and revolutionized approaches for alternately repurposing biowastes for environmental health security and sustainability have been the foremost pursuit of researchers across the globe. The study of naturally occurring substances that are biologically active is expanding all the time. Because of their use and advantages, particularly for human health, peptides are among the possible bioactive chemicals. Peptides can be found in a variety of foods that are made from both animal and plant sources; at the moment, they are found in food industry residues.

Peptides with high bioactive potential were more prevalent in fermented SCG, and these peptides may be used to treat diabetes, hypertension, and oxidative stress. There is not much or scarce information regarding the bioactivity of peptides from SCG protein hydrolysates; however, some peptide fragments with hydrophobic amino acid Tyr (Y) on the C-terminal resemble that generated after thermolysis of Arabica-SCG with alcalde and gastrointestinal digestion of coffee silver-skin with pepsin and pancreatin. Despite several advantages, it is still not well explored at the industrial level to use the SCG treasure trove. Hence, more comprehensive studies are required to identify and evaluate the activity and mode of action of the peptides extracted and their in vivo bioavailability. Thus, coffee can be considered a source of peptides that could aid in reducing the risks of non-communicable chronic diseases. Additionally, the protein obtained from SCG could be used as an alternative food supplement or as functional food over artificial protein sources.

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Author contribution TAS & NP: Writing – original draft, Data curation, Investigation, Formal analysis, Editing. PS: Data curation, Manuscript Revision and Editing; Editing Figures, AKP: Conceptualization, Validation, Visualization, Investigation, Supervision, Writing – Reviewing & Editing.

Declarations

Conflict of interest The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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