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Review

Spent coffee grounds: A review on current research and future prospects

Rocio Campos-Vega[a,*], Guadalupe Loarca-Piña[a], Haydé A. Vergara-Castañeda[c] and B. Dave Oomah[b,1]

[a]Programa en Alimentos del Centro de la República (PROPAC), Research and Graduate Studies in Food Science, School of Chemistry, Universidad Autónoma de Querétaro, Querétaro, Qro 76010, Mexico (Tel.: +52 55 1921304; e-mail: chio_cve@yahoo.com.mx)

[b]National Bioproducts and Bioprocesses Program, Pacific Agri-Food Research Centre, Agriculture and Agri-Food Canada, Summerland V0H 1Z0, BC, Canada

[c]Nucitec, S.A. de C.V., Comerciantes 15-3, Colonia Peñuelas, Querétaro, Mexico

Spent coffee ground (SCG) contains large amounts of organic compounds (i.e. fatty acids, amino acids, polyphenols, minerals and polysaccharides) that justify its valorization. Earlier innovation explored the extraction of specific components such as oil, flavor, terpenes, and alcohols as value-added products. However, by-products of coffee fruit and bean processing can also be considered as potential functional ingredients for the food industry. There is an urgent need for practical and innovative ideas to use this low cost SCG and exploit its full potential increasing the overall sustainability of the coffee agro-industry.

Introduction

Coffee, grown in about 80 countries, is one of the world's most popular beverage and second largest traded commodity after petroleum (Murthy & Naidu, 2012a). Global green coffee production increased by almost 17%, probably due to increased yield (24%), between 2000 and 2012. Several residues are obtained during coffee processing. Coffee producing countries generate residues from the coffee fruit amounting to >50% of the fruit mass (Tsai, Liu, & Hsieh, 2012). Spent coffee ground (SCG) is the residue obtained during the brewing process (Cruz *et al.*, 2012). The huge amount of residue generated annually in the production of soluble coffee requires waste management plan consistent with existing national regulations. For example, Nestlé, the world's biggest food company pledges to reduce waste in Europe by 2020 using spent coffee grounds as a source of renewable energy in more than 20 Nescafé factories. In most of the soluble coffee producing industries, the waste is collected by specialized agencies, which sell the residues for different purposes (i.e. composting, gardening, bioenergy production, mushroom growth). Spent coffee grounds (SCG) contain large amounts of organic compounds (i.e. fatty acids, lignin, cellulose, hemicellulose, and other polysaccharides) that can be exploited as a source of value-added products. Thus, coffee residue has been investigated for biodiesel production (Caetano, Silva, & Mata, 2012), as source of sugars (Mussatto, Carneiro, Silva, Roberto, & Teixeira, 2011), precursor for activated carbon production (Kante, Nieto-Delgado, Rangel-Mendez, & Bandosz, 2012), compost (Preethu, BhanuPrakash, Srinivasamurthy, & Vasanthi, 2007), and as sorbent for metal ions removal (Fiol, Escudero, & Villaescusa, 2008).

By-products of coffee fruit (Fig. 1) and bean processing can also be considered as potential functional ingredients for the food industry. The coffee husks, peel and pulp, comprising nearly 45% of the cherry, are the main by-products of coffee agro-industry and can be a valuable material for several purposes, including caffeine and polyphenols extraction. Coffee husks and skins are traded as crops and livestock products with export and import range of 857–27,209 and 490–11,474 tonnes from 2000 to 2012 according to FAO Statistics. These export and import were valued at 2.2–62.7 and 1.7–24.3 million US$, respectively for the same period. Other by-products of coffee processing such as mucilage and parchment have been less studied; however, they are potential sources of important ingredients. The pulp is easily fermented by yeast or metabolized by lactic acid bacteria producing alcoholic beverages and

* Corresponding author.
[1] Retired.

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Abbreviations

SCG	Spent coffee grounds
MOS	Mannooligosaccharides
AAA	Aromatic amino acids
MAE	Microwave assisted extraction
FOSHU	Food for Specified Health Uses
DF	Dietary fiber
AACC	American Association of Cereal Chemists
BCAA	Branched chain amino acids
SFE	Supercritical fluid extraction
HMW	High molecular weight
HMWM	High molecular weight melanoidins
COM	Cost of manufacturing
$scCO_2$	Supercritical carbon dioxide
CGA	Chlorogenic acid
CQA	Caffeoylquinic acids
GAE	Gallic acid equivalents
PHB	Poly 3-hydroxybutyrate

vinegars. Furthermore, roasted coffee silver skin has been evaluated for use as a dietary fiber rich ingredient with antioxidant properties. Finally, SCG have been studied mainly for their antioxidant activities (Esquivel & Jiménez, 2012). These antioxidants have been associated with health benefits (Campos-Vega, Oomah, Loarca-Piña, & Vergara-Castañeda, 2013; Campos-Vega *et al.*, 2009; Vergara-Castañeda, Oomah, & Campos-Vega, 2013).

Spent coffee ground was rarely investigated until the beginning of this decade with half (36 out of 72) of the total number of papers published in the last 4 years since 1973. A cursory search of 'spent coffee ground' on "Scopus" produces similar result with 11, 27, 14, 15 and 2 publications annually from 2014 to 2010. This review aims to use existing knowledge on spent coffee ground and/or its components in developing a biorefinery platform to add value to this inexpensive waste product.

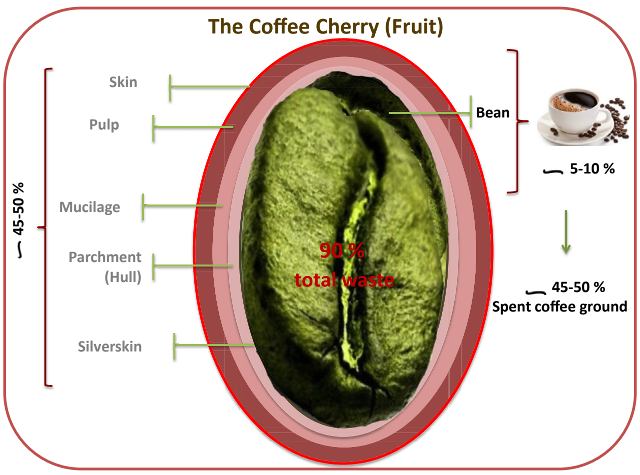

Fig. 1. The coffee cherry fruit wastes (With information of: Murthy & Naidu, 2012a; Esquivel & Jiménez, 2012).

Carbohydrates

The coffee bean is a rich source of polysaccharides (~50% of the green bean's dry weight) mainly consisting of mannans or galactomannans, type II arabinogalactans, and cellulose. Mannan, the main polysaccharide of coffee extract, is responsible for its high viscosity, which in turn negatively affects the technological processes involved in instant coffee production. This polysaccharide consists of β-(1 → 4)-linked mannan chains substituted at approximately every 100 residues in the *O*-6 position with single galactose residues. Arabinogalactans have an arabinose/galactose ratio of 0.4/1 and consist of β-(1 → 3)-linked galactose backbone substituted at the *O*-6 position with arabinose and/or galactose residues. The side-chains contain arabinose and galactose residues with arabinose as terminal residue. These linkages are characteristic of type-II arabinogalactans, a polymer usually covalently linked to protein (Bradbury & Halliday, 1990). The roasting process increases both bean arabinogalactan and mannan solubility by loosening the cell-wall structure as it swells and by polysaccharide depolymerization (Wei *et al.*, 2012). The water-soluble polysaccharides that appear after roasting play an important role in retaining volatile substances, and contribute to the coffee brew viscosity and, thus, to the creamy sensation known as "body" in the mouth (Illy, Viana, & Roasting, 1995).

These galactomannans and arabinogalactans are extracted upon coffee roasting, during the beverage preparation, using hot pressurized water (Nunes & Coimbra, 2010). However, most of these polysaccharides remain as insoluble material bound to the SCG matrix (Mussatto, Carneiro, *et al.*, 2011; Simões, Nunes, Domingues, & Coimbra, 2013). Galactomannans exhibit different physicochemical properties and are therefore used in many applications: they are excellent stiffeners and emulsion stabilizers, and the absence of toxicity allows their use in the textile, pharmaceutical, biomedical, cosmetics and food industries. The main applications of galactomannans in food are in dairy products, fruit-based water gels, powdered products, bakery, dietary products, coffee whiteners, baby milk formulations, seasonings, sauces and soups, tinned meats and frozen and cured meat foods (Prajapati *et al.*, 2013).

Spent coffee ground is rich in sugars polymerized into cellulose and hemicellulose structures, which correspond to almost half (45.3%, w/w, dry weight) of the material. SCG contains 46.8% mannose, 30.4% galactose, 19% glucose, and 3.8% arabinose, with mannans as the major polysaccharides (Mussatto, Carneiro, *et al.*, 2011). However, further investigation by the same group (Mussatto, Machado, Carneiro, & Teixeira, 2012) revealed a lower (2.2-fold) sugar composition for the same SCG consisting of 21.2% mannose, 13.8% galactose, 8.6% glucose, and 1.7% arabinose. This SCG can be hydrolyzed