TITLE

Development of Sustainable Novel Foods and Beverages Based on Coffee By-products for Chronic Diseases

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Synopsis

Obesity and type 2 diabetes have reached epidemic proportions in the past few years. The market of functional foods has greatly increased for the reduction of risk of chronic diseases. Coffee is one of the most frequently consumed drinks worldwide and large amounts of coffee wastes need to be recycled in order to reduce its environmental impact. Coffee by-products contain appreciable amounts of bioactive nutrients exerting health promoting properties. Therefore, the valorization of coffee wastes represents a great opportunity for the sustainability of the coffee sector and the industry of functional beverages and foods for chronic diseases.

Abstract

At present, the global obesity epidemic is showing no signs of abating, which is fueling an explosion in numbers of type 2 diabetes (T2D) worldwide. In order to control these two associated diseases, lifestyle modification, which encompasses diet, physical activity, and healthy habits, might be useful. The use of bioactive compounds obtained from vegetable sources might be a favorable approach to reduce the risk of metabolic chronic diseases; however, it is still a challenge to face. Coffee silverskin (CS) and spent coffee grounds (SCG) are very abundant coffee wastes worldwide generating global environmental problems. They are natural sources of several bioactive compounds with potential to reduce the risk of chronic non-communicable diseases, such as chlorogenic acid (CGA), caffeine and dietary fiber. The widespread interest in select foods that might promote health has resulted in the use of functional foods to provide specific health benefits beyond basic nutrition. Therefore, these two coffee wastes may become sustainable high value-added ingredients of interest for the management of obesity and T2D. The present chapter presents the feasibility to produce sustainable high sensorial quality beverage and foods, for reducing the risk of chronic metabolic diseases, by means of employing as novel ingredients coffee by-products (CS and SCG) and their derivatives, in combination with other functional ingredients.

Introduction

Currently, chronic diseases are the leading global causes of death. It will increase up to 52 million of deaths by 2030 (World Health Organization, 2014). Obesity and type 2 diabetes (T2D) have reached epidemic proportions and are worldwide health problems. These metabolic chronic diseases are caused, to a large extent, by behavioral risk factors such as changes in dietary macronutrient intake.

Obesity is a chronic disease characterized by the expansion of adipose tissue and an inflammatory component. Adipose tissue releases a variety of adipokines, anti- or pro-inflammatory cytokines such leptin, TNF-α and interleukin [IL]-4 (Lee, Lee and Choue, 2013). These pro-inflammatory molecules play an important role on the development of metabolic disease such as T2D (Hajer, van Haeften and Visseren, 2008). Diabetes mellitus is a chronic disorder characterized by major derangements in glucose metabolism and abnormalities in fat and protein metabolism (Mentreddy, 2007). T2D is the most common type of diabetes representing 90–95% of all cases. Most patients with T2D, but not all, are overweight or obese, in fact, this excess weight itself causes some degree of insulin resistance. Several epidemiologic studies reveal a parallel increase of obesity and diabetes. Diabesity is a new term, which refers to diabetes occurring in the context of obesity. The increase in the prevalence of T2D is associated to the upsurge in obesity. It is estimated that about 90% of T2D is attributable to excess weight (Verma and Hussain, 2017). Previous studies support the protective role of diet, exercise and its combination in individuals genetically susceptible to both pathologies (Temelkova-Kurktschiev and Stefanov, 2012). Table 1 provides information on the role of lifestyle facts on the risk of obesity and T2D.

<Table 1 near here>

Therefore, it is possible to reduce the risk of these metabolic diseases through different strategies being the most sustainable the promotion of a healthy diet. Dietary fiber is positively associated with enhanced weight control and obesity (Slavin, 2008) and reduced risk of T2D (de Munter *et al.*, 2007). Several antioxidant compounds, such as the chlorogenic acid (CGA), which is the main antioxidant of the coffee, have been proposed as anti-obesity and anti-diabetic agents (Meng *et al.*, 2013; Sun, Wu and Chau, 2016). Moreover, a wide range of phytochemicals present in plants and foods, might behave as α-glucosidase and/or lipase inhibitors so they are used as bioactive compounds for glycemic control in T2D (Kim, 2015) and management of obesity (Adisakwattana *et al.*, 2012). On the other hand, there are food components that might promote the feeling of fullness by stimulating gut-derived hormones involved in satiety like glucagon-like peptide-1 (GLP-1) and serotonin. Peptides (Geraedts *et al.*, 2010, 2011)., carbohydrates (Cani *et al.*, 2005), steviol glycosides (Ripken *et al.*, 2014) and CGA (Olthof *et al.*, 2011) among others, have showed satiating properties.

In this sense, coffee by-products could play an important role as natural sustainable sources of functional ingredients. They are natural sources of several bioactive compounds with potential to reduce the risk of chronic non-communicable diseases (Galanakis *et al.*, 2015; María Dolores del Castillo *et al.*, 2016; del Castillo *et al.*, 2017). In this chapter we propose the development of sustainable high sensorial quality beverage and foods, for reducing the risk of chronic metabolic diseases, by means of employing as novel ingredients coffee by-products (CS and SCG) and their derivatives, in combination with other functional ingredients. In addition, the impact of the digestive process of these functional foods containing coffee by-products on the release of satiety hormones is also presented.

Coffee silverskin and spent grounds as natural sustainable sources of functional ingredients

Due to the great coffee demand, large amounts of by-products are generated in the coffee industry, which might be used as novel products to achieve a global sustainable management. Figure 1 represents coffee silverskin (CS) and spent coffee grounds (SCG) production employing the wet process of the bean and the instant coffee processing.

<Figure 1 near here>

CS is a thin tegument of the outer layer of the green coffee beans obtained as a by-product of the roasting process, which represents 4% (w/w) of the coffee cherry. CS has a high content in dietary fiber (68-80%) and polysaccharides (60-70%). CS contains protein, fat, and ash, at 16–19%, 2–3%, and 5-7%, respectively (del Castillo *et al.*, 2018). This coffee by-product presents phenolic compounds, mainly CGA, and other phytochemicals that contribute to its high antioxidant capacity. An aqueous CSE from Arabica (*Coffea arabica*) and Robusta (*Coffea canephora*) enriched in caffeine and CGA and obtained using an environmentally friendly technology have been patented (del Castillo *et al.*, 2013). CSE presents a total dietary fiber content ranging from 29 to 36%, including 4-9% insoluble dietary fiber and 24-26% soluble dietary fiber. CSE is a good source of polyphenols, in particular CGA (1-7%), caffeine (3%) and melanoidins (17-23%) (Mesías *et al.*, 2014).

SCG are the most abundant coffee by-product (45%) generated during the treatment of coffee powder with hot water to prepare coffee infusion or steam for the instant coffee preparation (Murthy and Madhava Naidu, 2012). About 2 kg of wet SCG are obtained from each kg of instant coffee produced, with an annual generation of around 6 million tons worldwide. Regarding their chemical composition, polysaccharides are the major macronutrients (75%). Among them, dietary fiber is the most important fraction (43-

54%), being the insoluble fiber predominant (47-50%). SCG also contain protein, fat and ashes (14-17%, 2.3% and 1.3-1.6%, respectively). Caffeine ranges from 0.2 to 0.8% and different health-related chemicals bound to dietary fiber and proteins such as CGAs (Bravo *et al.*, 2012; Jiménez-Zamora, Pastoriza and Rufián-Henares, 2015).

CS due to its bioactive compounds has been associated to food technology and health properties. This coffee by-product can be used as prebiotic carbohydrate (Borrelli *et al.*, 2004) and is involved in the production of short chains of FOS, which have more prebiotic activity and stronger sweetness (Mussatto *et al.*, 2013). Moreover, CS is used to obtain innovative coffee blends rich in bioactive compounds (Ribeiro *et al.*, 2014) and formulations of bread to reduce caloric density and to increase the dietary fiber content (Pourfarzad, Mahdavian-Mehr and Sedaghat, 2013). On the other hand, new evidence on CSE and its effects on reducing the risk of metabolic chronic diseases has been reported (Fernandez-Gomez, Lezama, *et al.*, 2016). Moreover, CSE improves glucose-stimulated insulin secretion, protects against streptozotocin-induced damage in pancreatic INS-1E beta cells (Fernandez-Gomez, Ramos, *et al.*, 2016) and inhibits AGEs formation (Fernandez *et al.*, 2018). Regarding SCG, it has been used as additives and coadjuvants for the conversion of isoflavone glycosides into their aglycones with high biological activities in black soymilk (Chen *et al.*, 2013). A distilled beverage with a coffee aroma has been produced from SCG (Sampaio *et al.*, 2013). In addition, dietary fiber can be extracted from SCG employing different processes such as ohmic technology and fermented by colon microbiota producing metabolites that exhibit strong anti-inflammatory potential (Vázquez-Sánchez *et al.*, 2015; Campos-Vega *et al.*, 2016).

Therefore, validation of CS and SCG into food ingredients with health promoting properties to reduce the risk of metabolic chronic diseases may contribute to a sustainable nutrition of the population.

Novel foods and beverages based on coffee by-products

Sweet drinks, packaged snacks, and biscuits provide significant amounts of energy to the population, which contributes to the risk of obesity and T2D. In order to satisfy consumer's demands, recent research focuses the attention on the design of sustainable healthier beverages and bakery products. These novel foods have been formulated by using CS and SCG as natural sources of health-promoting compounds.

Novel beverages

Coffee wastes have been hardly used in the design of functional beverages so far. Two commercial beverages based on coffee husks are attracting the interest of the western consumers: Bai Brands uses coffee husk extract as an ingredient in their beverages which contain antioxidants and caffeine, and KonaRed preserves the majority of the nutrients from the coffee plant and the dominant polyphenols (chlorogenic acid, quinic acid and ferulic acid) in the beverages prepared with coffee husks. However, these drinks have not been associated yet to any particular health benefit beyond those described for their individual bioactive compounds present in the coffee wastes.

The use of CS for the preparation of novel beverages has been proposed for the first time in this study (Martinez-Saez *et al.*, 2014). The CSE was obtained by a simple water extraction stage (100 °C for at least 10 min) described in patent WO2013004873 A1, enriched in bioactive compounds. New knowledge on the potential effect of CSE prepared as an antioxidant beverage on body fat accumulation *in vivo* and the responsible bioactive compounds was obtained (Martinez-Saez *et al.*, 2014). The development of novel beverages requires sensorial analyses in order to evaluate the quality attributes of the product and the results concluded that the acceptance level of the beverages made with

CSE was satisfactory since 95% of the panel were favorable towards the beverages (figure 2). In addition, the beverages presented low sugar content since they were prepared without addition of nutritive sweeteners and glucose amount was not detected. These novel drinks respond to the global obesity concerns and fit perfectly with the requests from the European Union to reformulate drinks and set a target of 10% added sugar reduction.

<Figure 2 near here>

Regarding the *in vivo* biological effects of these new beverages on the body fat reduction, *Caenorhabditis elegans (C. elegans)* was employed as the animal model (Martinez-Saez *et al.*, 2014). This worm is considered an excellent candidate for whole organism-based high-throughput screening in drug assessment as a preclinical model (O'Reilly *et al.*, 2014) and for initial studies of nutrition interventions prior to confirmation in higher animal species (Gao, King, *et al.*, 2015). The results of the study showed that the main bioactive compounds of the CSE, CGA and caffeine, significantly reduce lipid deposits in *C. elegans*. They were found in physiologically active doses in the beverages prepared with CSE, however unexpectedly a synergic and/or additive effect was not detected. Melanoidins, which are also present in the CSE beverages, are constituted by carbohydrates, including dietary fiber (soluble Maillardized fiber), proteins and polyphenols such as CGA (Silván, Morales and Saura-Calixto, 2010). All of them conform the matrix of the beverage and thereby may be affecting the bioaccessibility and bioavailability of CGA and caffeine, respectively, by adhering them to their complex structure. Moreover, unlike those beverages prepared with ACSE, those containing RCSE achieved higher effects on lipid metabolism and similar to those found in a commercial dietary supplement, made from Robusta decaffeinated green coffee extract. Robusta specie has been shown to possess higher content of bioactive compounds and CGA appears as the main one to affect the lipid metabolism.

Recently, it has been demonstrated that CSE and CGA are able to significantly inhibit the activity of pancreatic lipase *in vitro* (M.D. del Castillo *et al.*, 2016), which may be one of the possible mechanisms of action exerted by the CSE beverages to reduce fat accumulation. Moreover, dietary fiber of the beverages from CSE might also have impact on body fat accumulation. Several studies showed effect of dietary fiber from barley and oat (0.5, 1 and 3 %) on the body fat of *C.elegans* wild type N2, primarily mediated via sir-2.1, daf-16, and daf-16/daf-2 and daf-2 gen (Gao, Gao, *et al.*, 2015; Gao, King, *et al.*, 2015). In addition, these novel beverages based on CSE have antioxidant properties which may be attributed no only to polyphenols such as CGA but to other compounds like melanoidins. These bioactive compounds present multiple biological activities that may enhance the value of these beverages (Mesías and Delgado-Andrade, 2017).

Novel foods

Biscuits represent the largest category of snack item among bakery products and compounds from coffee by-products have become excellent ingredients to be incorporated in bakery products in order to enhance their sensorial and nutritional quality and to simultaneously achieve a sustainable effect in the coffee sector. Coffee flour is a new ingredient developed from the coffee pulp presenting high fiber and ash content and low fat level (Ramirez Velez and Jaramillo Lopez, 2015), which has been proposed for its use in different food formulations such as breads, cookies and muffins with better nutritional properties. The high content of dietary fiber in coffee husk appears as an advantage in making “energy bars”, by grinding the whole coffee husk and thereby including all antioxidants and fiber into the product. Then, the coffee husk could be launched as an allergic-friendly ingredient since it's naturally gluten free. (Bondesson, 2015). Just one study on the use of chemically pre-treated CS as an ingredient of bread formulations has been reported (Pourfarzad, Mahdavian-Mehr and Sedaghat, 2013). Very recently, research on the use of natural whole SCG and CS as food ingredients for improving technological and nutritional quality of bakery products has been conducted (Garcia-Serna *et al.*, 2014; Martinez-Saez, Tamargo, *et al.*, 2017)

- *Biscuits based on coffee silverskin*

The feasibility and effectiveness of applying 1) CS, 2) CSE, or 3) CSE combined with the solid residue recovered from the extraction process, to non-added sugar biscuits was studied (Garcia-Serna *et al.*, 2014). For the first time a full recovery of CS was achieved through the whole conversion into two products, natural coloring and source of fiber.
On one hand, the dietary fiber plays a key role on the technological quality as a texturizing agent and on the nutritional properties enhancing the nutritional value of the biscuits. On the other hand, the coloring has an essential impact on the sensorial properties of the biscuits, which will provide the typical golden color expected of this type of baked products. This double effect of the use of whole CS on sensorial and nutritional quality plays an essential role in achieving high acceptancy by the consumers. Results showed that in sugar-free biscuits the non–enzymatic browning reactions, such as Maillard reaction, phenol oxidation and caramelization, are limited (Garcia-Serna *et al.*, 2014). However, those biscuits containing stevia as non-nutritive sweetener and CSE did not present significant differences in color compared with the sucrose-containing biscuits. The results support the validity of using CSE as a natural coloring (figure 3).

<Figure 3 near here>

Furthermore, along with the desired flavor and color related substances, food processing contaminants such as acrylamide and hydroxymethylfurfural (HMF) are formed in the Maillard reaction. Both, acrylamide and HMF, possesses genotoxic and carcinogenic properties (Nguyen *et al.*, 2016). CSE and its main phenolic compound, CGA, have been shown to possess antiglycative properties thereby limiting the Maillard reaction (Mesías *et al.*, 2014). The use of CS as an ingredient of the biscuits partially improves to a great extent this food processing contaminant formation. In addition, the non-nutritive sweetener stevia, plays a key role on the safety quality of the products since results show reduced formation of these food processing contaminants when sugar is replaced with stevia. The combination of both coffee by-product and non-nutritive sugar replacers provide a safer product.

Likewise, the digestive process plays a decisive role on the release of compounds of interest in health and disease. The results of the research (Garcia-Serna *et al.*, 2014) showed that after *in vitro* simulated oral-gastrointestinal digestion of the biscuits formulations, acrylamide was not bioaccessible to be absorbed. Gastrointestinal conditions and food composition affect the levels of bioavailable acrylamide. Acrylamide possess the potential to react with the nucleophilic groups (–SH, –NH2) of amino acid side chains under the digestion conditions and the levels of acrylamide ingested with foods may not directly indicate its absorption rate through gastric, duodenal and colonic routes (Hamzalıoğlu and Gökmen, 2015). Furthermore, these biscuit formulations present low content of bioaccessible glucose, in fact, a serving of four biscuits would provide less than 3 g sucrose. This is in line with the need of formulating food with reduced sugar content as it is suggested by the European Union. Consequently, these innovative foods may be potentially suitable for diabetics or people who want to lose weight.

– *Biscuits based on spent coffee grounds*

The use of SCG from the industrial instant coffee process as food ingredient in the development of a healthy product line of pastry, confectionery and/or bakery products has been recently aimed (*patent WO2014128320 A1*) (del Castillo, Martinez-Saez and Ullate, 2014). The patented application proposes the use of SCG as sustainable natural antioxidant insoluble dietary fiber. Since SCG comes from the food industry, its use as coffee fiber is of grade as well, and its conversion in a co-product may be feasible regarding food safety and traceability. It can be used in the range between 4-8%, which correspond to the nutrition claims "source of fiber" and "high fiber content", respectively (European Regulation (EC) No 1924/2006). The antioxidant properties of the insoluble coffee fiber present in SCG can be associated with phenolic compounds bound to proteins, polysaccharides and melanoidins (Jiménez-Zamora, Pastoriza and Rufián-Henares, 2015). There is evidence for the existence of a complex named "maillardized insoluble dietary fiber" constituted of dietary fiber, protein, Maillard reaction products and polyphenols, in bakery products (Pérez-Jiménez *et al.*, 2014).

The coffee antioxidant insoluble dietary fiber combines beneficial effects of both dietary fibers and antioxidants. Insoluble fiber may play an important role for weight loss during consumption of a high-fat diet (Du *et al.*, 2010) as well as for reducing the risk of T2D (Meyer *et al.*, 2000). The insoluble fiber can result in a reduced appetite and food intake, which may lead to a decreased caloric intake and body mass index (Samra and Anderson, 2007). The short chain fatty acids, via fermentation of the insoluble fiber, have been shown to reduce postprandial glucose responses (Ostman, Liljeberg Elmståhl and Björck, 2002). On the other hand, the intake of antioxidant dietary fiber has been recommended for health improvement of the gastrointestinal tract. The pathogenesis of various gastrointestinal diseases such as irritable bowel syndrome and inflammatory bowel disease is in part due to oxidative stress. Antioxidant compounds may be beneficial at reducing the risk of these gastrointestinal diseases (Moura *et al.*, 2015).

This gluten-free coffee fiber can be used into diverse combinations with other basic and/or novel ingredients such as non-nutritive sweeteners and gluten-free flours, and thereby it may allow their use for people with special nutritional needs such as diabetic people and overweight or obese people. SCG possess a very high amount of insoluble dietary fiber (42%) which is superior to other are natural sources of insoluble fiber such as black beans (16%), lentils (8%) or almonds (12%). This coffee fiber is stable to thermal process such as a baking and to the abiotic gastrointestinal digestion *in vitro* (Martinez-Saez, Tamargo, *et al.*, 2017). On the other hand, it contains low amounts of free CGA and caffeine, none levels of free sugar and small quantity of acrylamide (37 µg/kg) and HMF (61 mg/kg). The acrylamide values are 92–96% lower than the indicative values proposed by European Commission (2013) for roast (200-250 µg/kg) and instant coffee (350-595 µg/kg) (European Commission (EC)., 2013). Likewise, HMF levels are also very far from those amounts found in the coffee (100–1900 mg/kg) and instant coffee (400–4100 mg/kg) (Capuano and Fogliano, 2011). The coffee fiber is exhausted of these compounds since they were extracted during the preparation of soluble coffee beverage. In addition, the coffee fiber derived from the instant coffee production presented high microbiological safety in this particular case. Therefore, SCG become a cost-friendly source of healthy insoluble dietary fiber that does not require further purification to be used as food ingredient of bakery products to enhance their nutritional and biological quality.

Sugar was replaced with non-nutritive sweeteners such as stevia, and FOS were added as soluble dietary fiber and enhancer of the taste of the coffee fiber-containing biscuit (CFB). The sensory and acceptance tests of the novel biscuits show that the coffee fiber and stevia are highly accepted ingredients, and above all when combined with FOS in the formulation. FOS present slightly sweetness and might act masking negative off-flavors from the stevia and the coffee fiber. The novel biscuits containing coffee fiber and non-nutritive sweeteners (figure 2) seem to meet consumer's preferences.

CFB presented lower levels of both dietary early Maillard reaction products and advanced glycation end products (AGEs) than the sucrose-containing biscuit (SCB). This indicates that the presence of sucrose during baking increases the amount of compounds that can be limited by the replacement with non-nutritive sweetener. Moreover, it has been reported antiglycative properties of CGA (IC50 = 0.4 mg/ml) and RCSE (0.6 mg/ml) (Mesías *et al.*, 2014). The coffee fiber presents CGA and other phenolic compounds (2 mg/g) and one CFB (≈10 g) would provide 0.4 mg CGAs. Thereby this coffee fiber might also prevent the formation of these compounds, which are associated with oxidative stress and inflammation, eventually causing higher risk of most chronic diseases such as T2D and obesity (Vlassara and Uribarri, 2014; Sayej *et al.*, 2016). Incorporation of FOS to the biscuits also contributes to the balance of soluble: insoluble dietary fiber and promotes the growth of specific beneficial gut bacteria (Bosscher, Van Loo and Franck, 2006). Recently, relationship between non-digestible carbohydrates, including FOS, and reduction of post-prandial glycemic responses was established by the EFSA (European Food Safety Authority (EFSA)., 2014).

Additionally, *in vitro* effects of the bioaccessible food components released during the simulated human digestion of the novel CFB, on α-glucosidase activity and satiety hormones were examined (Martinez-Saez, Hochkogler, *et al.*, 2017). To the best of our knowledge, this is the first report on the potential antidiabetic and satiating effects of foods comprising coffee fiber and non-nutritive sweeteners.

The content in glycemic sugars such as glucose and fructose in the biscuit digests was significantly reduced. The CFB can be classified as “no added sugars” declaring that may “contains naturally occurring sugars” (European Regulation (EC) No 1924/2006). Likewise, the content of insoluble and soluble dietary fiber of the novel biscuits provided by the coffee fiber from SCG and FOS respectively, lead to categorize these novel biscuits under the nutrition claim “high fiber” (≥ 6 g of fiber per 100 g or ≥ 3 g of fiber per 100 kcal).

The present study shows antioxidant character of the CFB digest. The transportation of dietary antioxidants through the gastrointestinal tract has been described as an essential function of dietary fiber. Polyphenols linked to dietary fiber may be released in the colon by the action of the microbiota, producing bioactive metabolites and an antioxidant environment, thereby reducing the risk of gastrointestinal diseases associated with oxidative stress and inflammation (Saura-Calixto, 2011) (figure 4 (i)). CGA, which is present in the coffee fiber, has shown potential to inhibit signaling molecules involved in inflammation processes, thereby acting as an anti-inflammatory antioxidant compound (López-Barrera *et al.*, 2016).

<Figure 4 near here>

Stevia and FOS present in the novel biscuit were effective inhibitors of α-glucosidase activity *in vitro* (figure 4 (ii)). Moreover, previous studies have reported an association of antioxidants, in particular polyphenols, with α-glucosidase inhibition (Xiao *et al.*, 2013). The release of phenolic compounds incorporated in the coffee fiber structure during the digestion process may enhance tolerance to carbohydrates by inhibiting intestinal α-glucosidase. Diterpens such as cafestol and kahweol, which have been described to be present in SCG (Acevedo *et al.*, 2013), might be contributing to this inhibitory effect on α-glucosidase exerted by the novel biscuits. Alpha-glucosidase inhibitors reduce the impact on blood sugar and therefore postprandial hyperglycemia. The control of glucose absorption plays a key role in the management of T2D.

The coffee fiber exhibited a potent stimulation of the gut serotonin and GLP-1 hormones *ex vivo* by using Caco-2 and HuTu-80 cells, respectively (figure 4 (iii)). These intestinal hormones can regulate the feeling of fullness via neural paracrine routes with subsequent afferent signaling to brainstem nuclei. GLP-1 also regulates the feeling of fullness via the endocrine pathway through the hepatic portal and cava vein (Steinert, Beglinger and Langhans, 2016). The intestinal secretion of serotonin responds to chemical and mechanical stimuli after food intake (Voigt and Fink, 2015). Thus, the antioxidant coffee fiber is expected to exhibit a greater stimulation of satiety hormones *in vivo* than that described in this study, due to the physical effect of the indigestible material obtained from the digestive process. In addition, the soluble fiber (FOS) incorporated to the novel biscuits may be also positively affect the release of these satiety hormones. It has been described, in a double blind randomized clinical trial, an increase of the satiety feeling when FOS enriched cookies (10 per day) were consumed by obese patients for a month (de Luis *et al.*, 2013). On the other hand, galactomannan, a soluble fiber that is released from the SCG during the digestive process, may enhance satiety by forming a viscous gel in the stomach, and thereby slowing gastric emptying and enhancing fullness. The secretion of GLP-1 hormone also participates in glycemic tolerance via glucose-induced secretion of insulin from pancreatic β-cells and via glucagon release inhibition from pancreatic α-cells (Yabe and Seino, 2011) (figure 4). Therefore, a double antidiabetic and satiating potential effect might be achieved thanks to the secretion of GLP-1.

Conclusion

The use of coffee by-products in the development of novel sustainable beverages and foods with enhanced technological, nutritional and sensorial quality is feasible. Technological strategies are achieved for valorization of coffee by-products into novel health promoting food ingredients, avoiding the production of new industrial wastes. Scientific evidences regarding the potential of the sustainable beverages and foods for reducing the risk of obesity and T2D are obtained.

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