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Plant Food By-Products

Industrial Relevance for Food Additives and Nutraceuticals

J. Fernando Ayala-Zavala, PhD
Gustavo González-Aguilar, PhD
Mohammed Wasim Siddiqui, PhD
Editors

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CHAPTER 8

BY-PRODUCTS OF THE NUT AND PEANUT AGRO-INDUSTRY AS SOURCES OF PHYTOCHEMICALS SUITABLE FOR THE NUTRACEUTICAL AND FOOD INDUSTRIES

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ABSTRACT

Nut by-products are the materials discarded from the peeling process of edible peanuts and tree nuts such as almonds, pistachio, pecans, and hazelnuts. These by-products constitute more than 50% of the total weight generated by the nut industry and represent a large amount of solid waste to handle by the producers. Currently, few useful strategies, with low or nule-added value, exist for disposal of these by-products. Some authors point out that there are more ambitious applications for their uses. They are an excellent source of phenolic compounds and dietary fiber with potential applications, not only as nutraceuticals or functional food ingredients to protect human health but also to enhance shelf life or quality of several foodstuffs when used as natural additives. The aim of this chapter is to review the nutraceutical potential of phytochemicals from nut by-products, their physiological effects in human health, and their use in the food industry.

8.1 INTRODUCTION

The term "nuts" refers to the dry and hard seeds that some trees develop; these include almond (*Prunus amygdalus*), pecan (*Carya illinoinensis*), pistachios (*Pistacia vera*), hazelnuts (*Corylus avellana*), walnuts (*Juglans regia*), among others (Brown, 2003). Peanuts (*Arachis hypogaea*) are not nuts from a botanical point of view; however, their chemical composition and nutrient profile (Prior and Gu, 2005) is very similar to that of tree nuts and therefore are included in the present chapter. Nuts have been part of the human diet for thousands of years; however, they are not a basic diet food group (Pimenta, 1992), since they are popularly regarded as "fatty foods" due to their high fat and caloric content (Vadivel and Biesalski, 2011). A lack of correct information has contributed to misunderstand the impact of nut consumption on body weight; nevertheless, some epidemiologic studies have shown that inclusion of nuts in a diet does not induce weight gain (Vadivel and Biesalski, 2011). The perception on this food has gradually changed and the average intake has risen specially after 2003, when the United States Food and Drug Administration made the first statement suggesting that consumption of 1.5 Oz (42.5 g) of nuts a day, as a part of a diet low in saturated fat and cholesterol, can reduce the risk of suffering from heart diseases (Brown, 2003). This statement may have contributed to the increase of amount of nuts consumed on average by the North American consumer for up to 45% since 1995 (Buzby and Pollack, 2008). Moreover, as nuts have been now regarded as “functional foods,” that is foods that, in addition to their nutritive value, provide nonnutrient ingredients that promote health and reduce disease-risk in humans; scientific interest in these nonnutrient health-promoting ingredients has also risen (Bolling et al., 2011). Of special interest to scientists and producers has been the fact that some of these health-promoting or bioactive ingredients are highly concentrated in the shells and skins of nuts (Wijeratne et al., 2006; de la Rosa et al., 2011; O’Shea et al., 2012), which are usually discarded as waste products during nut commercialization, so these by-products are rich sources of health-promoting natural compounds with several biological and chemical properties, potentially useful for the food and health industries (O’Shea et al., 2012).

The purpose of this chapter is to provide a general overview of the trends that researches are taking on the isolation of bioactive compounds from by-products of the nut industry and their biological activities, as well as their in vitro and in vivo experiments to prove their functional or bioactive properties. Especial attention is given to the animal studies which suggest protective activity of by-product extracts against different kinds of disease. Potential applications of some extracts as food preservatives or additives capable of maintaining food quality and increasing its healthy properties are also discussed, considering, when possible, the doses that would be required for their actual biological activity.

8.2 NUT BY-PRODUCTS

As a consequence of the current increase in the consumption of nut products, the nut industry faces the issue of by-product accumulation. By-products are derived from the inedible portion of nuts: leaves, husks, plant bark, and most of all, shells which are harvested with the dried fruits and released in the peeling process. These by-products are a concern for the industry due to the lack of dumping sites appropriate to avoid the spread of insects and unwanted wildlife in areas nearby its confinement, becoming, therefore, an environmental problem (Suppadit et al., 2012; Zhao et al., 2012). According to Food and Agriculture Organization of the United Nations (Nations, 2013), the production of tree nuts was about 14 million tons in 2013. Approximately, 50–60% of the whole nut production of the nut industry drifts into devalued by-products through the peeling process, and, in the best case, is used as a resource to obtain heat energy (Chen et al., 2010), applied as fertilizer on agricultural crops, production of activated carbon filters (Esfahlan et al., 2010), or as dietary supplement for barnyard animal food (Chen et al., 2010). Nevertheless, the post-crop utilization of this by-product is not sufficiently profitable, and development of new applications that lead to a transformation and to a greater usefulness of these products is desirable.

Nowadays, consumers are searching for new and better foods that not only fulfill the daily requirements of nutrients for the body but also provide some bioactive ingredients to promote and protect their health, the so-called functional foods, that may exert health benefits beyond basic nutrition by the presence of phytochemical compounds, which are not properly nutrients (e.g., polyphenolic compounds). Functional foods can contribute to improve physiological, physical, and mental health and the functional food industry has been steadily growing in the last decade. Closely linked to the design and production of novel functional foods, commercialization, and use of nutraceuticals (i.e., pharmaceuticals obtained from food) or health supplements, which are constituted by the isolated bioactive principles of functional foods and presented to the consumers as capsules, or other medical form, has also risen (Lau et al., 2012). It has been proposed that by-products from the nut and other agricultural commodities can be used as sources of bioactive components, exploitable by the functional food and nutraceutical industry, adding economic value to these by-products (O'Shea et al., 2012).

Almond, pecan nut, hazelnut, pistachio, and peanut by-products are the most studied as sources of nutraceuticals and bioactive ingredients. The amount and type of nut by-product varies according to the nut processed. Some nuts such as almonds, hazelnuts, and peanuts possess not only the hard and outer shell but also an inner thin layer, which we identify as a skin, that surrounds the kernel. In other nuts, such as pecan and pistachios, the skin is not discarded due to the difficulty to separate it from the edible kernel, and or consumers' preference, so they are consumed as part of the kernel (Grijalva-Contreras et al., 2011). There is strong scientific evidence for the presence of high concentrations of bioactive compounds in the shells or skins of peanut (Taha et al., 2012), pecan nut (Villarreal-Lozoya et al., 2007), pistachio (Fabani et al., 2013), hazelnut (Alasalvar et al., 2006; Shahidi et al., 2007), and almond (Mandalari et al., 2010a; Tsujita et al., 2013), all of which are promising sources of bioactive compounds for the functional foods industry. However, to take full advantage of their properties, it is first necessary to effectively isolate and characterize their main bioactive ingredients, and to test their biological activities in several systems from in vitro chemical tests to cell and animal models to finally use them in human trials. Also, if the by-product-derived component is designed to be used as a food ingredient, both its effectiveness and safety should be evaluated, as well as its effects on the sensory attributes of the finished food product.

8.3 BIOACTIVE COMPONENTS OF NUT BY-PRODUCTS

The edible portion of nuts has been, in general, well characterized on their nutritional quality and bioactive components, due to the fact that it is part of the human diet. Some authors point out that the constituents of this portion are a reflection of what exists in the outermost surrounding layers but up to 10 times more concentrated in the latter (Villarreal-Lozoya et al., 2007; Prado et al., 2009) because they act as an protective barriers for the seed which constitutes the edible portion. However, nutshells and skins are not rich in all of the compounds of the fruit; this is especially evident by their lack of lipids and their scant proteins (Zhao et al., 2012). In this way, the main shell and skin phytochemicals are dietary fiber and polyphenolic compounds (Table 8.1).

Phenolic compounds are secondary metabolites synthesized by plants; they are characterized by the presence of at least one aromatic group with at least one hydroxyl moiety in its structure. In plant tissues, phenolic compounds act as defensive mechanisms against herbivores, producing a bitter taste or inducing digestive enzyme inhibition (Tsujita et al., 2013; He et al., 2008; Sarnoski et al., 2012). As part of the human diet, the main property for which phenolic compounds are recognized is for their antioxidant activity. It is well described that the beneficial effect of antioxidants is through the protection of cells against free radicals caused by metabolism, smoking, inflammatory processes, and others (Chen et al., 2010), although many other mechanisms of action of antioxidant polyphenols are recognized (Wang et al., 2014).

Phenolic compounds are ubiquitous in plants and include several types of chemical structures. Many good reviews on the structure of phenolic compounds exist in the scientific literature (Soto-Vaca et al., 2012). Table 8.1 shows major classes of phenolic compounds, and, in some cases, main individual polyphenols found in by-products of hazelnut, almond, peanut, pecan, and pistachios. From the analysis of this table, it is evident that condensed tannins, as well as their precursors: catechin, epicatechin, and epigallocatechin are major components of almost all nut by-products. Other polyphenols include the flavonolsquercetin and kaempherol and their glycosides (Pereira et al., 2007; Montella et al., 2013). However, most of the studies have only reported total phenolic compounds, usually determined by the method of Folin–Ciocalteu, without identifying individual components. This has some advantages, as a total phenolic extract is simple to obtain, total phenolic compounds are easy to quantify, and some applications can be found for this kind of extracts. Nevertheless, further characterization and purification of bioactive principles may be needed for other uses, as will be discussed in the following sections.

TABLE 8.1 Phenolic Compounds and Dietary Fiber in By-products of the Nut Industry.

Source	Type of phytochemical	References
Almond skin	Catechin (90 μg/g)	Esfahlan et al. (2010)
	Epicatechin (36 μg/g)	
	Condensed tannins (75 μg/g)	
	Insoluble dietary fiber (40%)	Xu et al. (2012)
	Insoluble dietary fiber (4–8%)	Mandalari et al. (2010b)
Hazelnut skin	Catechin (250 mg/g)	Montella et al. (2013)
	Quercetin (85.9 mg/g)	
	Kaempherol (35.6 mg/g)	
	Condensed tannins (2.94 mg CE/g)	Alasalvar et al. (2006)
	Insoluble dietary fiber (52.7%)	Montella et al. (2013)
Hazelnut hard shell	Total phenols (211.1 mg CE/g)	Shahidi et al. (2007)
Hazelnut green cover	Total phenols (134.7 mg/CE g)	Shahidi et al. (2007)
Peanut skin	Epigallochatequin, catechin, and epicatechin	Francisco and Resurreccion (2008)
	Total phenolic compounds (149–169 mg GAE/g)	Taha et al. (2012)
Peanut shell	Condensed tannins (17%)	Ma et al. (2014)
	Insoluble dietary fiber (55%)	Ma et al. (2014)
	Insoluble dietary fiber (60–70%)	Zhao et al. (2012)
Pecan shell	Condensed tannins (310–460 mg CE/g)	de la Rosa et al. (2011)
	Insoluble dietary fiber (44–49%)	do Prado et al. (2013)
Pistachio skin	Flavonoids (70 mg CE/g) and condensed tannins (27.5 mg CyE/g)	Tomaino et al. (2010)
Walnut leaves	Quercetin-3-galactoside, 3-caffeoylquinic acid, and quercetin-3-xyloside	Pereira et al. (2007)

CE, Catechin equivalents; *CyE*, cyanidin equivalents, *GAE*, gallic acid equivalents.

Another important phytochemical found in nut by-products is dietary fiber, which is defined as carbohydrate polymers with 10 or more interconnected monomer units that fail to be endogenously hydrolyzed by enzymes in the small intestine (Kendall et al., 2010). Dietary fiber consists mainly of pectin, cellulose, hemicellulose, and lignin; nevertheless, the most abundant constituents in nutshells are the insoluble fibers lignin and hemicellulose, which comprise at least a 40% of the total shell. Table 8.1, shows the amount of dietary insoluble fiber found in different nut by-products. Peanut shells and skins contain the largest fiber concentration with 70% and 55% of insoluble fiber, respectively. On the other hand, hazelnut skin shows the lowest fiber value. Neither fiber nor phenolic compounds represent an essential dietary nutrient, but actually provide biological benefits to the consumer by reducing the risk of diabetes mellitus 2, cardiovascular diseases, and colon cancer, among others (O'Shea et al., 2012).

It is complicated to establish a comparison between by-products, to select the best source of bioactive ingredients, since studies have determined these compounds under different extraction conditions, which affect yields and quantifications especially for phenolic compounds. For instance, acetone extraction has been reported as the best solvent for the extraction of phenolic compounds from almond and hazelnut shells and skins (Alasalvar et al., 2006; Contini et al., 2008), due to the presence of high molecular weight phenolic compounds (condensed tannins) in these materials. The authors explain this due to the ability of acetone to break the bonds between polyphenols and cell walls (dietary fiber) from the matrix (Mandalari et al., 2010a). However, other authors have pointed out that some polyphenols may be too tightly bound to the cell walls or have molecular weights too high to be soluble in solvents such as acetone, so other extraction conditions may be required to obtain this "nonextractable" phenolic compounds (Taha et al., 2012).

It is advisable to extend the research and find the best extraction conditions for other nut products whose production and commercialization is of regional interest in different parts of the world, and whose by-products may be an economical source of dietary fiber or phenolic compounds, noncaloric functional ingredients and capable of providing added physiological benefits (O'Shea et al., 2012).

8.4 PROPERTIES OF BIOACTIVE COMPOUNDS FROM NUT BY-PRODUCTS

The biological activities that have been found in phenolic compounds and dietary fiber from nut by-products have been divided into two major groups. The first group includes those that have a direct impact on the health of living organisms, or are applicable to improve any physiological condition, such as antioxidant (Garrido et al., 2007), anti-inflammatory (Zhao et al., 2012), anticancer (Villarreal-Lozoya et al., 2007), neuroprotective (Reckziegel et al., 2011; Trevizol et al., 2011), antimicrobial (Rajaei et al., 2009), weight-control (McDougall et al., 2009; Gonçalves et al., 2011; Kimura et al., 2011), antidiabetes (Zhao et al., 2012), antimutagenic (Rajaei et al., 2009), and cardioprotective activities (Tamura et al., 2012). The second group is integrated by those activities which are suitable to improve food processing such as antioxidant properties that can increase the shelf life of food products.

Antioxidant activity of phenolic compounds occurs by donation of a hydrogen atom from the phenol hydroxyl group to the free radical in the food or biological matrix, avoiding the oxidation processes on lipids, protein, and DNA molecules. In vivo, the antioxidants are also capable to inhibit enzymes such as, lipoxygenase, responsible for the oxidative changes in cell lipids (do Prado et al., 2013). It is known that nuts have high fat content, and that is why it is believed that antioxidant compounds are abundant in the outer layers that surround the seed, since they protect and prevent the lipid oxidation of these seeds. Several in vitro studies have demonstrated the antioxidant activity against lipid oxidation of most nut by-products (Villarreal-Lozoya et al., 2007; Prado et al., 2009; do Prado et al., 2013).

The antioxidant activity is probably one of the most commonly studied biological activities of nut by-products. Table 8.2 summarized the main studies carried out on polyphenolic compounds extracted from nut by-products and their antioxidant activity. DPPH and $ABTS^{\cdot+}$ radical scavenging techniques are certainly the most commonly used assays. Results in this table show high antioxidant activity indicating that nut by-products are promising economical sources of natural antioxidant compounds. Nevertheless, it is important to point out that the lack of a unique method to express the antioxidant capacity hinders the comparison between studies. Furthermore, many of these studies are in vitro systems, so more information about in vivo assays, both in living and food systems, is needed.

On the other hand, natural products and their derivatives are important sources of new anti-infectious drugs and many nut by-products have demonstrated these properties. Antimicrobial activity has been shown from the lipid fraction (triterpenoids and phytosterols) of the leaves and bark from the pecan tree, against the bacteria *Mycobacterium tuberculosis H37Rv*. A dose of 125 mg/mL was enough to inhibit 50–80% of the bacterial growth in vitro (Cruz-Vega et al., 2008). Also, a study of our research group found that a polyphenolic extract of pecan shell showed antimicrobial activity against Gram-positive and Gram-negative bacteria with minimal inhibitory concentrations in the range 15–24 mg/mL and minimal bactericidal concentrations of 18–27 mg/mL (Fig. 8.1).

TABLE 8.2 Antioxidant Activity of Phenolic Compounds Extracted from By-products of the Nut Industry.

Source	Active compound	Antioxidant activity	References
Hazelnut skin	Total phenolic compounds and total tannins	DPPH EC_{50} = 143 µg/mL	Contini et al. (2008)
	Total phenolic compounds and total tannins	DPPH 99.5% radical inhibition	Alasalvar et al. (2006)
Hazelnut shell	Total phenolic compounds and total tannins	DPPH 74% radical inhibition ABTS 157.6 µmol TE/g	Xu et al. (2012)
Hazelnut shell	Total phenolic compounds and total tannins	DPPH EC_{50} = 2.28 mg/mL	Contini et al. (2008)
Hazelnut green cover	Total phenolic compounds	DPPH 99.5% radical inhibition	Shahidi et al. (2007)
Peanut shell	Poliphenolic-rich purified extract	DPPH 95% radical inhibition, 80% β-carotene bleaching	Zhang et al. (2013)
Pecan nut shell	Phenolic compounds and condensed tannins	ABTS 644.2 µmol TE/g, DPPH 720 µmol TE/g, ORAC 227 µmol TE/g	de la Rosa et al. (2011)
Pecan nut shell	Phenolic compounds and condensed tannins	ABTS 2228 µmol TE/g, DPPH 529.4 µmol TE/g	Reckziegel et al. (2011)
Pistachio shell	Flavonoids	DPPH EC_{50} = 2.53 µg/mL, β-carotene EC_{50} = 7.85 µg/mL	Rajaei et al. (2010)
Walnut husk	Polyphenolic compounds	DPPH 60% radical inhibition	Fernández-Agulló et al. (2013)

The green husk of walnut (an outer layer than the shell) was also evaluated as a natural antimicrobial agent. Pathogenic Gram-positive (*Bacillus cereus*, *Bacillus subtilis*, *Staphyloccocus aureus*, *Staphyloccocus epidermis*) and Gram-negative bacteria (*Escherichia coli*, *Pseudomonas aeruginosa*) were sensible to the alcoholic extract, rich in phenolic compounds, from this by-product. The major effect was over the Gram positive, with a minimum inhibitory concentration of 20 mg/mL for *B. cereus*, and 50 mg/mL for *B. subtilis*, *S. aureus*, and *S. epidermis*. Thus, walnut by-products like the green hulk not only could be a rich source of compounds that could be applied in food technology, against food-poisoning bacteria, but also in the pharmaceutical industry for the treatment of pathogenic human bacteria (Fernández-Agulló et al., 2013). Almond skin phenolic extracts have antimicrobial activity over Gram-positive and Gram-negative bacteria. *Salmonella enterica*, *Listeria monocytogenes*, and *S. aureus* were mostly affected by the phenolic extracts of these by-products in doses ranging from 250 to 500 µg/mL. Authors

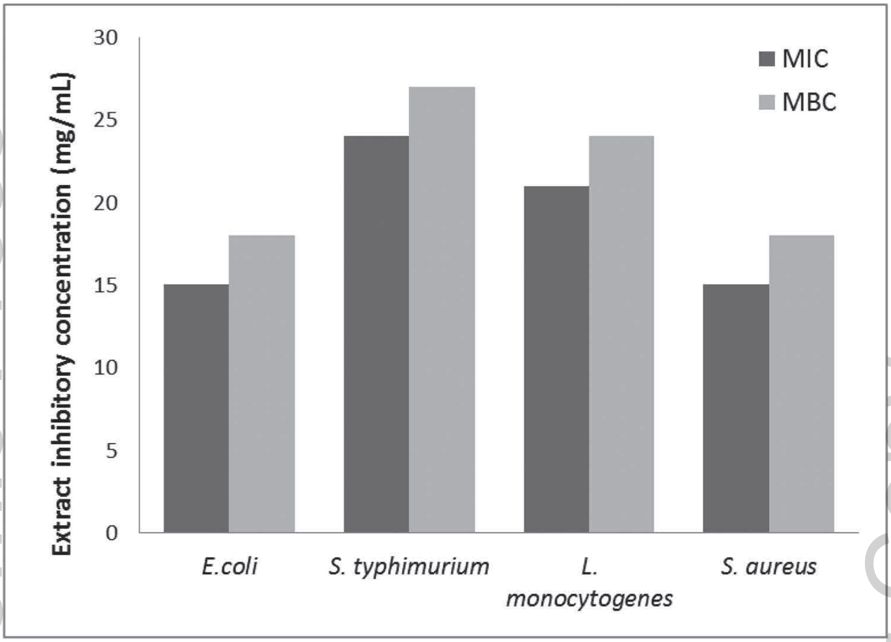

FIGURE 8.1 Minimal inhibitory concentrations (MIC) and minimal bactericidal concentrations (MIB) of a pecan shell acetonic extract against different Gram-negative (*Escherichia coli*, *Salmonella typhimurim*) and Gram-positive (*Listeria monocytogenes*, *Staphyloccocus aureus*) bacteria (unpublished results).

suggested that this activity was due to the presence of antioxidants acting synergistically among them, specifically epicatechin, protocatechuic acid, and naringenin (Mandalari et al., 2010a). Pistachio by-products have also been tested as antibacterial agents in vitro. Shell extracts in a concentration of 1 mg/mL showed inhibitory activity against *S. aureus*, *Escherichia coli*, *Salmonella thyphi*, *Navia intermedia*, *P. aeruginosa*, *B. cereus*, and *Candida albicans*. This activity is attributed to the presence of flavonoid compounds acting on the enzyme DNA gyrase of bacteria (Rajaei et al., 2009). Another mechanism that explains the antimicrobial effect of this type of extracts is the presence of phenolic compounds that inhibit the adhesion of bacteria to the urethra walls, in such a way that is not possible for the bacteria to maintain a bacteria–host relation (Hisano et al., 2012; Krueger et al., 2013). Considering the above, we can suggest that nut by-products are economically and easily accessible sources of antimicrobial compounds, allowing us to explore alternative pharmaceutical applications on these by-products.

Other studies have found that nut by-products possess beneficial effects for protecting against metabolic ailments, all of which have in common the uncontrolled absorption and accumulation of lipids and carbohydrates. Insoluble dietary fiber is a very important part of nut by-products (Table 8.1), and there are many studies that demonstrate its health benefits in the control of glycemic response, weight gain, and diabetes. Dietary fiber, especially soluble fiber, is known to impair the absorption of cholesterol on the small intestine, due to its capability to increase the viscosity of the intestinal lumen, hindering the interaction between digestive enzymes and nutrient transporters with their substrates, so the absorption of nutrients is decreased (Mandalari et al., 2010b). Insoluble dietary fiber, which is the major type of dietary fiber in some nut by-products (Table 8.1), increases the fecal material and accelerates the intestinal transit, and, through this mechanism, also reduces the absorption of cholesterol and carbohydrates, leading to an improved control of diabetic patients. The effect of dietary fiber on weight control seems to be also related to the fact that these compounds can increase satiety and decrease voluntary food intake (Kendall et al., 2010). The glycemic response seems to be also influenced by phenolic compounds that are bonded to fiber. Authors suggested that these compounds can inhibit carbohydrate absorption and increase insulin production, improving the control of glucose in blood. Nonetheless, these studies were made with fiber and phenolic compounds obtained from edible parts of fruit products (Devalaraja et al., 2011). There is a scarcity of investigation about the use of fiber and phenolic compounds from nut by-products in the control of these health issues. One study found that phenolic compounds obtained from peanut by-products showed hipocholesterolemic activity in an animal model, where additions of a polyphenol extract in the drinking water of Wistar rats increased the amount of cholesterol in feces. Authors suggested that polyphenols are capable of reducing the cholesterol solubility at the small intestine level, by inhibiting the formation of bile micelles (Tamura et al., 2012).

Other nut by-products may also be used as sources of bioactive ingredients for the development of drugs that prevent the absorption of nutrients with high caloric content, therefore helping to control the obesity pandemic. Inhibition of enzymes involved in fat and carbohydrate absorption, significantly reduces the caloric content of a diet (Gonçalves et al., 2011; Kimura et al., 2011). A peanut shell extract demonstrated inhibitory activity of pancreatic lipase, avoiding excessive weight gain on rats fed on a high lipid diet (de la Garza et al., 2011). A mechanism that explains this phenomenon lies on the ability of the phenolic compounds to complex proteins, generating conformational changes in lipase through hydrophobic interactions of the aromatic groups from both molecules (McDougall et al., 2009). A study on almond skins showed that polymeric phenolic compounds from this product, mainly condensed tannins based in flavan 3-ol monomers, inhibited human α amylase with an IC_{50} = 2.2 μg/mL, thus showing a potential for slowing carbohydrate absorption and lowering postprandial hyperglycemia (Tsujita et al., 2013). These two studies show the presence of bioactive compounds with inhibitory lipase and amylase activity, in nut by-products, and suggest the possibility for developing effective natural anti-obesity drugs from these sources.

Several extracts from nut by-products have been tested to prevent growth on tumor cells of several types of cancer. Pecan shell extracts showed anti-proliferative activity in colon cancer cell lines (Villarreal-Lozoya et al., 2007). Phenolic compound extracts from peanut skins inhibited the growth of colon, cervix, and liver tumoral cell lines in vitro. Colon cells showed more sensibility to this compounds with an IC_{50} = 10.9 μg/mL, followed by cervix cancer cells (IC_{50} = 12.6 μg/mL) and liver cancer cells (IC_{50} = 19.3 μg/mL). This effect is attributed to the phenolic compounds like catechin, epicatechin, gallic acid, and protocatechuic acid already known for their anticarcinogenic properties (Taha et al., 2012). Nevertheless, in vivo research is required to know the real extent of these antitumoral effects.

There are some reports showing that extracts of nut by-products are effective in reducing the symptoms of certain neurological disorders in animal models, suggesting its possible use as a raw material for the extraction of nutraceutical compounds which may be included in commercial drug formulations (Reckziegel et al., 2011) found that pecan shell aqueous extracts with high antioxidant activity also minimized the anxiety induced by cigarette abstinence in rats that had been exposed to the smoke of at least six cigarettes daily for 3 weeks. The authors concluded that the antioxidant attributes of the extract prevented superoxide radical formation in the brain, protecting the cell membranes, rich in polyunsaturated acids. In a related study, an aqueous extract from the pecan shell showed a positive effect in the prevention of dyskinesia induced by prolonged treatment with antipsychotics in rats (Trevizol et al., 2011). This study also showed a partial recovery of the disease for those animals that already had symptoms and were treated with the pecan shell extract. Authors proposed that the protective effect of the shell extract was also by controlling the oxidative stress generated in the brain area (Trevizol et al., 2011). Further studies on the beneficial effects of nut by-products on the central nervous system are necessary to explore the mechanisms for their actions and the possibility of extracting and purifying the active compounds.

Despite all the information on the different biological activities of extracts obtained from nut by-products, it is necessary to carry out toxicological evaluations to assess the safety of these materials for human use. This type of study has been performed for the aqueous extract of pecan shells, and authors found no acute or subacute toxicity of the pecan shell aqueous extract in doses up to 2000 mg/kg, single dose (acute test), or 100 mg/kg for 28 days (subacute test). The same extract was not mutagenic in *Salmonella typhimurium* strains (Porto et al., 2013).

In summary, although several studies show that nut by-products are rich in bioactive ingredients with many potential health effects, and some extracts possess antioxidant, antimicrobial, anticholesterolemic, anti-obesity, antiproliferative, and neuroprotective activities, more studies are needed to provide strong evidence for the nutraceutical and pharmaceutical industries to consider their use. These studies should include a complete characterization of the by-products or their extracts, which is sometimes difficult due to the high content of polymeric compounds (fiber and tannins), more in vivo animal studies, including safety assessments of the extracts, and finally human studies with carefully characterized extracts or purified active ingredients.

8.5 POTENTIAL USES OF NUT BY-PRODUCTS

An important option for the use of nut by-products is their addition, either as raw materials or in different grades of purification, to human foods and animal feeds, as sources of bioactive ingredients and also to extend the product's shelf life and quality attributes. Some by-products from the wine industry are already processed and added in foodstuffs to enrich the original product and improve their functional quality (Taha et al., 2012; Chouchouli et al., 2013). In other cases, isolated bioactive compounds from the natural matrix may be transformed into nutraceutical products.

The addition of insoluble fiber or phenolic compounds to processed foods is not only done to impact on the consumer's health but also to improve their organoleptic conditions or prolonging its shelf life (Mudgil and Barak, 2013). In the latter case, phenolic compounds and insoluble dietary fiber are added as food additives. In this context, both bioactive compounds have different functions when added to processed foods: first, as "functional food enhancers," and second, as food preservatives and additives. However, until now, phenolic compounds or insoluble dietary fiber isolated from nut by-products have been applied only on a few food products, increasing their functionality or as preservatives (Stintzing et al., 2001).

On recent studies, the skin that covers peanuts was added in powder during the elaboration of peanut butter. Authors pointed out that addition of 20% peanut peel to the peanut butter increased by more than 50% the antioxidant activity of the final product, with only slight modifications in color, and no significant changes in the taste nor smell (Hathorn and Sanders, 2012). Another application for peanut skins is on flaxseed oil products, where the addition of peanut skins can extend the shelf life of flaxseed oil, due to its phenolic portion and antioxidant capacity, delaying the presence of unwanted odors and flavors that come after an oil oxidation process (Taha et al., 2012).

In a different study researchers have combined a beverage, the Espresso coffee, with hazelnut skins, which are one of the richest edible sources of antioxidant compounds (Rio et al., 2011), and found a greater in vitro antioxidant capacity (DPPH and FRAP techniques) of the new beverage, as well as a greater antioxidant activity in vivo on serum from the rats which were fed with this beverage (Contini et al., 2012). Some authors have pointed out that hazelnut skin could be also a good prebiotic ingredient due to its high content of dietary fiber. Its prebiotic activity was tested with two strains of bifidobacteria, where the addition of 0.01% of hazelnut skin, increased bacterial growth (Montella et al., 2013). Almond skin has also shown prebiotic activity on beneficial bacteria of the human gut, a condition that favors a better balance in the intestinal flora. Authors explained this phenomenon due to the ability of the colonic bacteria, to ferment the dietary fiber to obtain energy. Consequently, populations of bifidobacteria and rectal coccoids were increased to a sufficient level to prevent growth of other pathogenic bacteria in the intestine (Mandalari et al., 2010b). Is important to point up that the scarcity of studies about the technological applications of nut by-products may be due to the lack of evidence that ensure the extracts are safe to humans. Therefore, safety-assessment studies of carefully characterized extracts are much needed. The effect of the addition of nut by-products or their extracts to the sensory attributes of the food products should also be considered, although, when low concentrations are effectively used, their impact on sensory quality is usually insignificant (Hathorn and Sanders, 2012).

Finally the potential use of nut by-products, their extracts, or active ingredients in animal feeds is also a promising field of study and future applications.

8.6 CONCLUSION

Currently, several countries, especially in the developed world, are going through an "epidemiological transition," with a lower incidence of infectious diseases and an increase of degenerative and chronic disease like cardiovascular and metabolic disorders, diabetes, and cancer. By-products of the nut industry contain high amounts of active compounds that can significantly contribute to control these diseases over the next years. Therefore, the development of studies demonstrating the best methods for their extraction, purification, and characterization as well as their safe use in the production of functional foods or nutraceutical formulations is of great importance. In this way, if we can ensure that all by-products from this industry, are safely processed, applied, and effectively used, they will increase their economic value and become a new source of profit for the agro-industry. On the other hand, it is important to consider that in spite of the biological applications that have been described about dietary fiber and phenolic compounds, their optimal doses, in enriched functional foods or nutraceutical supplements, must be determined to develop their maximal functionality, while making sure that its addition will not generate unwanted changes in food, which can be linked to the consumers' rejection. We noted in this chapter, the scarcity of studies on the safety and effectiveness of extracts from by-products and even on the detailed identification of the active principles, which currently delays the full use of these products, in any of the areas suggested by this chapter.

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KEYWORDS

- **nuts**
- **health-promoting natural compounds**
- **husks**
- **peeling process**
- **bioactive ingredients**

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