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Improving bioaccessibility and bioavailability of phenolic compounds in cereal grains through processing technologies: A concise review

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ABSTRACT

Bioactive phenolic compounds in cereal grains are mainly located in the bran fraction and covalently bound to indigestible polysaccharides. They have very low bioavailability because the complex bran matrix severely hinders their access to the necessary enzymes which contribute to their release in the human gastrointestinal tract. Liberating these phenolic compounds from bran matrices and/or increasing their accessibility have been demonstrated to be effective in enhancing their bioavailability. For this purpose, various processing technologies have been developed. The aim of this study was to concisely review these processing technologies including mechanical treatment, thermal treatment, extrusion cooking, and bioprocessing.

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1. Introduction

Epidemiological studies have shown that a constant intake of whole-grain cereal products is inversely associated with the risk for developing various types of chronic diseases such as obesity, cardiovascular disease, type 2 diabetes, and some cancers (Arts & Hollman, 2005; Fardet, 2010; Fernandez-Panchon, Villano, Troncoso, & Garcia-Parrilla, 2008; Scalbert, Manach, Morand, Remesy, & Jimenez, 2005). It has been suggested that these health benefits are not attributed solely to any single compound but the combined effects of dietary fiber, phenolic compounds and other bioactive components present in cereal grains (Fardet, 2010). The major phenolic compounds present in cereal grains are phenolic acids, flavonoids, and tannins. The chemistry of these cereal phenolic compounds can be found in previous reports (Liu, 2007; Shahidi & Naczk, 1995). Phenolic antioxidants such as phenolic acids may modulate cellular oxidative status and prevent biologically important molecules such as DNA, proteins, and membrane lipids from oxidative damage (Yu, Haley, Perret, & Harris, 2002). In addition to direct antioxidant functions, they may also exert some effects in the regulation of cell signaling pathways, thus modifying gene regulation and/or cell redox status (Maggi-Capeyron et al., 2001; Yun et al., 2008). The health effects of antioxidants and other phytochemicals from consumption of whole-grain cereals were reviewed by Liu (2007).

Phenolic compounds (mainly phenolic acids) are concentrated in the bran fraction of cereal grains and exist in free, soluble conjugated, and insoluble bound forms (Adom, Sorrells, & Liu, 2005; Hemery, Rouau, Lullien-Pellerin, Barron, & Abecassis, 2007; Martinez-Tome et al., 2004; Shahidi & Naczk,

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Table 1 – Phenolic acids present in common cereal grain.

Phenolic acid	Cereal grain	References
Hydroxycinnamic acids		
Ferulic acid	Predominant phenolic acid in maize, wheat, barley, rye, millet, sorghum, rice; major phenolic acid in oat	Andreasen et al. (2000), Beta, Liu, and Qiu (2012), Cai et al. (2012), Dykes and Rooney (2007), Hahn, Faubion, and Rooney (1983), Kim, Tsao, Yang, and Cui (2006), Laokuldilok, Shoemaker, Jongkaewwattana, and Tulyathan (2011), McDonough and Rooney (2000), Shahidi and Naczk (2004), Yu, Vasanthan, and Temelli (2001), Zhang and Hamaker (2012)
p-Coumaric acid	Major phenolic acid in maize, wheat, barley, rye, sorghum, millet, rice, oat	Andreasen et al. (2000), Beta et al. (2012), Cai et al. (2012), Dykes and Rooney (2007), Hahn et al. (1983), Kim et al. (2006), Laokuldilok et al. (2011), McDonough and Rooney (2000), Shahidi and Naczk (2004), Yu et al. (2001), Zhang and Hamaker (2012)
Sinapic acid	Major phenolic acid in rye, rice; also present in wheat, maize, barley, sorghum, millet, oat in lower amount	Andreasen et al. (2000), Beta et al. (2012), Cai et al. (2012), Dykes and Rooney (2007), Hahn et al. (1983), Kim et al. (2006), Laokuldilok et al. (2011)
Cinnamic acid	Major phenolic acid in millet; also present in wheat, sorghum, oat in lower amounts	Linda Dykes and Rooney (2006), Dykes and Rooney (2007), McDonough and Rooney (2000), Shahidi and Naczk (2004)
Caffeic acid	Major phenolic acid in oat, sorghum, rice, rye, barley, wheat; also present in maize, rye, millet in lower amounts	Andreasen et al. (2000), Beta et al. (2012), Cai et al. (2012), Dykes and Rooney (2007), Hahn et al. (1983), Kim et al. (2006), Laokuldilok et al. (2011), McDonough and Rooney (2000), Shahidi and Naczk (2004), Yu et al. (2001), Zhang and Hamaker (2012)
Hydroxybenzoic acids		
p-Hydroxybenzoic acid	Predominant phenolic acid in barley; major phenolic acid in oat, rice, millet; also present in wheat, maize, rye, sorghum in lower amounts	Andreasen et al. (2000), Beta et al. (2012), Cai et al. (2012), Dykes and Rooney (2007), Laokuldilok et al. (2011), McDonough and Rooney (2000), Shahidi and Naczk (2004), Yu et al. (2001)
Salicylic acid	present in wheat, barley, sorghum	Dykes and Rooney (2007), Kim et al. (2006)
Syringic acid	Major phenolic acid in sorghum, wheat, maize; also present in oat, millet, barley in lower amounts	Dykes and Rooney (2007), Kim et al. (2006), Shahidi and Naczk (2004), Zhang and Hamaker (2012)
Vanillic acid	Major phenolic acid in barley, oat, millet, wheat; also present in sorghum, rye, maize in lower amounts	Andreasen et al. (2000), Beta et al. (2012), Cai et al. (2012), Dykes and Rooney (2007), Hahn et al. (1983), Kim et al. (2006), Shahidi and Naczk (2004), Zhang and Hamaker (2012)
Gallic acid	Major phenolic acid in rice; also present in sorghum, millet, oat, wheat in lower amounts	Cai et al. (2012), Dykes and Rooney (2007), Hahn et al. (1983), Laokuldilok et al. (2011), Zhang and Hamaker (2012)
Protocatechuic acid	Major phenolic acid in rice, sorghum; also present in millet, rye, barley, oat, maize in lower amounts	Andreasen et al. (2000), Beta et al. (2012), Cai et al. (2012), Dykes and Rooney (2007), Laokuldilok et al. (2011), Zhang and Hamaker (2012)

2004). Ferulic acid is the most abundant phenolic acid in cereal grains, followed by *p*-coumaric, synapic, and caffeic acids (Andreasen, Christensen, Meyer, & Hansen, 2000; Lempereur, Rouau, & Abecassis, 1997). Table 1 shows phenolic acids present in common cereal grains. In wheat, ferulic acid represents up to 90% of total phenolic acids and 99% of which in the bound form (Adom & Liu, 2002). However, it has been reported that phenolic acids in finger millet (*Elusine coracana*) occur mostly in free form (71%) and protocatechuic acid is the major free phenolic acid (Chandrasekara & Shahidi, 2011a; Chandrasekara & Shahidi, 2011b; Subba Rao & Muralikrishna, 2002). Table 2 illustrates phenolic acid compositions in wheat grain and wheat bran determined by different extraction and hydrolysis procedures. Free and some conjugated phenolic acid is thought to be readily available for absorption in the human small and large intestines (Manach, Scalbert, Morand, Remesy, & Jimenez, 2004; Zhao, Egashira, & Sanada, 2004), however, those covalently bound to indigestible polysaccharides can only be absorbed after being released from cell structures by digestive enzymes or microorganisms in intestinal lumen (Anson et al., 2009; Chandrasekara & Shahidi, 2012; Zhao, Egashira, & Sanada, 2003). The bound phenolic acids have very low bioavailability because the bran matrix severely hinders their access to the necessary enzymes (such as ferulate esterases, xylanases) that contribute to their release in the human gastrointestinal tract (Nystrom, Paasonen, Lampi, & Piironen, 2007; Zhao, Egashira, & Sanada, 2005). For example, the reported urinary recovery level of ferulic acid was as low as 3.9% in rats (Adam et al., 2002) and 3.1% in humans (Kern, Bennett, Mellon, Kroon, & Garcia-Conesa, 2003) for

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