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Wheat germ: not only a by-product

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Abstract

The wheat germ (embryonic axis and *scutellum*) represents about 2.5–3.8% of total seed weight and is an important by-product of the flour milling industry. The germ contains about 10–15% lipids, 26–35% proteins, 17% sugars, 1.5–4.5% fibre and 4% minerals, as well as significant quantities of bioactive compounds such as tocopherols [300–740 mg/kg dry matter (DM)], phytosterols (24–50 mg/kg), policosanols (10 mg/kg), carotenoids (4–38 mg/kg), thiamin (15–23 mg/kg) and riboflavin (6–10 mg/kg). Oil recovery is achieved by mechanical pressing or solvent extraction, which retrieve about 50% or 90% lipids, respectively; innovative approaches, such as supercritical carbon dioxide extraction, are also proposed. The oil is rich in triglycerides (57% of total lipids), mainly linoleic (18:2), palmitic (16:0) and oleic (18:1) acids, but relevant amounts of sterols, mono- and diglycerides, phospho- and glycolipids are present. The lipophilic antioxidants tocopherols and carotenoids are also abundant. The main by-product of oil extraction is defatted germ meal, which has high protein content (30–32%), is rich in albumin (34.5% of total protein) and globulin (15.6%), and thus presents a well-balanced amino acid profile. Its principal mineral constituents are potassium, magnesium, calcium, zinc and manganese, in decreasing order. Total flavonoid content is about 0.35 g rutin equivalent/100 g DM. The wheat germ is therefore a unique source of concentrated nutrients, highly valued as food supplement. While the oil is widely appreciated for its pharmaceutical and nutritional value, the defatted germ meal is a promising source of high-quality vegetable proteins. Better nutrient separation from the kernel and improved fractioning techniques could also provide high-purity molecules with positive health benefits.

Keywords: *defatted wheat germ, wheat germ composition, wheat germ separation, wheat germ oil*

Introduction

Most of the wheat germ produced worldwide during wheat milling is used as a diet supplement in animal feed formulation (Ge et al. 2000). However, the wheat germ is a unique source of highly concentrated nutrients such as proteins, lipids, sugars and minerals, as well as tocopherols (vitamin E), B-group vitamins, carotenoids, flavonoids, phytosterols and policosanols (Pomeranz 1988; Pietrzak and Collins 1996; Nyström et al. 2007; Eisenmenger and Dunford 2008; Hidalgo and Brandolini 2008). As such, wheat germ is potentially a nutritious food supplement, as well as an excellent raw source for the preparation of foods such as bread (Cakmakli et al. 1995), cookies (Bajaj et al. 1991; Arshad et al. 2007), muffins (Turnbough and Baldwin 1986), comminuted meat products (Gnanasambandan and Zayas 1992, 1994), etc.

Furthermore, the oil obtained from the germ is widely utilized for vitamin production (e.g. α -tocopherol) in medication and cosmetic industry (Barnes 1983) as well as in food, feed and as biological insect control agent, while the defatted wheat germ and wheat germ proteins are useful ingredients for several food products including processed meat, cereals and baked goods, extruded high-protein foods and beverages (Hassan et al. 2010).

The benefits ascribed to wheat germ and its derivatives include lowering plasma and liver cholesterol, reducing cholesterol absorption, inhibiting platelet aggregation, improving physical endurance, retarding aging, improving fertility (Kahlon 1989; Malecka 2002), as well as preventing and curing carcinogenesis (Zalatnai et al. 2001). The human

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consumption of wheat germ is mainly limited by the presence of some antinutritional molecules (raffinose, phytic acid, wheat germ agglutinins), although baking, mild thermal treatments and sourdough fermentation improve its digestibility (Rizzello et al. 2010).

However, wheat germ can adversely affect flour quality when left in the flour, because highly unsaturated germ oil and oxidative and hydrolytic enzymes can promote reactions leading to an increase in acidity and oxidative rancidity (Eisenmenger et al. 2006). Thus, an efficient separation of wheat germ from whole wheat is a significant commercial factor.

For the milling industry, the 'wheat germ' is the embryo part of the wheat germ organ. Nevertheless, morphologically the germ includes both embryo and *scutellum* fractions of the wheat kernel. Millers are unable to efficiently remove the *scutellum* and this fraction normally is carried over with the bran. Economically, the *scutellum* is even more valuable than the embryo fraction, because it has higher vitamin and total fat contents. In any case, the current germ separation technology gives yields of about 0.4–0.5% of embryonic germ (Posner and Li 1991), while the germ as a whole represents 2.5–3.8% of the total kernel weight (Dubois et al. 1960; Hargin and Morrison 1980; Pomeranz 1988; Hidalgo and Brandolini 2008).

Separation

An extensive, albeit slightly dated, review of the available technology of germ separation is presented by Posner (1985). Two approaches are paramount in commercial mills. In the most widespread method, the middlings containing germ particles are passed through a pair of smooth rolls where the germ is flattened (its high lipid content allows flaking under compression) and separated by sifting. However, during compression some oil can be transferred to the flour, causing a loss in oil as well as contamination of the flour. The second method separates the germ in a break system by a specially designed germ separator; however, this system requires a large investment in sophisticated equipment and high operational costs.

A stepwise procedure to remove both the embryo and *scutellum* fractions from whole wheat as a part of the milling process was proposed by Posner and Li (1991). Their method requires tempering the wheat to a total moisture content (about 13.5%) permitting maximum impact detachment of embryo; thereafter, the tempered wheat is subjected to mechanical impact forces to free the embryo from the wheat. The de-embryonated wheat is then subjected to a second tempering step (to about 16%) for *scutellum* separation by treatment with successive pairs of break rolls. The embryo and *scutellum* are thus separately removed from the wheat, while the endosperm fraction is processed into a high quality final flour having only a minimum of germ-related contaminants. This method

allows the recovery of 50–100% of the embryonic axis and *scutellum*, depending on wheat cultivar/type (Posner and Li 1991), vs. 15–20% achieved with the traditional techniques (Hemery et al. 2007).

Composition

The germ contains about 10–15% lipids (Dubois et al. 1960; Barnes 1983; Pomeranz 1988; Posner and Li 1991), 26–35% protein (Posner and Li 1991; Eisenmenger and Dunford 2008), 17% sugar (Dubois et al. 1960; Pomeranz 1988), 1.5–4.5% fibre (Cara et al. 1992; Panfili et al. 2003) and about 4% minerals (Posner and Li 1991). Particularly appealing is the presence of significant quantities of bioactive compounds such as tocopherols (300–740 mg/kg DM; Barnes 1982; Panfili et al. 2003; Hidalgo and Brandolini 2008), phytosterols (24–50 mg/kg; Nyström et al. 2007), policosanols (10 mg/kg; Irmak et al. 2006), carotenoids (4–38 mg/kg; Hidalgo and Brandolini 2008), thiamin (15–23 mg/kg; Barnes 1982) and riboflavin (6–10 mg/kg; Barnes 1982). Wheat germ also contains innumerable enzymes related to its embryonic nature (Pomeranz 1988).

In the germ fraction recovered from the milling process, the carbohydrates represent about 45% of the total (Zhu et al. 2006a). However, they come mainly from other contaminating fractions (starch from the endosperm, and most cellulose and hemicelluloses from bran; Pomeranz 1988).

Oil

The wheat germ contains about 10–15% oil (Dubois et al. 1960; Pomeranz 1988; Dunford and Zhang 2003). Oil recovery is achieved by mechanical pressing or by solvent extraction, which retrieve about 50% or more than 90% of total lipids, respectively (Barnes 1983). Innovative approaches, such as supercritical carbon dioxide extraction, yield about 92% of solvent-extracted oil, while avoiding the use of toxic solvents (Panfili et al. 2003). Additionally, oil content is influenced by the extent of contamination with bran and endosperm, which have low lipid content, and by oil loss during flaking (Barnes 1983).

Crude wheat germ oil is usually dark-coloured and may have strong odour and flavour, depending on the oxidative conditions of the oil. To produce high quality, stable oils, undesirable compounds must be eliminated while retaining as much of tocopherols and other nutritional compounds as possible (Wang and Johnson 2001). During conventional refining processes, a significant portion of the nutritional components is lost (Dunford 2004); for example, deodorization significantly reduced the tocopherol content (Wang and Johnson 2001). Hence, alternative ways of oil refining, such as supercritical fluid fractionation, are proposed (Eisenmenger et al. 2006).

Wheat germ lipids consist largely of fatty acids (FA). The free fatty acid (FFA) content of the crude oil is usually high (5–25%), and varies depending on germ rancidity, separation method, storage and oil extraction conditions; the bitter and soapy flavour in food is often due to FFA (Wang and Johnson 2001).

The majority of FA are triglycerides (57%; Kahlon 1989); the most abundant is linoleic acid (18:2), which accounts for 42–59% of the total triglycerides, followed by palmitic acid (16:0) and oleic acid (16:1). The unsaturated acids account for about 80% of triglycerides (Kahlon 1989; Hidalgo et al. 2009). The variation between reported percentage compositions may be attributed to differences in wheat varieties, growth conditions, storage of the germ and the extraction method of lipids. Different FA profiles, with higher monounsaturated fatty acid concentrations, are reported for spelt (Grela 1996) and einkorn (Hidalgo et al. 2009) wheats. Small quantities of polar lipids are also present: Hargin and Morrison (1980) reported 14–17% phospholipids and little or no glycolipids.

Wheat oil also contains relevant quantities of tocopherol (1300–2700 mg/kg) (Wang and Johnson 2001; Panfili et al. 2003; Hassanein and Abedel-Razek 2009) and carotenoid (56 mg/kg; Panfili et al. 2003), two well-known antioxidants (Hidalgo et al. 2006) which play an important role in disease prevention (Palozza and Krinsky 1992; Halliwell et al. 1995; Andlauer and Fürst 1998). Furthermore, two groups of alcohols present in wheat oil sport cholesterol-lowering effects: policosanols (a mixture of high molecular weight aliphatic primary alcohols) and phytosterols (steroid alcohols). Policosanols detected (628 and 38 mg/kg in solid and clear crude oil) are C22 (docosanol), C24 (tetracosanol), C26 (hexacosanol), C28 (octacosanol) and C30 (triacontanol) (Irmak et al. 2006). Phytosterols, more abundant than in other commercial oils, are mainly sitosterol (60–70%) and campesterol (20–30%) (Itoh et al. 1973). Among minerals, wheat germ oil is especially rich in phosphorus (1.4 g/kg; Wang and Johnson 2001).

Defatted germ

The main by-product of the oil extraction process is a defatted wheat germ meal. This fraction has a high protein content (about 35%; Zhu et al. 2006a), particularly abundant in albumin (34.5% of total protein) and globulin (15.6%), and with a well-balanced amino acid profile, rich in essential amino acids (especially lysine; Zhu et al. 2006a), thus indicating it as one of the most attractive and promising sources of vegetable proteins. The defatted germ is also a source of carbohydrates such as sugars (around 20%, of which sucrose 58.5% and raffinose 41.5%; Dubois et al. 1960), fibre, pentosans and starch (the latter mostly as a contaminant from residual endosperm; Amadó and Arrigoni 1992),

as well as of carotenoids (3 mg/kg; Panfili et al. 2003) and flavonoids (0.35 g rutin equivalent/100 g DM; Zhu et al. 2006b). Its principal mineral constituents are potassium, magnesium, calcium, zinc and manganese, in decreasing order (Zhu et al. 2006b). The antioxidant activity of the total phenolic from defatted germ is high (Zhu et al. 2011) and suggests a possible utilization in the formulation of nutraceuticals with potential applications to reducing levels of oxidative stress (Zhu et al. 2011). Furthermore, its use for the enrichment of cereal-based foods offers a valuable supplementation vehicle for nutritional improvement in many developing countries (Arshad et al. 2007).

The defatted wheat germ meal proteins exhibit emulsifying properties and stability similar to those of bovine serum albumins, good foaming capacity and excellent water retention (Ge et al. 2000).

Conclusions

This review summarizes up-to-date information on chemical composition and valuable functional properties of wheat germ and its derivatives (germ oil and defatted germ meal). Acknowledging the high nutritional valence of wheat germ, the industry today is going beyond its traditional use as a low-cost integration to animal feed. Better germ separation and improved, solvent-free extraction methods allow the almost complete recovery of wheat germ oil, as well as the retrieval of specific, high-value molecules such as tocopherol. Furthermore, the remaining wheat germ meal still is a valuable source of proteins and minerals. Moreover, to improve the suitability of wheat germ and derivatives to food processing and consumption, studies are in progress on their stabilization, the reduction of specific antinutritional compounds and the improvement of some nutritional characteristics.

In summary, exceptional nutritional value and good palatability make wheat germ an affordable source of valuable ingredients, suitable for the most diverse human requirements, from basic life source to highly sophisticated end products.

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