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Biovalorisation of okara (soybean residue) for food and nutrition

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ABSTRACT

Background: Okara is the soybean residue that remains after the manufacture of soymilk or soybean curd. The high moisture content (70–80%) makes it susceptible to spoilage, and so it is often discarded. Yet, okara still holds many nutrients (on a dry weight basis, approximately 50% carbohydrates, 20–30% proteins and 10–20% lipids, as well as minerals and phytochemicals), making it a suitable substrate for biovalorisation.

Scope and approach: The composition of okara is assessed with respect to its potential for biovalorisation to obtain bioactive substances and food products. Studies on okara fermentation by fungi, bacteria and yeasts are highlighted, with their main drawbacks and challenges critically discussed and the research gaps identified.

Key findings and conclusions: Studies to date have demonstrated the feasibility of okara fermentation to produce a variety of functional ingredients and foodstuffs. The health benefits and nutritional quality of okara are often enhanced by fermentation, and the fermented okara is also an inexpensive substrate for extraction of bioactive substances. Present research remains largely at bench-scale, and the main challenges are related to scaling-up, efficiency and/or yield. There is much scope for further exploration into various aspects of okara biovalorisation, including applying bioprocessing treatments as a pre-fermentation step, using combinatorial microbes or enzymes, and evaluating organoleptic property, dietary effects and potential allergenicity of the fermented products.

1. Introduction

The common industrial practice of discarding food processing by-products leads to economic loss and socio-environmental problems, and the search for their alternative uses and value addition has gained much global attention in recent years (Scialabba, 2014). Okara, also known as biji (Korean) or douzha (Chinese), is a food processing by-product derived from soybeans (*Glycine max*). It is the ground soybean residue remaining after filtering the water-soluble fraction during soymilk or soybean curd production.

For every 1 kg of soybeans used in manufacturing soybean curd, about 1.1–1.2 kg of okara is obtained (Khare, Jha, & Gandhi, 1995). Therefore, large amounts of okara are produced annually, especially in Asian countries with high soybean consumption. The top soymilk-consuming region and country are Hong Kong and Singapore, while non-Asian countries with significant soymilk consumption include Australia and Canada (Starling, 2011). The amount of okara generated by the soybean curd-manufacturing sector is about 800,000 tons in Japan, 310,000 tons in Korea and 2,800,000 tons in China (Ahn et al., 2010; Li, Qiao, & Lu, 2011; Muroyama, Atusumi, & Andoh, 2006). The amount of okara produced annually in Singapore alone is at least 10,000 tons, comparable to that produced in Canada (Khaw, 2013; Soy 20/20, 2005).

Despite the large volumes of okara generated by the food industry, most of it is discarded as the high moisture content in okara makes it very perishable. In the past twenty years, there has been growing interest in ways of reusing the okara. The direct incorporation of okara into animal feed or human food is possible, but it is limited by the presence of enzyme inhibitors (if the soybeans are not heat-treated prior to grinding) and flatulence-causing oligosaccharides in okara, and the undesirable 'fishy' and 'beany' flavour of fresh okara (Anderson & Wolf, 1995; Li & Ma, 2014; Mateos-Aparicio, Redondo-Cuenca, Villanueva-Suárez, Zapata-Revilla, & Tenorio-Sanz, 2010a). Dried okara can also be used as an ingredient

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in various foodstuffs, especially baked goods, and a handful of studies on the drying process parameters and technologies have been done. However, the drying process is usually energy-intensive given the large amount of water in okara, and economic analysis has also shown that the cost of drying okara greatly exceeds the value of protein contained within (Soy20/20, 2005).

Hence, the microbial biotransformation of okara provides an alternative to value-add to this soy food processing waste. This review highlights the valorisation of okara by fermentation for food applications, focusing on the research conducted thus far, their main challenges and limitations, and the potential areas for further exploration and development. Other approaches to okara valorisation and microbial production of non-food substances from okara have also been studied, but these areas lie beyond the scope of this review, and interested readers are referred to the review articles by Li et al. (2011) and Li et al. (2013).

2. Composition of okara and potential for biotransformation

The composition of okara differs depending on the cultivar of soybean, the method of soymilk processing, and the amount of water soluble components extracted from the ground soybeans. The general composition of okara is shown in Table 1. Soybean cultivars vary in their crude protein and lipid contents, lipoxygenase activities and fatty acid compositions. The sequence of soymilk processing steps also matters, as illustrated in Fig. 1. In the Japanese way of soymilk manufacture, soaked whole soybeans are first cooked before grinding and filtering; in the Chinese way, the raw soybeans are first ground and then extracted with water, filtered, and then heated (O'Toole, 1999).

Although okara has high moisture content of 70%–80%, most of the water is bound to the fibre, resulting in a clumpy appearance and structure that resemble wet sawdust. Fibre, mainly insoluble fibre (in the form of cellulose and hemicellulose), makes up the bulk of the dry matter content at 40–60% (Redondo-Cuenca, Villanueva-Suárez, & Mateos-Aparicio, 2008; Van der Riet, Wight, Cilliers, & Datel, 1989). In comparison, the amount of free carbohydrates (such as arabinose, glucose, galactose, fructose, sucrose, raffinose and stachyose) is low at 4–5% (Redondo-Cuenca et al., 2008), and the lack of fermentable carbohydrates is the main factor limiting efficient microbial growth in okara. Notably, okara contains 1.4% stachyose and raffinose, which may cause flatulence and bloat in some individuals. The monomers in the cell wall polysaccharides of okara are mainly galacturonic acid, galactose, arabinose, glucose, xylose, fucose and a low amount of rhamnose and mannose (Mateos-Aparicio, Redondo-Cuenca, & Villanueva-Suárez, 2010b).

Table 1
General composition of okara.

Macro components	Amount (g/100 g dry matter)
Carbohydrate	3.8–5.3
Protein	15.2–33.4
Fat	8.3–10.9
Dietary fibre	42.4–58.1
Insoluble dietary fibre	40.2–50.8
Soluble dietary fibre	4.2–14.6
Ash	3.0–4.5
Micro components	**Amount (mg/100 g dry matter)**
Thiamine (B_1)	0.48–0.59
Riboflavin (B_2)	0.03–0.04
Niacin (B_3)	0.82–1.04
K	936–1350
Na	16–96
Ca	260–428
Mg	130–165
Fe	0.6–11
Cu	0.1–1.2
Mn	0.2–3.1
Zn	0.3–3.5
Phytochemicals	**Amount (g/100 g dry matter)**
Isoflavone aglycones	5.41
Isoflavone glucosides	10.3
Malonyl glucosides	19.7
Acetyl glucosides	0.32
Phytic acid	0.5–1.2
Saponins	0.10

References: Anderson & Wolf (1995), Jackson et al. (2002), Li, Qiao, & Lu (2011), Redondo-Cuenca, Villanueva-Suárez, & Mateos-Aparicio (2008), Van der Riet, Wight, Cilliers, & Datel (1989).

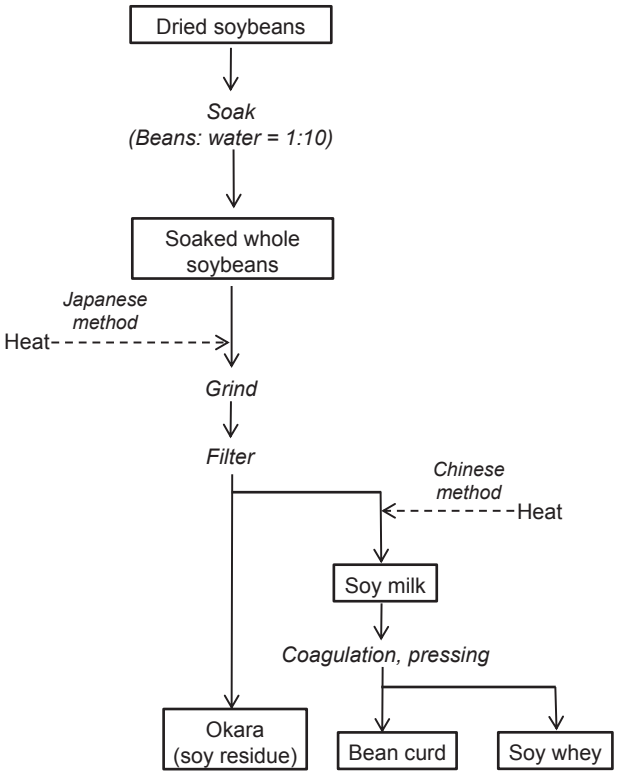

Fig. 1. Generation of okara from the manufacture of soy milk and bean curd.

Protein makes up 15.2–33.4% of okara (dry basis), with the two main proteins being basic 7S globulin and 11S globulin (Singh, Meena, Kumar, Dubey, & Hassan, 2015). Okara protein isolates contain all essential amino acids but have low solubility in water (Chan & Ma, 1999; Ma, Liu, Kwok, & Kwok, 1996). Okara protein has also been shown to resist complete digestion by the gastrointestinal enzymes, pepsin and pancreatin. The low molecular weight fraction of these digestion-resistant peptides (less than 1 kDa) is most potent in inhibiting angiotensin converting enzyme and displays the greatest antioxidant activity, possibly due to its high proportion of hydrophobic amino acids (Jiménez-Escrig, Alaiz, Vioque, & Rupérez, 2010). Trypsin inhibitors make up about 5.19–14.4% of the okara protein, although they can be inactivated with adequate heat treatment (Stanojevic, Barac, Pesic, Jankovic, & Vucelic-Radovic, 2013).

Microbial biotransformation of okara protein may offer a few advantages. The bioconversion of high molecular weight okara proteins to smaller ones may increase the solubility of okara protein isolates as well as generate bioactive peptides or amino acids.