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Review

The potential use of cereal $(1\rightarrow3,1\rightarrow4)$-β-D-glucans as functional food ingredients

Charles S. Brennan[a,b,*], Louise J. Cleary[b]

[a]Institute of Food, Nutrition and Human Health, Massey University, Private Bag 11222, Palmerston North, New Zealand

[b]Applied Food Research Group, Department of Agriculture and Food Studies, University of Plymouth, Drake Circus, Plymouth PL4 8AA, UK

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Abstract

The health-related importance of dietary fibre, as part of a balanced diet, has been recognised for decades. More recently, soluble fibre such as $(1\rightarrow3,1\rightarrow4)$-β-D-glucan (referred to as β-glucan), has been shown to have effects on the glycaemic, insulin, and cholesterol responses to foods. Cereals (such as barley and oats) are good sources for these functional ingredients, with studies clearly demonstrating their potential nutritional benefits. At the same time research has indicated that the efficacy of β-glucans may be related to extraction procedures, and factors such as dose, molecular weight and fine structure, and rheological characteristics of extracted and native β-glucans. Concurrently, research has focussed on the inclusion of β-glucans into both cereal and dairy-based food systems, illustrating their potential as ingredients to manipulate food structure and texture. Thus, β-glucans (from barley, oat, and other cereals) should be regarded as important functional ingredients for the cereal foods industry.

Keywords: Barley; Oats; Bread; Pasta; Dietary fibre; Glycaemic response

1. Introduction

Cereals are an important economic commodity worldwide. In the UK, the cereal harvest is predominated by wheat (15 million tonnes), with barley (7.8 million tonnes) representing the second most important cereal crop, and oats (0.6 million tonnes) being a relatively minor crop (HGCA, 1999). The $(1\rightarrow3, 1\rightarrow4)$-β-D-glucan, commonly referred to as β-glucan, content of cereals ranges from 1% in wheat grains, to 3–7% in oats, and 5–11% in barley (Skendi et al., 2003). Thus, barley grains are a rich source of β-glucans.

Barley belongs to the genus *Hordeum* and can be considered as one of the most ancient crop plants, with its cultivation being mentioned in the Bible. Archaeological studies have revealed two-rowed barley cultivation by about 8000 BC in Iran, with six-rowed barley appearing at approximately 6000 BC (Bothmer and Jacobsen, 1985). World production of barley in 2000/2003 was approximately 134 million metric tonnes. By far the leading barley producer is the EU (51.659 million tonnes) followed by the Russian Federation (25.013 million tonnes), and Canada (13.172 million tonnes).

The principal uses of barley are as feed for animals, in the form of barley meal, and as grain for malting and brewing in the manufacture of beer and whisky. Much research has focussed on the role of endosperm components in determining the malting potential of barley (Bamforth et al., 1979; Bathgate et al., 1974; Brennan et al., 1996a, 1997; Edney and Mather, 2004; Henry and Blakeney, 1986; Molina-Cano et al., 2002; Palmer, 1987). However, the barley crop may be considered relatively under-utilised with regard to its potential use as an ingredient in processed human foods. Recent attention has focussed on the potential use of β-glucan from barley and other cereals as a functional food ingredient (Malkki, 2004; Trepel, 2004).

Oats (genus *Avena*), are generally regarded as a minor cereal crop when considered in terms of grain produced

Abbreviations: DP, degree of polymerisation; FDA, US Food and Drug Administration; GI, glycaemic index; β-glucan, $(1\rightarrow3,1\rightarrow4)$-β-D-glucan; HDL, high density lipoprotein; HWM, high molecular weight; LDL, low density lipoprotein; LWM, low molecular weight; MW, molecular weight.

* Corresponding author. Address: Institute of Food, Nutrition and Human Health, Massey University, Private Bag 11222, Palmerston North, New Zealand. Tel.: +64 353 5307.

E-mail address: c.s.brennan@massey.ac.nz (C.S. Brennan).

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annually, or areas sown for production. Traditionally, most of the crop has been used as animal feed. However, UK figures on the usage of oats (HGCA, 1999) sees slightly more of the crop (44%) going towards human and industrial uses, compared to the animal feed sector (38%). Oats have been linked to the health claims attributed to the use of β-glucans (Weightman et al., 2002, 2004) and are a valuable source of β-glucans.

The purpose of this review is to explore some of the applications, and potential nutritional advantages, of using cereal β-glucans (predominately those in barley grain) as functional food ingredients.

2. Occurrence of β-glucans in barley and oat grain

β-Glucans ((1→3,1→4)-β-D-glucans) are the predominant components of cell walls of cereal grains such as barley and oats (Bacic and Stone, 1981a,b; Beresford and Stone, 1983; Buckeridge et al., 2004; Wood et al., 1983; Wood, 1993). Traditionally there have been concerns with the use of barley in animal feeds due to the negative effect that β-glucans, in conjunction with other non-starch polysaccharides, have on nutrient uptake and body weight gain. Work conducted on poultry has clearly illustrated the effect these components have on reducing feed digestibility, metabolisable energy (Annison, 1991; Bergh et al., 1999; Classen, 1996; Jeroch and Danicke, 1995), and the occurrence of other negative consequences such as sticky droppings (Choct et al., 1999). However, most of these problems can be alleviated by the use of (1→3,1→4)-β-D-glucan hydrolysing enzymes in poultry feed (Almirall et al., 1995; Fuente et al., 1998; Von Wettstein et al., 2003). Similar observations have been made in relation to the digestibility of cereal feeds in the pig (Baidoo and Liu, 1998; Knudsen and Canibe, 2000; Leterme et al., 2000; Morel et al., 2003). Thus the perceived anti-nutritional aspects of β-glucans in feed material can be minimised by the addition of specific enzymes to diet formulations.

Additionally, levels of β-glucan have long been regarded as one of the most influential characteristics in relation to malting potential and brewing yield in barley, regulating the rate of endosperm modification (Bacic and Stone, 1980, 1981a,b; Bamforth and Martin, 1983; Bourne et al., 1982; Brennan et al., 1998; Edney and Mather, 2004) and ultimately the viscosity of wort during brewing (Bourne and Pierce, 1970). Levels of β-glucan can vary dramatically between varieties, but usually range from 2 to 6% dry weight (Bamforth, 1981; Zhang et al., 2002). Despite their relatively small contribution to the total weight of the grain, it is clear that β-glucans have a disproportionate impact on the technology of barley utilisation and on the nutritional value of the grain.

Genetic and environmental factors impact on β-glucan content of barley grain (Knuckles et al., 1992; Savin et al., 1997; Yoon et al., 1995; Zhang et al., 2002). Although the relative contributions of these factors cannot be precisely quantified, there is a general agreement that the genetic background of the barley is more important than environmental conditions as a determinant of the final β-glucan content of the grain (Gill et al., 1982; Henry and Blakeney, 1986; Morgan et al., 1983; Stuart et al., 1988). For instance, Lehtonen and Ailasalo (1987) reported that two-row barley genotypes had higher β-glucan content than six-row barley. Studies have also indicated that waxy barley cultivars, with up to 100% amylopectin, have higher levels of β-glucans in their endosperm than non-waxy varieties (Ulrich et al., 1986; Yoon et al., 1995).

One of the major environmental factors that influence β-glucan levels appears to be the availability of water during grain maturation. Dry conditions (heat stress) before harvest have been shown to result in high β-glucan levels (Bendelow, 1975), with a positive relationship between β-glucan content and final grain weight (Savin and Molina-Cano, 2001). However, other experiments show a reduction in grain β-glucans related to heat stress within the plant during grain fill (Savin et al., 1997; Savin and Nicolas, 1996). This observation agrees with field studies on the effect of drought conditions on β-glucan content of the grain (Coles et al., 1991; Stuart et al., 1988). Conversely, moist conditions have been reported to cause a decrease in β-glucan levels (Aman et al., 1989; Stuart et al., 1988), so that increased levels of irrigation reduce β-glucan content of the grain (Guler, 2003). This may either be related to the fact that final grain fill is adversely affected in drought conditions through impairment of starch synthesis and deposition, or because β-glucan synthesis may be enhanced in dry conditions (Munck et al., 2004).

More recent research by Weightman et al. (2004) concentrated on the effect of nitrogen fertiliser treatments on the levels of β-glucan in oats. A positive correlation between protein and β-glucan content of the grain suggested that β-glucan deposition was associated with protein accumulation. Doehlert et al. (2001) examined the genotypic and environmental effects of grain yield, and composition, of oat lines grown in North Dakota over a 3 year period. In this case the authors found that although a positive correlation was established between starch content and β-glucan levels within the grain, correlations between β-glucan and protein content of the grain were not homogenous across genotypes. A negative interaction was found between β-glucan levels in oats and both crop yield and test weight of the grain. Peterson et al. (1995), examining the agronomic quality of a number of oat lines, found that many of the correlations between β-glucan content and agronomic quality characteristics of the grain, were inconsistent between the different oat lines. As such, the relationship between β-glucan levels in cereal grains and grain quality, or yield parameters, appear to vary greatly depending upon genetic background of the cereal line being examined.