ORIGINAL ARTICLE

The nutritional properties of flours derived from Orkney grown bere barley (*Hordeum vulgare* L.)

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Summary

Bere barley (*Hordeum vulgare* L.) is a six-row barley landrace, the ancestry of which may go back to the 8th century or earlier. The cultivation of bere on any scale is currently restricted to Orkney, although it was at one time grown more widely in Scotland. Within the UK, bere is unique in being the only barley grown commercially for milling and, in Orkney, flours derived from bere are traditionally used for making bannocks, bread and biscuits. There is potential for the use of bere flours in a much wider range of foods, and for this reason the nutritional properties of such flours were investigated. The energy, macronutrient and micronutrient content of both wholemeal and white flours derived from bere were measured. Flours derived from bere grown in Orkney contain a wide variety of nutrients including significant quantities of folate, thiamin, pantothenic acid, iron, iodine and magnesium. Although the nutrient content of bere bannocks has previously been published, to our knowledge, this is the first study to investigate the nutritional properties of wholemeal and white flours derived from bere.

Keywords: barley, bere, flour, grain, nutrient composition

Introduction

The term cereal describes the grain or edible seed of cultivated members of the Gramineae (grass) family, which may be used as food. The edible seeds or grains of cereals are highly nutritious, and cereals form the most important group of staple foods in the world, their use extending back many thousands of years. There is recent evidence that barley grains (as *Hordeum spontaneum* Koch and *H. marinum* Hudson) were processed and used to make bread in Israel as far back as 22 000 years ago (Piperno *et al*. 2004). The consumption of barley spread from the Middle East, across Europe, but these grains did not reach the UK until sometime between 4000 and 2000 BC (Vaughan & Geissler 1997).

Bere is a six-row barley landrace (shown in Fig. 1), adapted to growing on soils of a low pH and to the short growing season of the northern temperate region. Little is known about how bere came to the Orkney archipelago although it has been suggested (Jarman 1996) that it may have been introduced by Norse or Danish invaders in the 8th century.

Bere grows rapidly during the long summer days experienced in the Highlands and Islands of Scotland and, traditionally, it was one of the last to be sown but one of the first to be harvested; a practice which still continues. Cultivation of bere barley on any scale is cur-

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Figure 1 Bere barley (*Hordeum vulgare* L.) (photo John Wishart).

rently restricted to Orkney although in the past it was much more widely grown in Scotland, particularly during the 18th and 19th centuries. Agricultural records usually do not distinguish between bere and other types of barley, so it is not clear how the area planted with bere has declined over the years. Clearly, however, the agricultural improvements of the 19th century and the introduction of new, higher yielding varieties since then have had major effects on this. By the mid-1990s it was estimated that only about 5–15 hectares of bere was being grown annually in Orkney and Caithness (northern Scotland) (Jarman 1996).

Bere is unusual among barley grown in the UK in that it is used for milling: typically most barley grown in the UK is used as animal feed or in beer or whisky production. Bere flour is traditionally used in Orkney for making bannocks (round, unleavened bread baked on a griddle), breads and biscuits. Since it was once the only type of barley grown in many parts of Scotland, it would also have been used for making other products such as beer and whisky. Encouraging the production of more bere products would increase the demand for bere and could be beneficial for the economy of Orkney where agriculture is a major source of employment. Bere yields reasonably with low levels of inputs and is, therefore, well-suited to low-input agricultural production systems favoured by many growers in the Highlands and Islands of Scotland. Even so, its yields are low compared with modern varieties and it will be necessary to find high-value, niche markets for bere to make the crop commercially attractive to growers.

The aim of this study were to determine the nutritional properties of flours derived from bere barley, in order to determine whether their nutritional properties warrant development of new products incorporating Orkney grown bere.

Methods

Bere barley crop

Bere was planted at a seed density of 160 kg/ha on 15 May 2003. A compound fertiliser (nitrogen, phosphorus and potash) was applied to the field, supplying each nutrient at a rate of 50 kg/ha. A herbicide Ally [Du Pont (UK) Ltd, Hertfordshire, UK], was applied in June to control weeds and the crop was harvested on 1 September 2003. The site where the bere was sown had been planted with bere each year since 1998.

For the nutrient analysis, wholemeal bere flour was provided by the Barony Mill, Birsay, Orkney. Barony Mill is a water-powered mill, operated by the Birsay Heritage Trust, which uses a three-phase grinding process. The first of the grinding processes is known as shelling, where grains are milled by a pair of shelling stones which crack the husk of the grain and expose the kernel. Husks are removed by two fanners, which blow them away and the kernels then pass to a second pair of stones which grind them to a coarse meal or granular flour. This is then re-ground by a third set of stones to produce fine flour. In order to obtain white bere flour, the wholemeal flour provided by Barony Mill was sieved by RHM Technology, Marlow, Buckinghamshire, UK using 8N mesh to yield white flour of 62% extraction.

Analysis

Energy and macronutrients

The energy, protein, fat, carbohydrate, starch and sugar content of wholemeal and white flours derived from bere barley were determined by Direct Laboratories, Wolverhampton, UK which has United Kingdom Accreditation Service (UKAS) accreditation. Homogenised dry flour samples were analysed, following the removal of moisture, by mixing the sample with sand and heating at 102 ± 2°C. Moisture loss was determined gravimetrically. Single samples of flour were analysed. The methods used are summarised below.

The protein content of wholemeal and white flours derived from bere barley was determined according to the Kjeldahl method. In order to determine the crude protein content, the nitrogen content was multiplied by the conversion factor for barley, *i.e.* 5.83. The lipid content of flour samples was determined through the heating of samples with hydrochloric acid followed by petroleum spirit extraction (Soxhlet method). The carbohydrate content of flour samples was calculated by difference, based on the moisture, fat, protein and ash content. The calculation of energy did not take into account any alcohol, organic acids or polyols that may have been present in the sample. The energy content of flour samples was calculated by proximates. The starch content of bere flours was determined colorimetrically using the specific enzyme glucose oxidase. The sugar content of bere flours was determined by chromatographical separation on an amine column and detected using a refractive index detector.

Dietary fibre and dietary fibre fractions

Dietary fibre was determined according to the definition of the American Association of Cereal Chemists (American Association of Cereal Chemists 2001) and includes polysaccharides, oligosaccharides, lignin and associated plant substances. The methods of determining total dietary fibre, soluble fibre, insoluble fibre, lignin, β-glucan and resistant starch content of flour samples derived from bere are outlined below.

The Association of Analytical Chemists (AOAC) method 985.29 (Total Dietary Fiber in Foods – Enzymatic – Gravimetric Method) (AOAC International 1995) was used to determine the total dietary fibre content of bere flours, with measurements taken in triplicate. AOAC Method 995.16 was used to determine the *β*-glucan content of bere flours, with a slight modification of the method (McCleary & Codd 1991). Measurements were made in triplicate. Resistant starch was determined using AOAC method 2002.02 (McCleary *et al*. 2002); a total of six replicate measurements were made. The lignin content of bere flours was determined in duplicate using the ultraviolet (UV) method of Morrison (1972a) with modifications in order to remove soluble materials (Morrison 1972b).

Minerals

The calcium, chloride, copper, iron, iodine, manganese, magnesium, phosphorus, potassium, selenium, sodium, sulphur and zinc contents of flours derived from bere were determined by Direct Laboratories, Wolverhampton, using UKAS-accredited methods. Single samples of bere barley flours were analysed as homogenised dry flour samples. Methods used are summarised below.

The concentrations of calcium, chloride, chromium, copper, iron, magnesium, manganese, phosphorus, potassium, sodium, sulphur and zinc in flour samples were determined simultaneously, by inductively coupled plasma optical emission spectrometry. The iodine content of flour samples was determined through the destruction of organic matter by an alkaline ashing technique and determined by gas chromatography using a capillary column and electron capture detection. The selenium content was determined by hydride generation atomic fluorescence spectrometry employing continuous flow sample and reagent delivery.

Vitamins

The vitamin content of flour samples was determined by RHM Technology, Marlow, Buckinghamshire, with some assays being subcontracted to UKAS-accredited laboratories. Single samples of bere flour were analysed for vitamin A (including retinol and carotene equivalents), thiamin, riboflavin, niacin and tryptophan/60, vitamin B_6, vitamin B_{12}, folate, pantothenic acid, biotin, vitamin C, vitamin D and vitamin E. Exact methodologies have not been provided as they remain the intellectual property of RHM Technology; methodologies are summarised below.

The vitamin A content of bere flours was determined by high-performance liquid chromatography (HPLC) (BS/EN 12823–1: 2000 determination of vitamin A by HPLC method, part 1: measurement of *all-trans retinol* and *13-cis retinol*). Thiamin was also determined by HPLC, using the methodology of Wills *et al*. (1985). The riboflavin content was determined using an adaptation of the method devised by Lumley & Wiggins (1981) and determined by HPLC. Tryptophan and vitamins C, D and E were also analysed by HPLC. Vitamin E was determined according to the British Standard method: *BS/EN 12822:2000 Foodstuffs – Determination of Vitamin E by High Performance Liquid Chromatography – Measurement of α-, β-, γ-, δ-tocopherols*. Niacin (vitamin B_3), vitamin B_6 (pyridoxine), vitamin B_{12}, folates, pantothenic acid and biotin were determined by microbiological turbidimetric assay.

Results

The moisture lost from wholemeal bere barley flours was calculated to be 10.2 g/100 g sample for wholemeal flour and 10.6 g/100 g sample for white flour. Dry weight values derived from the analysis of bere flour samples were corrected for wet weight where appropriate. Results are reported in Tables 1–4.

The energy content of wholemeal and white bere flours were similar, as were the fat and carbohydrate contents (see Table 1). Wholemeal bere flours contain a greater amount of AOAC fibre than white flour, as expected. Insoluble fibre was the major form of fibre in wholemeal bere flour, while resistant starch (see Nugent 2005 for a review) was the major fraction in white

Table 1 Energy, protein, fat, carbohydrate, starch and sugar content of wholemeal and white flours derived form bere barley

	Energy (kJ/100 g)	Energy (kcal/100 g)	Protein (g/100 g)	Fat (g/100 g)	Carbohydrate (g/100 g)	Starch (g/100 g)	Sugar (g/100 g)
Wholemeal bere flour	1568	370	10.5	3.7	73.6	68.2	1.3
White bere flour	1565	370	9.9	3.9	73.7	71.0	1.5

Table 2 Dietary fibre content, including dietary fibre fractions, of wholemeal and white flours derived form bere barley

	Total fibre (AOAC) (g/100 g)	Soluble fibre (g/100 g)	Insoluble fibre (g/100 g)	β-glucan (g/100 g)	Resistant starch (g/100 g)	Lignin (g/100 g)
Wholemeal bere flour	17.5	5.8	11.7	3.2	0.09	1.26
White bere flour	13.5	5.5	8.1	2.7	3.09	0.85

AOAC, Association of Analytical Chemists.

Table 3 Mineral content of wholemeal and white flours derived form bere barley

	Wholemeal bere flour	White bere flour
Magnesium (mg/100 g)	110	80
Phosphorus (mg/100 g)	410	333
Potassium (mg/100 g)	410	320
Chloride (mg/100 g)	117	111
Iron (mg/100 g)	6.1	5.6
Zinc (mg/100 g)	2.4	2.0
Calcium (mg/100 g)	40	30
Copper (mg/100 g)	0.59	0.55
Sulphur (mg/100 g)	120	110
Manganese (mg/100 g)	1.3	1.3
Selenium (μg/100 g)	Not detected	Not detected
Sodium (mg/100 g)	Not detected	Not detected
Iodine (μg/100 g)	60	60

Table 4 Vitamin content of wholemeal and white flours derived form bere barley

	Wholemeal bere flour	White bere flour
Vitamin A (retinol) (μg/100 g)	Not detected	Not detected
Vitamin A (carotene) (μg/100 g)	Not detected	Not detected
Thiamin (mg/100 g)	0.50	0.52
Riboflavin (mg/100 g)	0.06	0.05
Niacin (mg/100 g)	0.50	0.52
Tryptophan/60 (mg/100 g)	2.5	2.3
Vitamin B_6 (mg/100 g)	0.22	0.21
Vitamin B_{12} (μg/100 g)	Not detected	Not detected
Total folates (μg/100 g)	107	105
Pantothenic acid (mg/100 g)	1.0	1.0
Biotin (μg/100 g)	1.7	1.4
Vitamin C (mg/100 g)	Not detected	Not detected
Vitamin D (μg/100 g)	Not detected	Not detected
Vitamin E (mg/100 g)	0.51	0.45

flours. Both β-glucan and lignin were found to be present in bere flours (see Table 2).

A range of minerals was detected in both wholemeal and white bere flours (see Table 3). Calcium, iron, magnesium, phosphorus, potassium and zinc were present in greater concentrations in wholemeal compared with white bere flour (although still present in significant quantities in the latter) suggesting that they are located predominantly in the outer layers of the grain. On the other hand, concentrations of chloride, copper, manganese, iodine and sulphur were similar in wholemeal and white bere flours, suggesting that these nutrients are predominantly found in the endosperm. This is unusual among cereal grains, as in wheat the majority of minerals are present in the outer layers of the grain, such as the pericarp. Selenium and sodium were not detected in bere flours.

As is the case for other cereal flours, vitamin A (as retinol or *β*-carotene), vitamin B_{12}, vitamin C and vitamin D were not detected in flours derived from bere. The thiamin, riboflavin, niacin and tryptophan/60, vitamin B_6, vitamin B_{12}, pantothenic acid and folate content of wholemeal and white bere flours were similar. Concentrations of vitamin E and biotin are slightly higher in wholemeal flours (see Table 4).

Discussion

To our knowledge, this is the first paper to report the nutritional content of flours derived from bere barley.

The nutritional composition of bannocks made from bere flour does, however, appear in Holland *et al.* (1988).

Based on the reported findings, a number of nutrients appear to be present in significant quantities in flours derived from Orkney grown bere, namely, folate, pantothenic acid, thiamin, iron, iodine and magnesium. However, the fact that only single samples were analysed for a number of nutrients does reduce the reliability and power of the analysis.

As with most cereal flours, flours derived from bere barley are a source of fibre. There is evidence to suggest that diets rich in fibre and wholegrain foods protect against a number of diseases including cardiovascular disease (Hu 2003; Liu *et al.* 2003) and type 2 diabetes (Murtaugh *et al.* 2003), and may play a role in weight management (Jacobs *et al.* 1998). There is also evidence to suggest that diets rich in wholegrain foods as well as fibre protect against colorectal cancers (Bingham *et al.* 2003; Peters *et al.* 2003). In addition to effects of total dietary fibre, different fractions of fibre play a role in health and disease; β-glucan exerts cholesterol-lowering effects (Ripsin *et al.* 1992) and has been shown to lower glycaemic and insulinaemic responses in healthy men in an experimental setting (Tappy *et al.* 1996). As the term dietary fibre is not used consistently, it is hard to interpret findings from clinical trails with confidence. Further work, notably randomised controlled trials, needs to be conducted to confirm the relationship between increased intakes of dietary fibre and its effect on risk of chronic diseases and whether bere barley itself could influence risk.

At present, in the UK, the minimum quantities of fibre that a food may contain in order to carry a claim that a food is a source or an excellent source of fibre, are based on the Englyst method of fibre determination and not the now-recommended AOAC method. In the absence of up-to-date guidance regarding the labelling of fibre using the AOAC method of determination, both wholemeal and white flours are likely to be considered a rich source of fibre in terms of nutrition labelling, based on comparisons with wheat flours and extrapolation from US values for fibre using the AOAC method. The Food Standards Agency has requested that the amount of fibre reported to be present in a food, as stated on a food label, is derived using the AOAC method of determination. The Food Labelling Regulations, 1996, have yet to be revised to reflect this change and, in the interim, there is no guidance on the use of such claims. Furthermore, dietary reference values for fibre refer to fibre in the form of non-starch polysaccharides as determined using Englyst method of analysis. It is not possible to make comparisons of the fibre content of bere flours with tabulated food data for wheat flours consumed in the UK, as the fibre content is expressed as non-starch polysaccharides rather than as AOAC fibre.

Whether bere flours and products derived from bere flours will have the same proposed benefits for health as other fibre-rich foods remains to be seen. This needs to be investigated through adequately powered and appropriately designed randomised controlled trials. For example, it has been reported that consumption of barley foods improves cholesterol concentrations (McIntosh *et al.* 1991; Li *et al.* 2003; Behall *et al.* 2004), glycaemic control (Tappy *et al.* 1996; Bourdon *et al.* 1999; Li *et al.* 2003) and increases faecal weight and reduces transit time (Lupton *et al.* 1993, 1994).

A number of minerals are present in wholemeal and white bere flours in significant quantities although most are at lower concentrations in white bere flour. Iodine, iron, magnesium and phosphorus are present in both wholemeal and white bere flours in significant quantities. Zinc is present in significant quantities in wholemeal but not white bere flours. A range of vitamins are present in bere flours: notably the B vitamins, thiamin, pantothenic acid and folate. As for other grain flours (with the exception of self-raising wheat flours), bere barley provides a small amount of sodium. The selenium content of bere flours is also low: the selenium content of grains reflects the selenium content of the soil in which it is grown.

Crude comparisons of the nutrient composition of wholemeal and white bere flours can be made with wheat flours (*Triticum* spp.) consumed in the UK (see Table 5). Comparing the nutrient content of bere flours, per 100 g, with data for wheat flours (Food Standards Agency 2002), it appears that wholemeal and white bere flour contain more folate per 100 g than wholemeal and white wheat flours. Similarly thiamin is present in greater quantities in wholemeal and white bere flours than in wheat flours even though white wheat flour in the UK is fortified with thiamin. Iron is also present in greater quantities in wholemeal and white bere flours than in wholemeal, brown and white wheat flours. Again, most brown and white wheat flours in the UK are fortified with iron as the Bread and Flour Regulations, 1995, dictate that wheat flours contain at least 1.65 mg iron/100 g, and as a result most brown and white wheat flour is fortified. Data on the content of iodine in commonly consumed grain flours is scant. However, data is available for white wheat flours; bere flours contain six times as much iodine as white wheat flour. Such comparisons should be interpreted with caution, as direct comparisons can only be made with confidence if

Table 5 Selected nutrient contents of wholemeal and white bere flours compared with wholemeal, brown and white wheat flours

	Wholemeal bere flour	White bere flour	Wholemeal wheat flour*	Brown wheat flour*	White wheat flour (self-raising)*
Folate (μg/100 g)	107	105	57	51	19
Thiamin (mg/100 g)	0.50	0.52	0.47	0.39	0.30
Pantothenic acid (mg/100 g)	1.0	1.0	0.8	0.4	0.3
Iron (mg/100 g)	6.1	5.6	3.9	3.2	2.0
Iodine (μg/100 g)	60	60	No information	No information	10
Magnesium (mg/100 g)	110	80	120	80	20

Comparisons should be made with caution as methodologies employed to derive values may differ.

*Data for wheat flours from Food Standards Agency (2002). © Crown copyright material is reproduced with the permission of the Controller of HMSO and Queen's Printer for Scotland.

the same methods are employed to conduct nutrient analyses.

The incorporation of foods derived from bere flours into the diet could have a beneficial impact on overall dietary quality in the UK, based on the nutrient profile of the flours. In the UK, there are particular groups of the population with inadequate intakes of certain nutrients. Amongst adults aged 19–64 years, a large percentage of women consume inadequate amounts of magnesium and iron, while among men intakes of magnesium are a concern. Data from the National Diet and Nutrition Survey (NDNS) of British adults aged 19–64 years reported that 9% of men and 13% of women aged 19–64 years fail to meet the lower reference nutrient intake (LRNI) for magnesium (a value considered sufficient to meet the needs of just 2.5% of the population: intakes less than the LRNI are often considered to be inadequate) and that 25% of women consume less than the LRNI for iron; the percentage of women aged 19–24 years consuming less than the LRNI for iron is as high as 42% (Henderson *et al.* 2003). In addition, biochemical assays suggest that 3% of men and 8% of women have haemoglobin concentrations indicative of iron deficiency anaemia and that thiamin deficiency occurs in 3% of men and 1% of women in the UK (Ruston *et al.* 2004). Biochemical analyses also suggest that a small proportion (5% of men and 5% of women) of the British population is deficient or marginally deficient in folate (Ruston *et al.* 2004). It is recommended that women of childbearing age who could become pregnant take a 400 μg supplement of folic acid/day, prior to conception and up until the 12th week of pregnancy (Department of Health 1992); over 80% of women of childbearing age consume less than 400 μg of folate from food and supplement sources (Henderson *et al.* 2003).

Although bere flours are a source of iodine, iron, magnesium, zinc (wholemeal bere flour), folate and thiamin, cooking of bere flours is likely to influence their nutrient profile, therefore, the analysis of bere flour products could form the basis of further research. This is particularly relevant to folates: folate is a heat labile vitamin and levels of folate in cooked bere flours are likely to be lower than those found in the uncooked flour; the extent of folate loss during cooking varies according to both the type of food and also the method of cooking (McKillop *et al.* 2002). As bread is the most commonly consumed foodstuff in the UK, the nutritional profile of bere based breads could be determined in comparison to breads made using wheat and other flours. Also, as savoury biscuits are manufactured from bere flours, the nutritional profile of these could be determined.

The market for functional foods is one that is expanding and expected to grow further over the next couple of decades. Functional foods may have a marketing advantage over similar foods lacking functional ingredients. There is potential for the development of functional foods based on bere, either through the addition of ingredients to bere flour or through the addition of components of bere to other foods (*e.g.* to breads, breakfast cereals and cereal bars). Fortified breakfast cereals, by definition, are a functional food and bere-based breakfast cereals is one potential route for new product development. Bere products could be developed based on the β-glucan content of the cereal; in the USA, barley β-glucans are sold as a dietary supplement. Additionally, in the USA and Canada, barley is used as a nut 'replacer', while in Sweden barley is sometimes used in a similar way to rice. In addition, whole grains of bere could be used to produce breakfast cereals, while bere flakes could be used to make muesli or porridge-type breakfast cereals.

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