

Composition and Utilization of Barley Pearling By-Products for Making Functional Pastas Rich in Dietary Fiber and β -Glucans

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ABSTRACT

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Pearling by-products and the pearled products of two commercial stocks of hulled barley, pearled according to an industrial process consisting of five consecutive pearling steps, were analyzed for β -glucans, dietary fiber (total, soluble, and insoluble), protein, lipid, ash, and digestible carbohydrate. The data showed that the pearling flour fractions, abraded in the fourth and fifth hullers, contained interesting amounts of β -glucans (3.9–5.1% db) from a nutritional point of view. These fractions were subsequently enriched in β -glucans using a milling-sieving process to double β -glucan content (9.1–10.5% db). Functional pastas, enriched with β -glucans and dietary fiber, were produced by substituting 50% of

standard durum wheat semolina with β -glucan-enriched barley flour fractions. Although darker than durum wheat pasta, these pastas had good cooking qualities with regard to stickiness, bulkiness, firmness, and total organic matter released in rinsing water. The dietary fiber (13.1–16.1% wb) and β -glucan (4.3–5.0% wb) contents in the barley pastas were much higher than in the control (4.0 and 0.3% wb, respectively). These values amply meet the FDA requirements of 5 g of dietary fiber and 0.75 g of β -glucans per serving (56 g in the United States and 80 g in Italy). At present, the FDA has authorized the health claim “may reduce the risk of heart disease” for food containing β -glucans from oat and psyllium only.

Barley, one of the earliest cultivated cereals in the world, is now gaining renewed interest as a food component because of its soluble dietary fiber and β -glucan content in particular. Compared with other cereals, barley has relatively high levels of β -glucans of 2–11 g/100 g (wb) (MacGregor and Fincher 1993). The highest β -glucan level reported (16.9% db) was found in Prowashonupana cultivar (Newman et al 1992).

Soluble dietary fiber and β -glucan are reported to lower plasma cholesterol and postprandial serum glucose levels in humans and animals (Newman and Newman 1991, McIntosh et al 1991, Bhatti 1993, Wood et al 1994, Jenkins et al 1995, Kahlon and Chow 1997, Yokoyama et al 1997).

The traditional barley products, dehulled, pot, and pearled barley, barley flakes, and barley flour, are produced by roller-milling dehulled or pearled barley. The dehulling and pearling processes differ in the amount of outer layers removed from the grain. Dehulling removes part of the hull with minimum damage to the kernel, whereas pearling is an abrasive process that gradually removes the seed coat (testa and pericarp), aleurone, subaleurone layers, and the germ to obtain a polished grain.

The by-products of the pearling process, \approx 30–40% of the total kernel weight, are mainly used in animal feed (Jadhav et al 1998). These by-products contain interesting amounts of bioactive compounds such as β -glucans, tocopherols, and tocotrienols (Wang et al 1993, Peterson 1994, Jadhav et al 1998). Therefore, the aim of this study was to assess the possibility of using pearling by-products in human nutrition by incorporating them into food formulations for functional pasta making. The dietary fiber and β -glucan contents in the by-products and in the pearled grains of two commercial barley stocks were evaluated during the five steps of an industrial pearling process. Subsequently, balanced pasta-making formulations and adequate technological processes were adopted to counteract any changes in the rheological properties caused by the incorporation of these unconventional ingredients.

MATERIALS AND METHODS

The hulled grains of two commercial stocks of barley (A = English, B = Italian) were pearled according to an industrial flow

chart consisting of five pearling steps. The grains of barley were first passed through a Carter disk separator to remove broken kernels and any foreign grains and then through a calibration disk to obtain uniform-sized grains (\geq 2.5 mm caliber). The cleaned barley grains were not tempered before pearling (the initial moisture of both barley stocks was \approx 12%).

Samples of the by-products removed at each pearling stage (BP1–BP5) and the five types of pearled residual kernels (PK1–PK5), together with the original grain (hulled kernel [HK]) were collected and evaluated for moisture, protein, lipid, ash, digestible carbohydrates, total, soluble, and insoluble fiber, and β -glucan content. The 1,000 kernel weight of HK and PK1–PK5 was obtained by weighing sets of 250 kernels randomly chosen after removal of broken grains.

BP5 by-products from both barley stocks and the PK1 pearled product from stock A were used to make the β -glucan-enriched barley flour. The enrichment process involved repeated milling and sifting to remove barley starch, as described by Knuckles et al (1992).

The pearling fractions and the pearled kernels were milled in a Cyclotec 1093 laboratory mill (0.5-mm sieve; Tecator, Hoganas, Sweden) and sifted through a sieve (Bühler, Uzwil, Switzerland), using 100 g of meal and 20 min of sifting time. The sieve was 20 cm in diameter and the mesh size was 44 μ m. A diagram of the process is shown in Fig. 1.

Functional pastas were produced by replacing 50% of durum wheat semolina with milled-sieved β -glucan-enriched barley flour fractions (fraction D) and adding 5% vital wheat gluten.

The composite flours used for the pasta-making trials were CF1 = 50% β -glucan-enriched fraction D of BP5 (stock A) + 45% semolina + 5% vital wheat gluten; CF2 = 50% β -glucan-enriched fraction D of BP5 (stock B) + 45% semolina + 5% vital wheat gluten; CF3 = 50% β -glucan-enriched fraction D of PK1 (stock B) + 45% semolina + 5% vital wheat gluten. A commercial durum wheat semolina was used as a control.

The composite flours were used to manufacture spaghetti (long pasta) under conditions previously reported (85°C drying temperature, 7-hr drying cycle) (Marconi et al 1999). An experimental pasta-making apparatus composed of a press and a dryer (Pavan, Padova, Italy) was used. The diameter of the dried spaghetti was 1.65–1.70 mm.

Analytical Tests

Whole-meal flour, pearling flour, by-product meal, and pasta samples were analyzed using standard procedures (ICC 1995) for moisture (Method 110/1), crude protein (N \times 6.25) (Method

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105/2), total fat (Method 136), and ash (Method 104/1). Soluble dietary fiber (SDF) and insoluble dietary fiber (IDF) were quantified by the enzymatic gravimetric procedures of Prosky et al (1988), and Methods 993.19 and 991.42 (AOAC 1997). Total dietary fiber (TDF) was calculated as SDF+IDF. Digestible carbohydrates (DC) were calculated by difference. β -Glucans were determined according to Approved Method 32-23 (AACC 2000) as described by McCleary and Glennie-Holmes (1985).

Spaghetti color was evaluated by measuring L^* (brightness, 100 = white; 0 = black), a^* (+, red; -, green) and b^* (+, yellow; -, blue) parameters by means of a reflectance colorimeter (CR300 Chroma-meter, Minolta, Japan) on dry, uncooked pasta ground in a mill (model MLI 204, Bühler-Miag). Values are the mean of five determinations.

The spaghetti (100 g) was cooked in 1L of unsalted boiling tap water. Optimum cooking time was taken as being when the white core of the pasta disappeared when squeezed between two test glasses. Spaghetti was evaluated by sensory and chemical procedures 9 min after draining.

Sensory assessment was made by a trained panel of three experts (assessors). The general test conditions (order and presentation of samples) were according to the international standard 7304 (ISO 1985). The stickiness, bulkiness, and firmness of the cooked spaghetti were determined according to the sensory assessment procedure reported by Cubadda (1988). The degree of stickiness, which is the amount of material that adheres to the surface of the cooked pasta, was assessed visually (with the aid of a standard reference samples) and by handling the samples. Bulkiness, which was assessed in the same way, is the degree to which the strands of pasta adhere to each other. Firmness is the degree of resistance of the cooked pasta when either pressed between the fingers or chewed. These parameters were rated on a five-point hedonic scale and then converted into numerical scores. The scale for both stickiness and bulkiness was 20 = very high, 40 = high, 60 = rare, 80 = almost absent, and 100 = absent. The firmness scale was 20 = rare, 40 = insufficient, 60 = sufficient, 80 = good, and 100 = very good. The score of each organoleptic parameter was the arithmetic mean of the values given by three assessors. The total score regarding cooking quality was obtained by summing the scores of the parameters, multiplying the total by 33.3 and dividing it by 100. The final score for cooking quality was correlated with a description. Spaghetti with a total score of 40 was of poor or

mediocre quality; >40 to 50 was not completely satisfactory; >50 to 70 was fair; >70 to 80 was good; and >80 was excellent. All cooking tests were made in duplicate.

Total organic matter (TOM), the amount of surface material released in the washing water after thoroughly rinsing the cooked pasta, was determined using the standard chemical method of D'Egidio et al (Method 153, ICC 1995). TOM values >2.1 g/100 g, corresponds to low cooking quality; 2.1–1.4 g/100 g corresponds to good cooking quality, and <1.4 g/100 g corresponds to very good cooking quality (D'Egidio and Nardi 1996).

The enzymic kit for the determination of β -glucans was purchased from Megazyme International Ireland, Bray, Ireland. All other chemicals were of analytical grade and were purchased from Sigma, St. Louis, MO.

All determinations were made at least in duplicate, and mean \pm standard deviation (SD) values are presented. Some data were statistically evaluated by analysis of variance and Fisher's least significant difference procedure (system package 1987, SAS Institute, Cary, NC).

RESULTS AND DISCUSSION

The 1,000 kernel weight and the weight of the successively removed by-products produced in pearling two barley stocks are given in Table I. The 1,000 kernel weight of starting material was more in stock A (46.9 g) than in stock B (44.0 g), with a percentile difference of 6.2%.

The material abraded, which is expressed as the percentage of weight removed from the original kernel, represents the by-products. The residual kernel (PK5) constituted 62.9 and 54.1% db of the starting material in stocks A and B, while the total cumulative by-products (total cumulative weight removed) were 37.1 and 45.9%, respectively. Similar pearling rates have been reported by several authors (Normand et al 1965, Bhatti 1993, Jadhav et al 1998).

Differences in the amount of fractions abraded at each pearling stage were found, as well as differences between the barley stocks. In particular, Table I shows that 1) the first pearling step produced more abraded material in stock B than in stock A (8.9 vs. 3.8% db of the original kernel, respectively); 2) the third step produced fewer by-products in both stocks ($\leq 2.0\%$ db); 3) the fourth and fifth pearling steps produced the greatest amount of by-products in both stocks A and B (16.4 and 11.6% db of the original kernel in step four; 10 and 20% db of the original kernel in step five, respectively); 4) the cumulative total weight removed in the first four steps were similar in both stocks (≈ 26 – 27% db of the original kernel).

TABLE I
1,000 Kernel Weight and Kernel Weight Removed from the Original Kernel During Industrial-Scale Pearling of Two Barley Stocks

Stock and Fraction ^a	1,000 Kernel Weight (g, db) ^b	% Kernel Weight Removed	% Total Cumulative Weight Removed
English (A)			
HK	46.9 \pm 0.9		
PK1	45.1 \pm 0.3	3.9	3.9
PK2	42.6 \pm 0.2	5.3	9.2
PK3	41.9 \pm 0.5	1.5	10.7
PK4	34.2 \pm 0.8	16.4	27.1
PK5	29.5 \pm 0.6	10.0	37.1
Italian (B)			
HK	44.0 \pm 1.0		
PK1	40.1 \pm 0.6	8.9	8.9
PK2	38.5 \pm 0.4	3.6	12.5
PK3	37.7 \pm 0.5	1.8	14.3
PK4	32.6 \pm 0.7	11.6	25.9
PK5	23.8 \pm 0.4	20.0	45.9

^a HK = hulled kernel, PK = pearled kernel.

^b Mean \pm standard deviation.

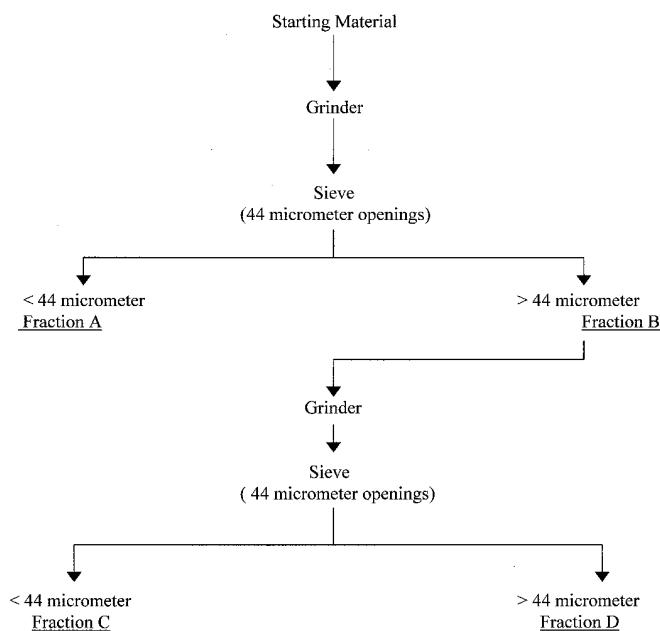


Fig. 1. β -Glucan enrichment diagram of barley materials.

The protein, lipid, ash, and digestible carbohydrate content of the successively removed by-products of two pearled barley stocks, together with their percentages with regard to the total amount, are given in Table II.

The findings show that, with the exception of the first fraction, there is more proteinaceous material in the by-products than in the original kernels of both stocks. The lowest concentrations of protein were found in the first by-products (BP1) of both stocks (8.2% db in stock A and 12.1% db in stock B), representing 2.6 and 9.2% of the total protein contained in the starting material. The highest concentrations of protein (19.4 and 19.8% db), were found in BP3 in stock A and BP4 in stock B, corresponding to 25.8 and 3.0% of total protein in stocks A and B, respectively. The amount of protein removed from the starting material in the cumulative by-products was 49.7% in stock A and 59.8% in stock B.

Lipid content showed that the germ was mainly removed during the second, third, and fourth pearling steps. In fact, the lipid content of these fractions had a range of 7.0–8.6% db vs. a lipid content of 3.5% of original kernels. The total cumulative amount of lipid removed in stocks A and B during the pearling process was 64.1 and 77.1%, respectively.

A progressive decrease in the percentage of ash from BP1 (8.13 and 8.43% db in stocks A and B) to BP5 (2.43 and 2.75% db in stocks A and B) was found, since the mineral components are mainly distributed in the outer layers of the kernel (pericarp, aleurone and germ) (Liu et al 1974, Weaver et al 1981). For this reason, the total cumulative amount of ash removed from the starting material in the pearling by-products was very high (71.9% db in stock A and 80.7% db in stock B). On the other hand, a gradual increase in digestible carbohydrates was found during the pearling process

TABLE II
Protein, Lipid, Ash, and Digestible Carbohydrates (DC) of Successively Removed By-Product Fractions of Two Barley Stocks (% db)

Stock and Fraction ^a	Protein in Fraction ^b	Amount of Total Protein in Fraction	Total Cumulative Amount of Protein Removed	Lipid in Fraction ^b	Amount of Total Lipid in Fraction	Total Cumulative Amount of Lipid Removed	Ash in Fraction ^b	Amount of Total Ash in Fraction	Total Cumulative Amount of Ash Removed	DC in Fraction ^{b,c}	Amount of Total DC in Fraction	Total Cumulative Amount of DC Removed
English (A)												
BP1	8.2 ± 0.2	2.6	2.6	2.9 ± 0.0	3.2	3.2	8.13 ± 0.05	13.8	13.8	7.4	0.5	0.5
BP2	15.1 ± 0.1	6.6	9.2	7.3 ± 0.1	11.3	14.5	6.50 ± 0.04	15.3	29.1	8.7	0.8	1.3
BP3	18.3 ± 0.2	1.9	11.1	8.4 ± 0.3	3.1	17.6	6.13 ± 0.02	3.5	32.6	22.8	0.5	1.8
BP4	19.4 ± 0.2	25.8	36.9	7.1 ± 0.2	33.5	51.1	4.01 ± 0.01	28.8	61.4	38.1	10.5	12.3
BP5	16.0 ± 0.1	12.8	49.7	4.6 ± 0.1	13.0	64.1	2.43 ± 0.05	10.5	71.9	53.2	8.8	21.1
HK	12.4 ± 0.3	100		3.5 ± 0.2	100		2.30 ± 0.03	100		59.7	100	
PK5	9.5 ± 0.1	50.3		1.8 ± 0.1	35.9		0.96 ± 0.02	28.1		74.8	78.9	
Italian (B)												
BP1	12.1 ± 0.1	9.2	9.2	6.9 ± 0.2	17.5	17.5	8.43 ± 0.07	28.8	28.8	8.0	1.2	1.2
BP2	17.8 ± 0.4	5.5	14.7	7.2 ± 0.1	7.4	24.9	6.56 ± 0.04	9.1	37.9	16.7	1.0	2.2
BP3	19.8 ± 0.2	3.0	17.7	8.6 ± 0.2	4.4	29.3	5.07 ± 0.02	3.5	41.4	33.4	1.0	3.2
BP4	18.4 ± 0.1	18.2	35.9	7.0 ± 0.1	23.2	52.5	4.07 ± 0.06	18.2	59.6	44.4	8.3	11.5
BP5	14.0 ± 0.3	23.9	59.8	4.3 ± 0.0	24.6	77.1	2.75 ± 0.02	21.1	80.7	57.3	18.5	30.0
HK	11.7 ± 0.1	100		3.5 ± 0.1	100		2.60 ± 0.01	100		61.8	100	
PK5	8.3 ± 0.3	40.2		1.5 ± 0.1	22.9		1.05 ± 0.01	19.3		80.0	70.0	

^a BP = by-product, HK = hulled kernel, PK = pearled kernel.

^b Mean ± standard deviation.

^c Calculated by difference.

TABLE III
Total, Soluble and Insoluble Dietary Fiber (TDF, SDF, IDF) and β-Glucans of Successively Removed By-Product Fractions of Two Barley Stocks (% db)

Stock and Fraction ^a	TDF in Fraction ^b (Mean)	Amount of Total TDF in Fraction	Total Cumulative Amount of TDF Removed	SDF in Fraction ^c	Amount of Total SDF in Fraction	Total Cumulative Amount of SDF Removed	IDF in Fraction ^c	Amount of Total IDF in Fraction	Total Cumulative Amount of IDF Removed	β-Glucans in Fraction	Amount of Total β-Glucans in Fraction	Total Cumulative Amount of β-Glucans Removed
English (A)												
BP1	73.4	13.0	13.0	1.1 ± 0.1	0.8	0.8	72.3 ± 1.0	16.9	16.9	1.0 ± 0.1	0.9	0.9
BP2	62.4	15.2	28.2	3.1 ± 0.2	3.1	3.9	59.3 ± 0.5	19.2	36.1	2.0 ± 0.1	2.5	3.4
BP3	44.4	2.6	30.8	4.4 ± 0.2	1.1	5.0	40.0 ± 0.2	3.1	39.2	3.3 ± 0.2	1.0	4.4
BP4	31.4	23.4	54.2	5.5 ± 0.3	16.8	21.8	25.9 ± 0.4	25.6	64.8	4.5 ± 0.2	16.9	21.3
BP5	23.8	10.7	64.9	6.6 ± 0.2	12.1	33.9	17.2 ± 0.4	10.2	75.0	5.1 ± 0.1	11.8	33.1
HK	22.1	100		5.4 ± 0.3	100		16.7 ± 0.5	100		4.3 ± 0.2	100	
PK5	12.9	35.1		5.4 ± 0.4	66.1		7.5 ± 0.1	25.0		4.5 ± 0.3	66.9	
Italian (B)												
BP1	64.6	28.2	28.2	1.9 ± 0.1	3.4	3.4	62.7 ± 0.3	36.2	36.2	1.1 ± 0.1	2.6	2.6
BP2	51.7	9.1	37.3	2.8 ± 0.2	2.0	5.4	48.8 ± 0.5	11.4	47.6	2.0 ± 0.1	1.9	4.5
BP3	33.1	2.9	40.2	4.6 ± 0.2	1.7	7.1	28.6 ± 0.6	3.3	50.9	3.4 ± 0.2	1.6	6.1
BP4	26.1	14.8	55.0	5.8 ± 0.3	13.5	20.6	20.3 ± 0.1	15.3	66.2	3.6 ± 0.1	11.4	17.5
BP5	21.6	21.2	76.2	6.1 ± 0.1	24.4	45.0	15.5 ± 0.3	20.1	86.3	4.4 ± 0.2	24.1	41.6
HK	20.4	100		5.0 ± 0.2	100		15.4 ± 0.3	100		3.7 ± 0.0	100	
PK5	9.2	23.8		4.5 ± 0.2	55.0		4.7 ± 0.2	13.7		4.2 ± 0.2	58.4	

^a BP = by-product, HK = hulled kernel, PK = pearled kernel.

^b SDF+IDF.

^c Mean ± standard deviation.

from BP1 to BP5, due to the increased abrasion of the starchy endosperm. In fact, DC content in stock A increased from 7.4% (BP1) to 53.2% (BP5) and from 8.0% (BP1) to 57.3% (BP5) in stock B. The total cumulative amounts of DC removed from the starting material in the pearling by-products of stocks A and B were 21.1 and 30.0% db, respectively.

Soluble, insoluble, and total dietary fiber, and β -glucan content of the by-products of two pearled barley stocks, together with their percentages with regard to the total amount, are given in Table III.

The TDF content of the first two by-products (BP1 and BP2) was >50% db, which almost entirely belonged to the insoluble fraction (lignin and cellulose) as attested by the SDF to TDF ratio <6% in both stocks. In fact, having removed \approx 10% of the outer layers of the kernels, most of the hull had been removed.

The β -glucan content in BP1 and BP2 was very low (\approx 1% db); β -glucan is, in fact, located in the inner layers of the kernel, since it is the main cell wall component of the starchy endosperm and aleurone (MacGregor and Fincher 1993, Jadhav et al 1998). A further decrease in TDF was found in BP3 and BP4, whereas SDF and β -glucan increased, the latter being the main soluble fiber component in barley (Newman and Newman 1991). The final by-product, BP5, had the lowest concentration of TDF (stock A = 23.8% db and stock B = 21.6% db), the highest concentration of SDF and β -glucan and the highest SDF to TDF ratio (\approx 30%). The total cumulative amount of TDF removed from the starting material in the by-products of stocks A and B were 64.9 and 76.2% db, respectively; the higher value of stock B was due to its greater pearling rate.

In conclusion, BP1 represents the hull layer surrounding the original barley grain, plus some embryo and pericarp layer material. BP2 represents the pericarp layer, plus some embryo and aleurone layers, BP3 and BP4 represent material from high-protein-bearing layers in the barley kernel, plus some embryo and the outer layer of the starchy endosperm. BP5 represents the outer layer of the starchy endosperm and the subaleurone layer, plus some components of peripheral layers (aleurone and pericarp layers).

The nonuniform distribution of the botanical fractions among the by-products is due to the fact that the removed fractions do not necessarily contain the same layers or components of the kernel because of differences in the natural shape of the kernels. In fact, some components of the external layers such as bran, aleurone etc., remained in the creases of the kernels even after several fractions had been removed.

The compositional differences between the two barley stocks in the same by-product are mainly due to differences in the extraction rates of the same fractions.

Pearled Products

The protein, lipid, ash, digestible carbohydrates, dietary fiber (TDF, SDF, IDF), and β -glucan contents of the pearled products of barley stocks A and B are shown in Figs. 2 and 3.

The successive removal of the outer layers of the barley kernels in the pearling process caused significant decreases in protein, lipid, ash, and IDF contents in the final pearled product (PK5) of both stocks. Compared with the original kernel, protein content in

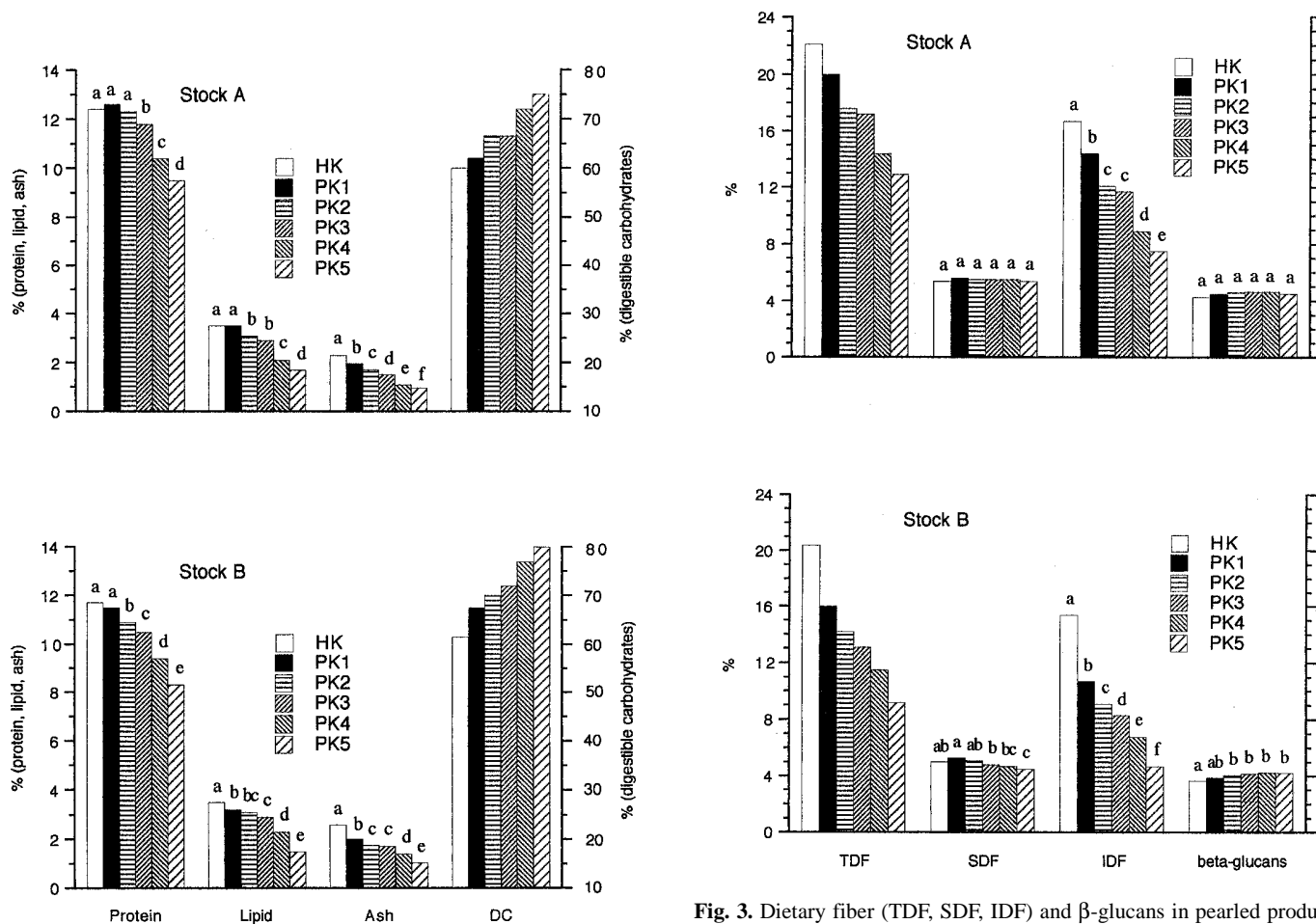


Fig. 2. Protein, lipid, ash, and digestible carbohydrates (DC) in pearled products at different pearling rates (PK1–PK5) of two barley stocks. HK = hulled kernel, PK = pearled kernel. Different letters above columns indicate significant differences at $P = 0.05$ within each nutrient.

Fig. 3. Dietary fiber (TDF, SDF, IDF) and β -glucans in pearled products at different pearling rates (PK1–PK5) of two barley stocks. TDF = Total dietary fiber (calculated by SDF+IDF), SDF = soluble dietary fiber, IDF = insoluble dietary fiber. HK = hulled kernel, PK = pearled kernel. Different letters above columns indicate significant differences at $P = 0.05$ within each nutrient.

stocks A and B decreased by 23.4 and 29.4% db, respectively. Lipid and ash contents decreased more than twofold during the pearling process.

β -Glucan content was not always significantly affected by pearling. However, it did cause a general upward trend that was the same in both stocks. Similar changes in the chemical composition of barley kernels due to pearling were also reported (Liu et al 1974, Sumner et al 1985, Baik and Czuchajowska 1997, Klamczynsky et al 1997). The substantial changes in the chemical composition of the barley kernels due to pearling may considerably affect the utilization and the nutritional quality of the final barley products. Pearling rates of 30–40% were most desirable, as at these levels the equilibrium between nutritional (β -glucans, protein, SDF) and physical properties (color, texture, etc.) was balanced (Normand et al 1965, Bhatta 1993, Klamczynsky et al 1997, Jadhav et al 1998, Marconi et al unpublished data). The pearling rate in stock B (PK5) which was >40%, in fact removed a large amount of protein, ash, lipid, and SDF.

Functional Pasta Manufacturing

Given the nutraceutical properties of both BP5 (high SDF and β -glucan content), these products could be used as potential ingredients for manufacturing functional foods. To increase β -glucan

content, these by-products were subjected to a physical enrichment process consisting of milling and sieving.

The yields and β -glucan content of the fractions produced by the enrichment process are given in Table IV. Fraction A from BP5 contained \approx 40% of the starting weight and >63% of the starting weight from PK1, the latter being the same as that reported by Knuckles et al (1992). Fraction C contained a much smaller amount of the starting weight (5.9–25.2%). The yield of the milled-sieved β -glucan-enriched fraction D was 27.9–35.2% of the starting weight. The concentrations of β -glucan in fraction D were double those of the unfractionated materials for both the BP5 and PK1. These β -glucan-enriched fractions were, therefore, used as ingredient to manufacture some functional pastas.

To compensate for the poor rheological properties of these unconventional ingredients, additives (vital gluten) and adequate processing (high-temperature pasta drying) were used. In fact, protein quantity and high drying temperatures are key factors in obtaining good quality products (D'Egidio 1990, Novaro et al 1993, Cubadda 1996, Marconi et al 1999) because they promote the building up of a diffused and coagulated protein network capable of entrapping starch granules and preventing them from exuding from pasta during cooking (Resmini and Pagani 1983, Cubadda and Acquistucci 1987).

TABLE IV
Weight and β -Glucan Content (% db) of Fractions from Laboratory-Scale Milling and Sieving of Pearling By-Products and Pearled Product of Two Barley Stocks

Milling Fraction	Particle Size (μ m)	Pearling By-Product (BP5)				Pearled Barley (PK1)	
		Stock A		Stock B		Stock B	
		Weight	β -Glucans	Weight	β -Glucans	Weight	β -Glucans
Starting Material		100.0	5.1 \pm 0.1	100.0	4.4 \pm 0.2	100.0	3.9 \pm 0.2
A	<44	41.2 \pm 1.2	1.6 \pm 0.1	35.8 \pm 0.9	1.2 \pm 0.1	63.8 \pm 1.1	1.3 \pm 0.1
B	>44	57.2 \pm 0.8	7.3 \pm 0.3	62.2 \pm 1.4	6.3 \pm 0.3	35.2 \pm 0.6	8.2 \pm 0.4
C	<44	22.6 \pm 0.4	3.0 \pm 0.1	25.2 \pm 0.7	2.1 \pm 0.1	5.9 \pm 0.3	3.7 \pm 0.2
D	>44	33.1 \pm 0.7	10.5 \pm 0.3	35.2 \pm 0.5	9.1 \pm 0.4	27.9 \pm 0.7	9.5 \pm 0.3

TABLE V
Proximate Composition (% wb), Color, and Cooking Quality of Barley Pastas Compared with Durum Wheat Pasta

Characteristics	Composite Flour Pasta ^a			Durum Wheat Pasta
	CF1	CF2	CF3	
Moisture	9.7 \pm 0.1	9.5 \pm 0.1	9.7 \pm 0.1	9.8 \pm 0.1
Protein	18.5 \pm 0.2	17.3 \pm 0.1	15.3 \pm 0.2	12.2 \pm 0.1
Fat	2.37 \pm 0.02	2.25 \pm 0.01	2.22 \pm 0.02	1.17 \pm 0.02
Ash	1.70 \pm 0.03	1.82 \pm 0.03	1.69 \pm 0.02	0.73 \pm 0.02
Digestible carbohydrates	51.6	53.8	58.0	72.1
Dietary fiber ^b				
IDF	8.4 \pm 0.3	7.9 \pm 0.1	7.2 \pm 0.2	1.3 \pm 0.1
SDF	7.7 \pm 0.2	7.3 \pm 0.2	5.9 \pm 0.1	2.7 \pm 0.1
TDF	16.1	15.2	13.1	4.0
β -glucans	5.0 \pm 0.2	4.3 \pm 0.2	4.3 \pm 0.1	0.3 \pm 0.0
Calories per 100 g, Kcal ^c	309	312	321	358
Color				
L*	68.0 \pm 1.0	68.8 \pm 1.2	69.8 \pm 1.3	77.0 \pm 0.8
a*	3.8 \pm 0.2	3.8 \pm 0.4	3.6 \pm 0.3	0.1 \pm 0.1
b*	15.1 \pm 0.7	15.5 \pm 0.6	15.8 \pm 0.6	21.5 \pm 0.9
Cooking quality				
Cooking time (min)	12:30	12:30	12:45	13:00
Stickiness	Rare	Rare	Absent	Absent
Bulkiness	Rare	Rare	Almost absent	Almost absent
Firmness	Good	Good	Very good	Very good
Total score ^d	67	67	93	93
Total organic matter ^e	1.6 \pm 0.2	1.6 \pm 0.1	0.9 \pm 0.1	1.1 \pm 0.1

^a CF1: 50% β -glucan-enriched milling fraction D of BP5 (stock A) + 45% semolina + 5% vital wheat gluten. CF2: 50% β -glucan-enriched milling fraction D of BP5 (stock B) + 45% semolina + 5% vital wheat gluten. CF3: 50% β -glucan-enriched milling fraction D of PK1 (stock B) + 45% semolina + 5% vital wheat gluten.

^b IDF = insoluble dietary fiber; SDF = soluble dietary fiber; TDF = total dietary fiber.

^c Fat = 9 Kcal/g; protein = 4 Kcal/g; carbohydrate = 4.13 Kcal/g.

^d 40 = poor or mediocre quality; >40–50 = not completely satisfactory; >50–70 = fair; >70–80 = good; >80 = excellent.

^e Grams per 100 g of dry pasta. >2.1 = low quality; 1.4–2.1 = good quality; <1.4 = very good quality.

The nutritional composition, appearance, and cooking quality of pasta produced with composite flours containing β -glucan-enriched barley fractions (fraction D) and durum wheat semolina are reported in Table V.

Protein content was high in the barley pastas due to the addition of vital gluten (5%). TDF (13.1–16.1% wb) and β -glucan (4.3–5.0% wb) contents in the barley pastas were much higher than in the control (4.0 and 0.3% wb, respectively).

These characteristics meet the FDA requirements of 5 g of TDF and 0.75 g of β -glucan per serving (56 g in the United States and 80 g in Italy), which could allow these pastas to deserve the health claims “good source of dietary fiber” and “may reduce the risk of heart disease” (Knuckles et al 1997, FDA 1998). At present, the FDA has authorized a health claim for β -glucan from oat and psyllium products only (FDA 1998). However, many recent studies have shown that barley β -glucan has similar or even greater physiological benefits (Knuckles et al 1997, Kahlon and Chow 1997, Yokoyama et al 1997, Hecker et al 1998). The caloric content in functional pastas was 9–14% less than in the control.

The color values of all barley pastas were similar. However, they were darker (lower L^* values and higher a^* values) and less yellow (lower b^* values) than the durum wheat pasta.

The cooking quality of the pastas produced with pearling by-products (CF1 and CF2) had acceptable organoleptic properties and a good chemical parameter (TOM). In the case of pearled barley pasta (CF3), the cooking quality scores were similar to those for durum wheat pasta, probably due to its lower dietary fiber content (13.1% wb) compared with CF1 and CF2 (15.2 and 16.1% wb, respectively). Pastas (semolina + egg white) with acceptable cooking quality, produced by substituting up to 20% of the wheat semolina with enriched β -glucan barley flour, were already reported by Knuckles et al (1997), however there are no findings reporting that good pastas can be obtained by substituting semolina with barley pearling by-products enriched in β -glucans.

These positive results could be attributed to the processing conditions adopted (high-temperature pasta drying) and to the vital gluten added. In fact, pasta-making trials with maximum drying temperatures of $\approx 60^\circ\text{C}$ only, or without adding vital wheat gluten, produced pasta samples of unsatisfactory cooking quality (i.e., very sticky: TOM > 2.3 g/100 g of dry pasta).

To assess how β -glucans were affected by the cooking process, they were also determined after the pasta was cooked. The findings showed that there were no significant differences between the β -glucan content in cooked and raw pasta (*unpublished data*).

CONCLUSIONS

The findings show that some pearling by-products have interesting amounts of bioactive compounds (dietary fiber and β -glucan) and could therefore be proposed as potential ingredients for the manufacture of functional food.

Given that consumers and manufacturers pay greater attention to the physiological benefits of foods, there should be plenty of opportunities for the use of barley by-products in human foods.

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