

Air Classification of Barley Flours

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ABSTRACT

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Flour samples from seven different barleys, including covered and naked barleys and barleys with normal, waxy, and high-amylose starches, as well as the high fiber barley Prowashonupana, were impact-milled and air-classified in a pilot unit. Six fractions (F1–F5 and C5) with increasing particle size were obtained from each barley. All fractions were analyzed for ash, protein, starch, dietary fiber, and total and unextractable β -glucan. Ash was enriched in C5; covered barleys (4.3–5.7% of dry matter) had a

higher ash content than naked barleys (2.1–3.2%). Starch was enriched in F4 for normal and waxy barleys (72–79%) and in F3 for high-amylose barleys (72–75%). Protein was enriched in F1 (14–26%) for the different barleys. β -glucan was enriched in F5 and C5 (7–23%), Prowashonupana had the highest value. The extractability of β -glucan decreased with increasing particle size, probably because of lower amounts of endogenous β -glucanase and poorer availability of the substrate in larger particles.

Air classification is an effective way to separate materials into fractions with different sizes and properties. Cereal flours can be separated into fractions with different contents of chemical components such as protein, starch, and dietary fiber (Wu et al 1994, Wu and Stringfellow 1995, Vasanthan and Bhatti 1995, Sundberg et al 1995, Luhalo et al 1996). Particle size is important in air classification of cereal flours and should be sufficiently small so that cell components can be separated (King and Dietz 1987).

The major components of normal barley are starch (60%), dietary fiber (20%), and protein (11%) (Åman et al 1985, Oscarsson et al 1996). β -Glucan and arabinoxylan are important dietary fiber constituents and vary between 3–7% and 4–7%, respectively (Ullrich et al 1986, Åman and Graham 1987, Oscarsson et al 1996). There is, however, a large variation in chemical composition between different barley types. Naked barleys contain less ash and dietary fiber and more starch, protein, and fat than covered barleys (Åman and Newman 1986, Oscarsson et al 1996, Andersson et al 1999). Furthermore, barley with waxy or high-amylose starches are higher in β -glucan than barley with normal starches. The extractability of β -glucan is also lower in high-amylose barleys than in normal and waxy barleys (Oscarsson et al 1996, Andersson et al 1999a). Prowashonupana, a recently developed barley, contains only 24% starch and as much as 35% dietary fiber including 15% β -glucan (Åman and Newman 1986; Andersson et al 1999a,b).

Barley flours have been sieved or air-classified to produce fractions with enhanced levels of different chemical components, mostly β -glucan and protein. Sundberg et al (1995) air-classified a high-fiber barley milling stream and obtained one fraction representing 11% of the flour with a β -glucan content of 12%. Stack-sieving of this fraction further increased the β -glucan content, but this fraction was very small. Knuckles and Chiu (1995) also showed that sieving of barley flour was more effective than air classification in producing enriched fractions of β -glucan. Air classification of the high-fiber barley Prowashonupana yielded one fraction with a β -glucan content of 30% and another fraction with a protein content of 30% (Wu et al 1994). Vasanthan and Bhatti (1995) air-classified barleys with normal, waxy, and high-amylose starches and showed that β -glucan was most effectively enriched in the waxy and high-amylose barleys, while protein was most effectively enriched in the normal barley.

In this study, flour from different barleys, covered and naked, with normal, waxy, and high-amylose starches, as well as the high-fiber barley Prowashonupana, was air-classified in a pilot system.

The objective was to compare the different barleys regarding yield and chemical composition of the fractions obtained.

MATERIALS AND METHODS

Materials

Seven different barley samples (*Hordeum vulgare* L.) were included in the study: Golf, High-amylose Glacier, SW 906129, SW 8775, Hashonucier, and Bz 489-30 were obtained from Svalöf Weibull AB, Sweden. Sieved Prowashonupana flour was supplied by ConAgra, Inc. According to the suppliers, Golf, High-amylose Glacier, and SW 906129 are covered barley types with normal, high-amylose, and waxy starch, respectively. SW 8775, Hashonucier, and Bz 489-30 are naked barley types with normal, high-amylose, and waxy starch, respectively. Prowashonupana is also a naked type with waxy starch, but with a very low starch content and high dietary fiber and β -glucan contents. All barleys except Prowashonupana were grown in 1995 in the same experimental field in Landskrona in the south of Sweden.

Before air classification, the barley grains were ground in a OHG mill (Brabender Duisburg) to pass a 0.7-mm screen. The naked barley Hashonucier contained a considerable amount of grains with the hull still left after threshing (\approx 30%) and was therefore treated in an oat dehuller before milling. After dehulling, the partly hulled grain content was \approx 10%.

Air Classification

Air classification was performed in a pilot system from Alpine AG (Augsberg, Germany). This system includes impact milling in a Circoplex classifier mill 50 (ZPS) with counter-rotating beaters and air classification with a Turboplex ultra-fine classifier 50 (ATP) with a horizontally running classifying wheel axis. Impact milling of \approx 2.5 kg of each barley flour was conducted in the ZPS mill at 16,000 rpm with air consumption of 95 m³/hr and a classifying wheel speed of 4,000 rpm to produce an ultra-fine flour. The impact-milled flour from each barley was then air-classified in the ATP classifier with a constant air consumption of 65 m³/hr and an initial classifying wheel speed of 16,000 rpm to produce one fine (F) and one coarse (C) fraction. This procedure was then sequentially repeated with the coarse fraction at decreasing speeds of 12,000, 8,000, 4,000, and 2,000 rpm. Thus, five fine fractions (F1–F5) and one coarse fraction (C5) were eventually obtained from each of the impact-milled flours (Fig. 1). Classifying of fractions F1 and F2 required cleaning of bearings and ducts every 10 and 15 min, respectively. The feeding rate was very slow, 0.2–0.7 kg/hr, depending on the barley. Feeding rate when classifying the other fractions was also slow; 0.5–1.0 kg/hr for fraction F3, 1.0–2.9 kg/hr for fraction F4, and 0.7–2.5 kg/hr for fraction F5. To determine the repeatability for yield of each fraction, air classification was repeated three times for Golf.

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For light microscopy, each fraction was stained with 50% Lugol's water solution. Iodine stained the amylose dark blue and the amylopectin brownish. Fractions were examined with a microscope (Reichert Diavar, Austria).

Chemical Analysis

Before analysis, the following samples were ground in a Tecator cyclone mill to pass a 0.5-mm screen: F5 and C5 for Golf, High-amylose Glacier, and SW 906129, and C5 for SW 8775, Bz 489-30, and Prowashonupana. The particle size of the other samples was already small enough for analysis. All chemical analysis are reported on a dry matter basis as an average of duplicate analyses. Dry matter content was determined by oven-drying at 105°C for 5 hr. Starch was determined enzymically (Åman et al 1994), while ash and crude protein ($N \times 6.25$) were analyzed according to standard methods (AOAC 1990). Total and water-unextractable β -glucan (in water at 38°C for 2 hr) were determined enzymically according to Åman and Graham (1987). The extractability of β -glucan was calculated as the difference between total and unextractable β -glucan divided by total β -glucan.

RESULTS AND DISCUSSION

The chemical composition of the impact-milled flours (Table I) showed some differences from the composition of the original flours as reported by Andersson et al (1999a,b). However, the chemical composition of Prowashonupana is not comparable because a sieved flour was used in the present study. The ash content was similar or slightly lower in the impact-milled flours than in the original flours, while the protein content was generally somewhat higher. The starch content was about the same as in the original flours, as was the β -glucan content, with the exception of SW 906129, SW 8775, and Prowashonupana, where it was somewhat different. Thus, the impact-milling procedure may have an effect on chemical composition of cereals but it is not pronounced. However, the extractability of β -glucan was greatly increased after impact-milling for all barleys except Prowashonupana, probably due to reduced particle size and increased availability of endogenous β -glucanase. The exception of Prowashonupana may be due to very low levels of endogenous β -glucanase. It may also be due to the fact

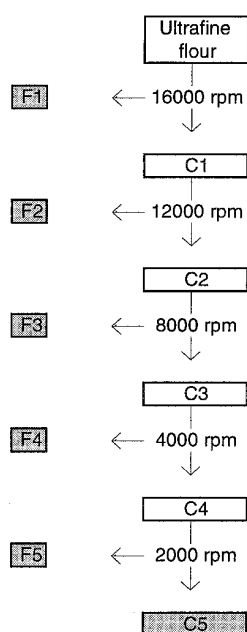


Fig. 1. Air classification of impact-milled barley flour. F1–F5 and C5 = fractions obtained with decreasing wheel speed (16,000–2,000 rpm).

that the particle size of Prowashonupana was already small before impact-milling because it was a sieved flour.

The repeatability for air classification was measured for Golf. The means and standard deviations for yield of each fraction (from three measurements) were $31.4 \pm 0.8\%$ for F1, $9.1 \pm 1.1\%$ for F2, $10.3 \pm 1.7\%$ for F3, $30.5 \pm 2.5\%$ for F4, $12.1 \pm 2.6\%$ for F5, and $6.7 \pm 2.3\%$ for C5. Because fractions were obtained in a sequential procedure, increasing variation in fraction yield could be expected.

The yields of fractions F1–F5 and C5 for each barley and the concentrations of ash and protein are shown in Table II. The yields, as well as the starch and total β -glucan concentrations in the fractions are also presented in Figs. 2–4. The original content in the impact-milled flours is shown as a dotted line in each diagram. Amount (yield \times concentration) of starch and β -glucan in each fraction is represented by the shaded area of the respective column. The extractability of β -glucan is shown as solid lines in Figs. 2B and 4.

The major fractions (Figs. 2–4 and Table II) for normal and waxy barleys, except Prowashonupana, were fraction F1 (28.5–36.1%) and F4 (28.1–35.6%), and for high-amylose barleys fraction F1 (30.3–33.0%). For Prowashonupana the major fraction was F5 (33.4%). The smallest fraction was fraction C5 (2.0–7.4%) for all barleys except Golf, for which it was fraction F2 (7.9%). Because fraction C5 contains the largest particles, as parts of the hull, it was generally larger for covered barleys than for naked barleys. An earlier study (Luhalo et al 1996) showed that impact-milling at 4,000 rpm compared with 2,000 rpm decreases the yield of fraction C5 from 37 to 5.5%, which means that the yield of the fine fractions increases and also the cell wall components in them. The yield of fraction C5 in the present study was in the same order of size as in the study of Luhalo et al (1996).

The total yield of the fine fractions F1–F3 was higher for the two high-amylose barleys than for normal and waxy barleys, while the yield of F4 was higher for normal and waxy barleys (Figs. 3–4 and Table II). This has also been shown by Vasanthan and Bhatti (1995). McDonald et al (1991) and Oscarsson et al (1997) reported that starch of high-amylose barley does not have as clear a bimodal distribution as do waxy and normal barley starches. The A-type granules are smaller and there are more small B-type granules in high-amylose starches. The microscopy studies showed that smaller granules were concentrated into the finest fractions. This has also been shown by scanning electron microscopy (Vasanthan and Bhatti 1995). Thus, the higher yields of fine fractions for high-amylose barleys found in the present study may be due to a higher amount of smaller A-type granules compared with the fine fractions of normal and waxy barleys.

The highest concentration of ash (Table II) was found in fraction C5 for all barleys except Prowashonupana, where it was found in F1. The content was higher in covered than in naked barleys which is due to the hull. The ash enrichment (increase in concentration) in C5 compared with the impact-milled flour was 89–152% for the covered barleys and 29–85% for the naked. The enrichment in fraction F1 for Prowashonupana was 71%. The highest amount (yield

TABLE I
Chemical Composition (% dry matter) of Impact-Milled Flours of Covered and Naked Barleys

Barley	Ash	Protein	Starch	Total β -Glucan	Extractability of β -Glucan
Covered					
Golf	2.3	9.0	62.8	4.6	55.1
High-amylose Glacier	2.3	12.2	53.2	6.9	44.9
SW 906129	2.3	12.0	56.9	5.6	56.4
Naked					
SW 8775	2.0	12.6	63.7	3.8	57.8
Hashonucier	2.0	12.7	59.5	7.2	45.8
Bz 489-30	2.0	13.5	60.8	5.6	59.8
Prowashonupana ^a	1.9	17.6	31.0	17.0	18.1

^a Sieved flour was used.

× concentration) of ash was found in fraction F1 for all barleys (Table II). For Prowashonupana the amount of ash was about the same in F1 and F5. Most of the ash in fraction F1 probably originates from finely ground aleurone cells that have a high mineral content, while in C5 it may come from hull and bran.

The highest concentration of starch (Figs. 2A and 3) was found in fraction F4 for normal and waxy barleys, except for Prowashonupana, and in F3 for the two high-amylose barleys. For Prowashonupana, it was also highest in F3. The starch enrichment in F3 compared with the impact-milled flours was 62% for Prowashonupana and 25 and 35%, respectively, for Hashonucier and High-amylose Glacier. The starch enrichment in F4 was 24–28% for the normal and waxy barleys. The amount of starch was highest in F4 for normal and waxy barleys, except for Prowashonupana, for which it was highest in F3 (Figs. 2A and 3). In High-amylose Glacier, it was also highest in F3, and in Hashonucier in it was highest in F1. The differences in starch profiles between normal and waxy barleys

and high-amylose barleys is probably due to the smaller A-type granules and higher amount of small B-type granules in high-amylose barleys. In normal and waxy barleys, there are more large starch granules that end up mostly in F4, while in high-amylose barleys there are more small granules that end up mostly in F1, F2, and F3. Vasanthan and Bhatta (1995) have also shown a higher starch content in finer fractions of a high-amylose barley than of a normal and a waxy barley. The different behavior of Prowashonupana from the other waxy barleys may be due to its different granule size distribution. The content distribution is very similar to that of the high-amylose barleys. The A-type granules in Prowashonupana are even smaller than in high-amylose barleys and there are even more small B-type granules (Andersson et al 1999b).

The highest concentration, as well as the highest amount, of protein (Table II) was found in fraction F1 for all barleys except Prowashonupana. For Prowashonupana, fraction F5 had the highest amount and F1 had the highest concentration of protein. The protein enrichment in F1 compared with the impact-milled flours was highest for Golf and SW 906129 with an increase of 60%, second highest for Bz 489-30 and Prowashonupana with ≈50%, and lowest for High-amylose Glacier, SW 8775, and Hashonucier with 38% each. While the highest concentration of protein was found in the fractions where the starch content was lowest, the lowest concentration of protein was found in the fractions where the starch content was highest: in fraction F4 for normal and waxy barleys and in F3 for high-amylose barleys (Fig. 3).

The highest concentration of β-glucan (Figs. 2B and 4) was found in F5 and C5 for all barleys. The concentration in these fractions was 8–23% with the highest concentration in C5 for Prowashonupana (Fig. 2B). The β-glucan enrichment in F5 and C5 was

TABLE II
Yield and Ash, Protein, and Starch (% dry matter) Content of Air-Classified Impact-Milled Flours of Covered and Naked Barleys

Barley	Fraction ^a	Rel. Yield	Ash	Protein
Covered Golf	F1	32.2	2.3	14.3
	F2	7.9	2.0	12.2
	F3	8.3	1.4	7.8
	F4	29.7	0.9	4.1
	F5	12.5	2.5	7.9
	C5	9.4	5.5	7.2
High-amylose Glacier	F1	30.3	2.7	16.7
	F2	15.6	2.1	12.0
	F3	23.6	1.2	7.0
	F4	11.7	1.8	12.8
	F5	11.5	3.0	12.1
	C5	7.4	4.3	7.8
SW 906129	F1	28.5	2.8	19.1
	F2	12.5	1.9	13.6
	F3	10.8	1.3	8.3
	F4	30.9	1.0	6.3
	F5	13.3	3.9	11.1
	C5	4.0	5.7	8.1
Naked SW 8775	F1	36.1	2.7	17.5
	F2	8.5	2.2	15.4
	F3	9.1	1.6	11.7
	F4	35.6	0.9	6.0
	F5	8.0	2.6	13.9
	C5	2.8	3.2	14.2
Hashonucier	F1	33.0	2.5	17.3
	F2	19.0	1.5	10.5
	F3	14.4	1.0	6.9
	F4	15.9	1.3	10.0
	F5	10.6	2.4	13.3
	C5	7.1	3.2	15.6
Bz 489-30	F1	29.6	2.5	20.6
	F2	14.1	1.9	15.1
	F3	15.7	1.1	7.3
	F4	28.1	0.8	6.7
	F5	10.4	2.2	13.9
	C5	2.0	2.6	14.8
Prowashonupana	F1	15.3	3.2	17.4
	F2	10.2	2.2	17.5
	F3	15.4	1.5	12.1
	F4	20.1	1.7	16.0
	F5	33.4	1.5	15.9
	C5	5.5	2.1	16.5

^a F = fine fraction, C = coarse fraction.

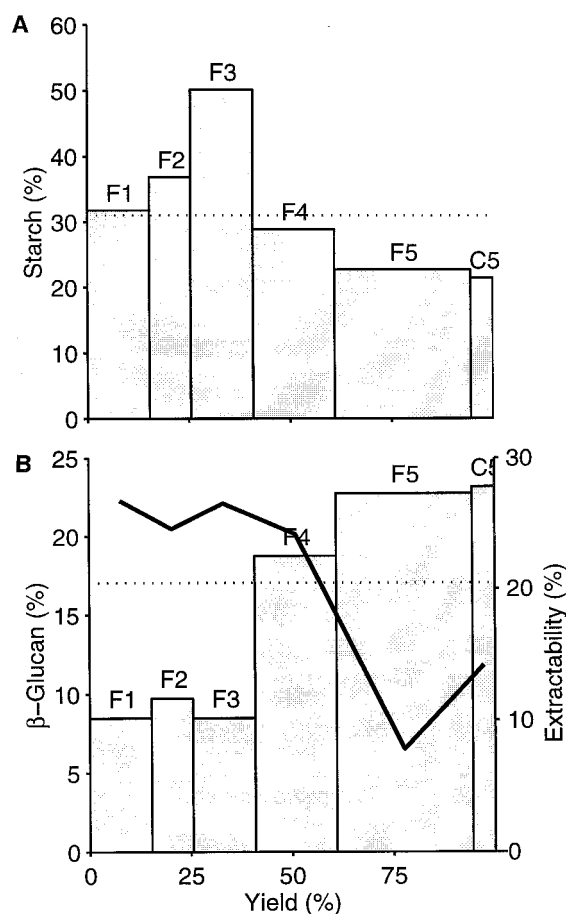


Fig. 2. Yield (%), starch content (A), and β-glucan content (B) (% dry matter) of air-classified fractions (F1–F5 and C5) from Prowashonupana. Dotted line represents content in impact-milled flour. Solid line represents extractability of β-glucan (%).

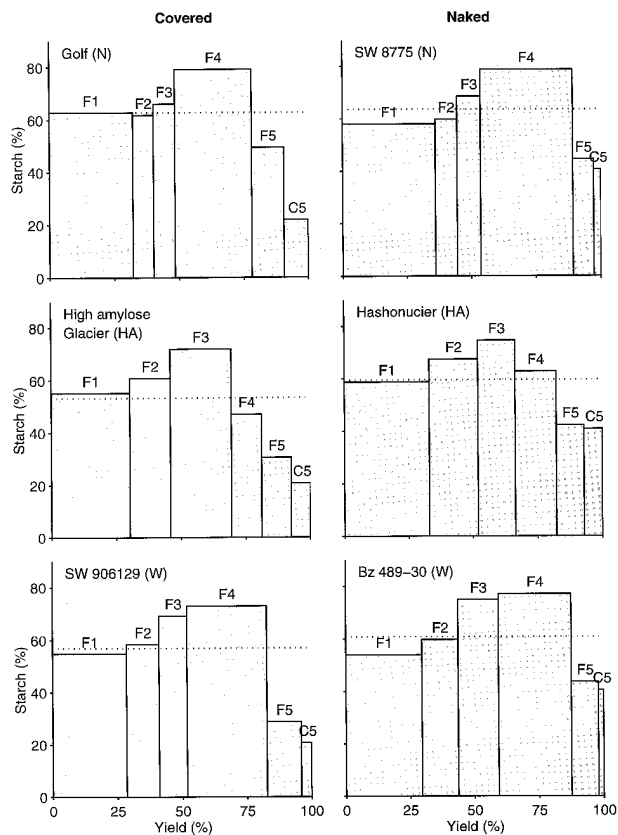


Fig. 3. Yield (%) and starch content (% dry matter) of air-classified fractions (F1–F5 and C5) from covered barleys (left) and naked barleys (right). Dotted line represents content in impact-milled flour. N, HA, W = Normal, high-amylose, and waxy barleys.

38% for Prowashonupana; $\approx 70\%$ for Golf, High-amylose Glacier, and Hashonucier; 95% for Bz 489-30 and SW 906129; and 114% for SW 8775. The enrichment was thus higher for barleys with a low original β -glucan content and lower for barleys with a high original content. Wu et al (1994) air-classified defatted Prowashonupana flour and obtained one fraction yielding 62% with a β -glucan enrichment of 58%. Defatting of material with a high fat content ($>2\%$) may increase the fractionation potential (Knuckles et al 1992). Because Prowashonupana contains $\approx 6\%$ fat and was not defatted in this study, the enrichment was lower. The highest amount of β -glucan was found in F1 for all barleys except SW 906129, where it was found in F4 and in Prowashonupana where it was found in F5. The combined fractions F4, F5, and C5 for high-amylose barleys had a yield of $\approx 30\%$ each and a β -glucan concentration of 10.5%, which is an enrichment of 40–45%.

High-amylose barley β -glucan has previously been shown to have lower extractability than normal and waxy barleys (Oscarsson et al 1996, Andersson et al 1999a). This is in agreement with the results in the present study, where extractability of β -glucan was lower in all fractions for high-amylose barleys than for normal and waxy barleys (Figs. 2B and 4). The extractability showed a decreasing tendency with increasing particle size for all barleys, but this was not as clear for SW 906129. It was generally higher in fraction F1–F4 than in the original flour and lower in F5 and C5. The method used for analysis of extractable β -glucan measures extractability at physiological conditions (in water at 38°C) and is influenced by solubility as well as endogenous β -glucanase activity (Åman and Graham 1987). The activity depends both on the amount of enzymes present and the availability of substrate. Most of the enzymes are found in the scutellum and the aleurone layer, which can explain the tendency of decreasing extractability with decreasing ash content (in F1–F3 or F1–F4).

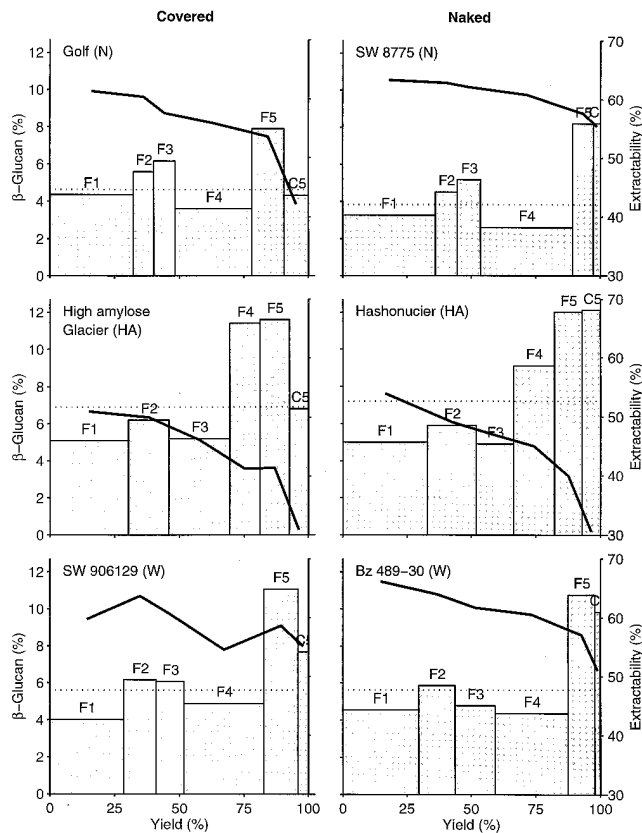


Fig. 4. Yield (%) and β -glucan content (% dry matter) of air-classified fractions (F1–F5 and C5) from covered barleys (left) and naked barleys (right). Dotted line represents content in impact-milled flour. Solid line represents extractability of β -glucan (%). N, HA, W = Normal, high-amylose, and waxy barley.

The different barleys showed different behaviors when air-classified. Naked and covered barleys made up two groups regarding the coarse fraction C5, which was larger and contained more ash for the covered types (Table II). High-amylose barleys behaved differently than normal and waxy barleys concerning yield of the fine fractions F2–F4 and also concerning starch content in these fractions (Fig. 3). Prowashonupana (Fig. 2) behaved differently than any of the other barleys. Because the main objective of this study was to compare different barleys, the process was not optimized for the individual samples. However, the results showed a potential to produce fractions enriched in different chemical components, such as protein, starch, and β -glucan. For example, the average concentration of β -glucan in fraction F4+F5+C5 for Prowashonupana, with a total yield of 59%, was 21.4%. An optimization of the process would probably give even better separation for individual barleys.

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