Extraction of starch from hulled and hull-less barley with papain and aqueous sodium hydroxide

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Abstract Starch was isolated from hulled (VJM 201) and hull-less (BL 134) barley with papain and aqueous sodium hydroxide treatments. For enzyme-assisted extraction, barley was steeped in water containing 0.2 % SO_2 +0.55 % lactic acid at $50^\circ\pm 2^\circ\text{C}$ for 4–5 h. The slurry was mixed with 0.4–2.0 g papain/kg barley and incubated at $50^\circ\pm 2^\circ\text{C}$ for 1–5 h. Aqueous sodium hydroxide (0.01–0.05 M) was added to the finely ground barley meal. The alkaline slurry was incubated at ambient temperature ($25^\circ\pm 2^\circ\text{C}$) for 15–60 min. The starch and grain fractions were isolated by screening and centrifugation. Increases in the time of treatment significantly affected the fiber, centrifugation and non-starch residue losses. Concentration of papain and sodium hydroxide had negligible effect on extraction losses. The enzyme-assisted extraction efficiency of starch was higher (80.7–84.6 %) than the alkaline method (70.9–83.7 %). The hulled barley showed higher extraction efficiency than the hull-less barley. The slurry treated with 0.4 g papain/kg barley for 5 h and 0.03 M sodium hydroxide for 60 min produced maximal yield of starch. Barley starch showed desirably high pasting temperature, water binding capacity and hold viscosity; and low final and setback viscosity compared with the commercial corn starch. The alkaline extracted hull-less barley starch showed exceptionally high peak and hold viscosities

Keywords Barley · Starch · Enzyme-assisted extraction · Alkaline extraction

Introduction

Starch is the most abundant, natural reserve polysaccharide and primary source of stored energy in cereal grains. It is an

important ingredient for foods and has many industrial applications. Nearly 95 % of the starch produced is extracted from corn. Starches with novel properties and functionalities have attracted attention of the researchers and industry. Barley starch with 0–45 % amylose content has excellent viscosity properties, freeze-thaw stability (Bhatti and Rosnagel 1997) and a wide range of potential applications in the food and industry (Zheng and Bhatti 1998). For these interesting properties, barley starch has the potential to replace corn and wheat starches, which are extensively used cereal starches for many food applications. Starch from barley with high amylose content has nutritional benefit. After hydrothermic treatment, it develops resistant starch (Björck et al. 1990), which may have positive health benefits such as improved glucose tolerance, lowering of blood lipids, lowering of colonic pH, colonic generation of short chain fatty acids, and increased faecal bulk (Björck 1996).

Wet-milling is the main process used to produce pure starch with high quality and yield. Production of barley starch is limited because of some difficulty due to strong binding between starch, protein and β -glucan, a major cell-wall polysaccharide that produces high viscosity in aqueous solutions and impairs separation of starch (Petersen and Munck 1993). Dry-milling followed by wet-processing was used to overcome the problem associated with β -glucan. According to Petersen and Munck (1993), flour from disc-milled barley could be used for wet extraction of starch. Vasanathan and Bhatti (1995) described a procedure for pin-milling and air-classification of hull-less barley to obtain fractions rich in starch, protein and β -glucan. The starch rich fraction was subjected to a short wet-processing procedure to obtain pure starch. Due to the presence of β -glucan in oat and its strong binding with starch and protein, Paton (1977) isolated starch with sodium carbonate and Wu et al. (1973) used sodium hydroxide. Matsunaga and Seib (1997) also extracted wheat starch with aqueous sodium hydroxide at pH 11.5–12.3, and 25° – 42°C for 0.17–24 h.

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Use of hydrolytic enzymes for separation of low protein content starch from cereal grains is not a new concept and was developed by Roushdi et al. (1981). Steinke and Johnson (1991) incorporated multiple enzymes in steeping solution to reduce steeping time and enhance starch separation during wet-milling of maize. Lim et al. (1992) isolated oat starch from oat flour using protease and cellulose. Zheng and Bhatti (1998) used multiple enzyme cocktail containing cellulase, endo-(1→3), (1→4)- β -D-glucanase and xylanase in wet separation of starch, protein, β -glucan, bran, and tailings from hull-less barley. No reports have appeared on the use of protease or sodium hydroxide to isolate starch from hulled or hull-less barley, nor has a comparison been made of the use of protease and sodium hydroxide extraction methods. In the present study conditions for concentration and time of treatment of enzyme (papain) or sodium hydroxide were optimized to give maximal yield of starch with minimal protein content. The yield and process losses from enzyme-assisted and alkaline wet-milling methods were compared. To explore potential for food uses, information regarding pasting characteristics of some isolated barley starches as compared with commercial corn starch is also reported.

Materials and methods

Materials

Two-row hulled barley cv VJM 201 and six-row hull-less barley cv BL 134 used in the investigation were obtained from the 2008 crop grown at the Research Farm of the Punjab Agricultural University, Ludhiana, India.

Steeping characteristics

Ten gram samples of each barley variety were steeped in water at 50 ± 2 °C for 6 h. The weights of the steeped kernels were noted at various intervals. The percentage of water uptake against steeping time was plotted to obtain the steeping curve.

Enzyme-assisted extraction of starch and other components

Steeping

Starch from barley kernels was extracted according to the procedure described by Eckhoff et al. (1996). Samples of hulled barley VJM 201 (200 g) and hull-less barley BL 134 (150 g) were placed in 1000 ml beaker with sufficient amount of water at 50 ± 2 °C containing 0.2 % SO_2 + 0.55 % lactic acid. The barley was steeped for 4–5 h. Temperature of the steeping water + grains was maintained in a thermostatically controlled water bath. The water was drained; aliquots of 20 ml were taken in Petri dishes and

then dried to determine total solids using the two-stage drying procedure (Approved Method 44-18, AACC 2000). The results were expressed as steeping loss.

First grind

The barley was milled in 1000 ml water using a Waring blender for 5 min at high speed to get fine slurry. Density of the slurry was adjusted to 1.025.

Incubation

The slurry was transferred to an Erlenmeyer flask and papain was added @ 0.4–2.0 g/kg of barley (dry basis). The flask was incubated at 50 ± 2 °C in a thermostatically controlled water bath for 1–5 h with stirring at 20 min intervals. After incubation, pH of the slurry was raised from 6.2 to 9.5 using 1 N sodium hydroxide solution. The contents were held at alkaline pH for 10 min to inactivate the enzyme. The pH was again adjusted to 6.2 with 1 N hydrochloric acid. The slurry was then centrifuged at $6000 \times g$ for 20 min. The sediment was resuspended in water and centrifuged as described above. The process was repeated thrice. The supernatant was collected and solid content was determined as described earlier. The results were expressed as centrifugation loss.

Second grind

The sediment obtained upon washing and centrifugation was again ground to fine slurry using a Waring blender. The ground slurry was filtered through a nylon screen (50 μm). The residue was washed 2–3 times with water. The washings were added back to the slurry. The fiber was dried at 60 °C for 48 h and weighed to express fiber loss. The slurry was allowed to settle undisturbed for overnight in a refrigerator. The water was decanted.

Starch protein separation

The decanted slurry was centrifuged as described above. The clear supernatant on top of the sediment was discarded and the top blackish layer of protein was removed with a laboratory spatula. The white starch layer was resuspended in water, centrifuged and protein layer was removed. This process was repeated three times. The starch and protein fractions were then dried in an air-oven at 40 °C for 48 h. The dried fractions were weighed and results expressed as starch yield and non-starch residue loss, respectively.

Alkaline extraction of starch and other components

Barley meal (200 g) was mixed with 800 ml of 0.01–0.05 M sodium hydroxide. Density of the slurry was adjusted to the

range of 1.031–1.035. The slurry was stirred for 15–60 min at ambient temperature ($25^{\circ}\pm 2^{\circ}\text{C}$). Thereafter, it was neutralized with 1 N hydrochloric acid and the mixture was centrifuged. The supernatant was discarded. The sediment was resuspended in water to recover starch and other fractions as described above.

Pasting properties

Starch pasting properties were determined using a Rapid Visco Analyzer (RVA) model Starch Mater (Newport Scientific, Australia). Barley starch (4 g, 14 % moisture basis) was mixed with 25 ml water in the aluminum canister. The starch suspension was equilibrated at 50°C for 1 min, heated to 95°C in 3 min 42 s, held at 95°C for 2 min 30 s, cooled down to 50°C in 3 min 48 s and finally held at 50°C for 2 min. Peak viscosity, peak temperature (temperature at peak viscosity), hold viscosity, final viscosity and setback were recorded. Four replicates per sample were analyzed.

Analyses

Moisture, protein (%N $\times 6.25$), crude fiber and ash contents were determined Using AACC (2000) methods. Starch was determined according the procedure of AOAC (1995) using a polarimeter. Kernel weight was determined by the ASBC (1992) method and husk by digesting weighed 1000 kernel lots with sulphuric acid (50 %v/v) for 3 h at ambient temperature ($25^{\circ}\pm 2^{\circ}\text{C}$) according the procedure described by Cook (1962).

Statistical analysis

Data obtained in this study were examined statistically according to the statistical graphic system (Statgraphics 1991) using a factorial design of the experiment. One-way analysis of variance with least significance of difference (LSD) at $p<0.05$ was applied. Linear coefficients (r) of correlation were calculated between the variables.

Results and discussion

The kernels of hulled barley VJM 201 were bold, contained more protein, ash and crude fiber but lower starch contents than the hull-less barley BL 134 (Table 1). The varieties had similar fat content. The husk content of VJM 201 was 8.7 %, slightly lower than that of six-row barley (Tejinder 2007).

Steeping characteristics

During the first 3 h of steeping, the water uptake of the two varieties of barley was rapid, and afterwards relatively slows

(Fig. 1). The hull-less barley absorbed more water for similar steeping times, as also observed by Singh and Sosulski (1985), though at 15°C . The samples for wet milling were steeped to 40–42 % moisture by adjusting the time.

Losses occurring during starch extraction

Steeping loss for VJM 201 and BL 134 barley was 1.7 % and 2.3 %, respectively. These results were comparable to those reported for wet milling of wheat (Wang and Chung 2002). High steeping loss for hull-less barley might be attributed to leaching of soluble solids through permeable pericarp, free from lemma and palea, at 50°C . The hull-less barley also had higher total sugars (8.0 %) than VJM 201 (5.4 %) which might have found their way into the steep water.

The total loss due to fiber, centrifugation and non-starch residue was 34.6–51.5 % for the enzyme-assisted and 38.9–43.4 % for the alkaline extraction method as compared to 46.9–47.4 % for the conventional extraction (control) method of starch.

Enzyme-assisted extraction

The values for fiber loss of untreated control barley samples were in the range of 25.5–27.5 % (Table 2). The hulled barley (VJM 201) slurry treated with 0.4 g papain/kg barley for 1 h showed values for fiber loss similar to those of the controls. For both the barley varieties, the fiber loss was significantly ($p<0.5$) reduced upon increasing the time of treatment from 1 h to 5 h. A similar trend was observed for the slurries treated with 1.2 and 2.0 g papain/kg barley (Table 2). However, the values for fiber loss of these treated slurries were negligibly different than those of the corresponding values for 0.4 g papain/kg barley treated slurry. The spectacularly lower values for fiber loss of hull-less barley BL 134 than those of VJM 201 (Table 2) might be the artifact of absence of hull. Decreases in the values for fiber loss with increases in the time of treatment of the slurry with papain might be attributed to extended hydrolysis of protein attached to the hull/bran.

Centrifugation loss increased with increases in the concentration of papain and the time of treatment (Table 2). Taking the base values of centrifugation loss for untreated control samples (0.68–0.80 %), an increase of 1.38–4.22 fold was caused by papain (0.4–2.0 g/kg barley) treatment for 1–5 h, the differences being statistically significant ($p<0.05$). This might be due to increased hydrolysis of protein by the proteolytic enzyme. The hull-less barley happened to show lower values for centrifugation losses than those of the hulled barley.

Table 2 shows the effect of papain (0.4–2.0 g/kg barley) treatment for 1–5 h on the non-starch residue loss. The 1 h

Table 1 Composition and grain characteristics of hulled (VJM 201) and hull-less (BL 134) barley (dry basis)

Barley variety	1000-Kernel Wt (g)	Starch (%)	Protein (%)	Fat (%)	Ash (%)	Crude fiber (%)	Husk (%)
VJM 201	41.4	71.6	12.5	2.3	3.3	6.2	8.7
BL134	34.0	79.0	11.8	2.5	2.3	3.0	–
LSD ($p<0.05$)	0.4	0.5	0.4	1.1	0.2	0.4	–

treated slurries from both the barley varieties showed considerably higher values for non-starch residue loss than those of the controls. Increasing the time of treatment from 1 h to 5 h decreased the loss, possibly, due to hydrolytic action of papain. The hull-less barley BL 134, however, showed higher values for non-starch residue loss than those of the hulled barley VJM 201 (Table 2). Lower centrifugation and higher non-starch residue losses of hull-less barley than those of the hulled barley corroborated the findings of Singh and Sosulski (1985) for less susceptibility of hull-less barley proteins to the proteolytic enzymes.

Alkaline extraction

Using sodium hydroxide (0.01–0.05 M for 15–60 m) for extraction of starch, the fiber loss for the hulled and hull-less barley varied from 20.9 to 27.5 % and 20.8–25.2 %, respectively (Table 3). These values were considerably higher than those obtained for enzyme-assisted extraction (Table 2). Unlike enzyme-assisted extraction, the hull-less barley meal treated with sodium hydroxide showed fiber loss values similar to those of the hulled barley (Table 3), despite absence of hull. Also, increasing the concentration of sodium hydroxide and the time of treatment had negligible effect

on the fiber loss values as compared to the corresponding controls. These results revealed that alkali, possibly, could not detach or separate the endosperm proportion originally attached to the hull/bran efficiently. According to Briggs et al. (1976), access of fully ionized salts, sugars and strong acids to the interior of the grain is less limited despite mechanical damage to the grain.

The centrifugation losses (0.10–0.84 %) obtained for the alkali treated slurries (Table 3) were lower than those reported for oat flour (1.7 %) used for alkaline extraction of starch (Lim et al. 1992). The values for alkaline extraction–centrifugation losses were lower than those obtained for enzyme–assisted extraction of starch (Tables 2 and 3). In contrast to the observations for enzyme–assisted extraction, the values for alkaline extraction–centrifugation losses decreased with increases in the time of alkali treatment, possibly due to β -elimination of proteins (Anglemier and Montgomery 1976), which probably became insoluble and found their way into non-starch residue. Increasing the concentration of sodium hydroxide from 0.01 M to 0.05 M had negligible effect on centrifugation losses for the corresponding time–treated samples. The hull-less barley showed significantly lower values ($p<0.05$) for centrifugation losses than those of hulled barley.

Like enzyme-assisted extraction (Table 2), the values for alkaline extracted-non-starch residue of hull-less barley were higher than those of the hulled barley (Table 3). Increases in the values for non-starch residue with increases in the time of treatment between sodium hydroxide and the barley meal slurries further confirmed the recovery of insoluble solids, possibly, the proteins. Evidently, a negative and significant coefficient of correlation ($r=-0.75$, $p<0.05$) was obtained between the values for alkaline extraction–centrifugation vs non-starch residue losses (Table 3).

Yield and protein content

Starch yield in the conventional extraction (control) varied from 42.6 % (BL 134) to 45.5 % (VJM 201) giving 54 % to 63 % extraction efficiency, respectively (Table 4). Compared to the controls, starch yield in the enzyme-assisted as well alkaline extraction was higher by 0.6–49.7 % and 15.2–31.8 %, respectively. On the basis of starch content in the grains, extraction efficiency of the starch using enzyme-assisted method was up to 84.6 % and 80.7 %, respectively,

Fig. 1 Water uptake of hulled (VJM 201) and hull-less (BL 134) barley kernels during steeping at $50^{\circ}\pm 2^{\circ}\text{C}$

Table 2 Losses occurring during enzyme-assisted extraction of starch from hulled (VJM 201) and hull-less (BL 134) barley

Papain (g/kg barley)	Treatment time (h)	Losses (%)					
		Fibre		Centrifugation		Non-starch residue	
		VJM 201	BL 134	VJM 201	BL 134	VJM 201	BL 134
Control	–	27.5	25.5	0.80	0.68	19.1	20.7
0.4	1	27.3	14.2	1.11	1.02	22.9	24.5
	3	20.6	12.8	1.60	1.23	16.3	22.3
	5	19.3	11.5	1.87	1.54	15.5	19.7
	1.2	23.1	15.4	1.19	1.91	22.2	27.0
1.2	3	19.9	13.2	1.52	1.28	16.0	24.5
	5	18.4	12.9	3.38	2.11	14.5	24.0
	2.0	25.1	17.1	1.36	1.13	22.6	28.5
	3	21.8	13.2	2.36	1.52	16.2	23.4
2.0	5	18.3	12.5	3.20	1.90	15.6	20.2
	LSD ($p<0.05$)	–	0.3	0.11	0.11	0.4	0.4

for VJM 201 and BL 134 barley, whereas it was up to 83.7 % and 70.9 % for alkaline extraction. The yield of starch from hull-less barley BL 134 using enzyme-assisted method was negligibly higher than that of hulled barley VJM 201, but an opposite trend was observed for the alkaline extraction method with significant differences in the starch yield values (Table 4). For alkaline extraction, low starch yield from hull-less barley might be the artifact of high slurry viscosities (Zheng and Bhatti 1998), developed in the presence of sodium hydroxide, made separation difficult and resulted in low starch extraction efficiencies. For both the extraction methods, the time of treatment had significant effect on starch yield than the concentration of papain or sodium hydroxide. Treatment of slurries with 0.4 g papain/kg barley for 5 h and 0.03 M alkali for 60 min showed maximal yield of starch (Table 4).

Protein contents of the starches extracted using the enzyme-assisted or alkaline extraction methods were spectacularly lower than those of the conventional extraction control method (Table 4). Effect of extraction methods on protein contents was similar to that observed for the starch extraction, except for decreases in the values with increases in the time of treatment. The values for protein contents of the starches extracted from both the barley varieties were negligibly different.

Pasting properties

Pasting properties of some starches extracted using enzyme-assisted and alkaline methods from both the barley varieties (selected on the basis of their maximum yield and minimum protein content) were compared with a commercial sample

Table 3 Losses occurring during alkaline extraction of starch from hulled (VJM 201) and hull-less (BL 134) barley

Sodium hydroxide (M)	Treatment time (m)	Losses (%)					
		Fiber		Centrifugation		Non-starch residue	
		VJM 201	BL 134	VJM 201	BL 134	VJM 201	BL 134
Control	–	27.5	25.2	0.80	0.68	19.1	20.7
0.01	15	25.3	22.6	0.80	0.23	14.1	20.9
	30	24.1	21.8	0.62	0.21	15.8	21.9
	60	20.9	20.9	0.35	0.16	17.6	23.2
	0.03	26.4	24.6	0.66	0.24	13.6	16.4
0.03	15	26.4	24.3	0.60	0.17	15.5	23.4
	30	23.4	20.8	0.47	0.10	16.1	24.6
	60	25.8	24.6	0.84	0.19	16.1	19.5
	0.05	24.8	24.1	0.76	0.18	16.3	24.4
0.05	60	23.4	21.5	0.54	0.14	19.3	26.7
	LSD ($p<0.05$)	–	0.3	0.11	0.11	0.4	0.4

Table 4 Yield and protein content of starch extracted from hulled (VJM 201) and hull-less (BL 134) barley using enzyme-assisted and alkaline extraction procedures

Papain (g/kg barley)	Treatment time (h)	Yield (%)		Protein (%)		Sodium hydroxide (M)	Treatment time (m)	Yield (%)		Protein (%)	
		VJM 201	BL 134	VJM 201	BL 134			VJM 201	BL 134	VJM 201	BL 134
Control	–	45.5	42.6	2.82	1.84	Control	–	45.5	42.6	2.82	1.81
0.4	1	45.8	56.2	1.34	1.30	0.01	15	55.2	50.4	0.65	0.78
	3	55.9	59.2	1.18	0.52		30	57.8	50.5	0.63	0.50
	5	60.6	63.8	0.81	0.17		60	59.6	52.5	0.25	0.21
1.2	1	50.8	49.6	1.40	1.18	0.03	15	55.3	53.3	0.97	0.76
	3	58.4	55.0	0.95	0.39		30	56.7	51.6	0.81	0.51
	5	60.4	58.6	0.86	0.13		60	58.1	50.4	0.05	0.16
2.0	1	48.4	50.7	0.38	0.67	0.05	15	55.8	52.9	0.44	1.03
	3	55.3	57.8	0.12	0.30		30	56.7	50.5	0.38	0.91
	5	60.4	62.6	0.05	0.08		60	56.6	49.1	0.17	0.52
LSD ($p<0.05$)		3.9	3.9	0.28	0.28	LSD ($p<0.05$)		3.9	3.9	0.28	0.28

of corn starch (Table 5). Pasting temperature of corn starch (commercial) was 79.5 °C. This was within the range reported by Brandemarte et al. (2004) for maize starch obtained from intermittent milling and dynamic steeping process. In this study, the pasting temperatures of barley starches obtained by both the extraction methods were nearly 8° to 13 °C higher than those of the corn starch (Table 5). The alkaline extraction starches showed negligibly lower values for pasting temperatures than those of the enzyme-assisted

extraction. Barley starches extracted using enzyme- assisted extraction method showed peak viscosity values similar to those the corn starch. Peak viscosity of the alkaline extraction hulled barley VJM 201 starch was lower that of enzyme-assisted extraction or corn starch. However, the alkaline extraction hull-less barley starch had significantly higher value for peak viscosity, as also observed by Lim et al. (1992), indicating higher water binding capacity than that of corn or hulled barley starches. Lower peak viscosity value for sodium

Table 5 RVA characteristics of some starch samples extracted from hulled (VJM 201) and hull-less (BL 134) barley using enzyme-assisted and alkaline extraction methods

Treatment	Sample type	Pasting temperature (°C)	Peak viscosity (cP)	Breakdown viscosity (cP)	Hold viscosity (cP)	Final viscosity (cP)	Setback viscosity (cP)
Corn							
Control	Commercial	79.5	2707	851	1856	2952	1096
Enzyme-assisted extraction							
Papain	VJM 201						
0.4 g/5 h	Max. Yield	91.9	2712	532	2180	2445	265
2.0 g/4 h	Min. Protein	91.7	2711	414	2297	2620	323
BL134							
0.4 g/5 h	Max. Yield	92.3	2697	527	2170	2493	323
2.0 g/4 h	Min. Protein	91.5	2835	479	2356	2674	318
Alkaline extraction							
Sodium Hydroxide	VJM 201						
0.03 M/60 m	Max. Yield/ Min. Protein	90.8	2239	403	1836	2082	246
BL 134							
0.03 M/60 m	Max. Yield/ Min. Protein	87.4	3173	699	2474	3156	682
LSD ($p<0.05$)		2.2	3	4	4	3	4

hydroxide extracted hulled barley VJM 201 starch might be attributed to formation of amylase-lipid-sodium hydroxide complex during the early stage of starch pasting (Lim et al. 1992). It is likely that the complex delayed swelling of starch granule and resisted dissociation at excessively high temperature of 95 °C (Ghiassi et al. 1982) and (Biliaderis et al. 1985). Compared to the corn starch (control), barley starches showed higher values for hold viscosity and substantially lower values for breakdown after cooking at 95 °C, indicating ability of barley starch to withstand heating and shear stress. Subjecting barley starch to a constant high temperature (95 °C) and mechanical shear, granule disintegration was 15.2 % to 22.0 % as compared to 31.4 % for corn starch (Table 5). The percent breakdown for alkaline extraction starches was similar to those of the enzyme-assisted extraction. Final viscosity and setback of the barley starches were generally lower than those of the corn starch (Table 5), excepting the hull-less barley alkaline extracted starch, which happened to be exceptionally high and similar to that of the peak viscosity. In contrast to this observation, Beta et al. (2001) observed excessive shear thinning and high values for final viscosity and setback of sorghum starches extracted using sodium hydroxide. The results of setback viscosity of barley starches obtained in this study revealed that the gel network (involving amylose) had weak strength. This might be ascertained to barley starch granular stability and minimal release of amylose during the annealing phase of heating starch in water up to 95 °C. High pasting temperature, water binding capacity, hold viscosity, integrity of granule to heating and shearing and thus low final and setback viscosity of barley starches might be the artifact of strong amylose-lipid complex formation (Jane et al. 1999; Lim et al. 1994; Song and Jane 2000) that resulted in its different behavior than those of corn starch. This study revealed that barley starch is more suitable for use in food products subjected to high temperature processing and shear stress than corn starch.

Conclusion

Low-protein barley starch could be extracted from hulled or hull-less barley at the expense of 36–51 % losses as steeping, fiber, centrifugation and non-starch residue with the recovery efficiency of 70–84 % on the basis of starch present in the grain. Though the alkaline method was rapid to isolate starch, recovery was more with enzyme-assisted extraction method. Compared to the conventional method, the enzyme-assisted extraction yielded up to 49 % more starch. Conspicuously high pasting temperature and hold viscosity but low breakdown and setback viscosity of barley starch than the corn starch should be considered for use of barley starch in high temperature-high shear processed foods.

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