Effect of Pearling Rate on Highland Barley: Chemical, Physical, Antioxidant and Digestibility Characteristics

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Abstract

The nutritional, processing, functional and edible qualities of three highland barley flour (HBF) with different pearling rates were assessed in this study. As expected, ash and dietary fiber content of three HBF showed downward trends with the increase of pearling rates, and a decreased of β-glucan content was observed. However, the total phenol and γ-aminobutyric acid contents in three HBF were overall the highest with 4% pearling rate. Pearling treatment slowed down the digestion speed of starch by decreasing the content of rapidly digestible starch and changed the thermomechanical properties. With the exception of total phenolic content and anthocyanin content, unpearled HBF showed much higher antioxidant activities such as total antioxidant capacity and radicals scavenging ability than the pearled ones. Noodles made with pearled HBF presented the better cooking and texture characteristics, which attributed to the lower breaking rate, the shorter cooking time, the higher hardness, chewiness and resilience.

Introduction

Highland barley (HB), the largest coarse cereal in China, is mainly distributed in Australia, North America and Asia. HB is rich in protein, dietary fiber, β-glucan and phytochemicals such as phenolic acids and anthocyanins, which possess the potential to reduce the risk of various diseases, such as obesity, atherosclerosis, hypertension and cardiovascular disease (Bai et al., 2021; Guo et al., 2020). The content of protein is higher than those in hulled barley protein and it is more soluble, emulsifiable and stable (Vita Šterna et al., 2016). But the foamability and foam stability are lower than that in wheat protein (Al-Ansi et al., 2021). Research has shown that lysine is scarce in wheat and hulled barley, but high in HB, which is helpful for the applicable supplement of human nutrition (Bhatty, 1999). Liu et al. have proved that people with abnormal glucose tolerance not only effectively adjusted their postprandial amino acid levels, but also improved their insulin sensitivity after ingesting a certain amount of HB food for a period of time (2015). Its fat content is about 2%, with a relative amount of vitamins and mineral elements (Obadi et al., 2021). With the continuous development of research, β-glucan has been shown to have anti-aging, anti-cancer and immune regulation effects, which has a high content in HB (Ashraf et al., 2021; Lin et al., 2018). Phenolic substances in HB exist in bound and free forms (Zhu et al., 2015), which present in cereals as antioxidants contribute to reducing the risk of cancer (Zhang et al., 2017).

Pearling can keep the inner layer rich in various nutrients and at the same time, peel off the part which is unfavorable to the processing quality of HB flour including hull, pericarp, seed capsule, aleurone layer and outer endosperm (Zhang et al., 2020). Bo Zhao studied the milling parameters of HB flour and the quality of noodles. They found that pearling 20% followed by roller milling could improve the flour yield and content of β-glucan and total dietary fiber, and noodles with 50% HB flour had better texture properties (2020). Mehfooz incorporated barely husk in chapatti and evaluated its compositional, thermal, textural and sensory characteristics. They found the content of dietary fiber and minerals increases, but the color of the products darker and the taste was affected to some extent (2017). Three diverse HB cultivars were used in this study to investigate the effects of pearling rate (PR) on nutrition, processing and eating quality of HB grains and flour. The results of present study can be helpful for the development, utilization and deep processing of HB.

Materials And Methods

Materials

Three highland barley cultivars were harvested in 2020 and provided by Tibet Academy of Agriculture and Animal Husbandry Sciences: black highland barley (BHB, a four-rowed, spring variety), zangqing 13 (QB13, a two-row, spring variety) and zangqing 27 (QB27, a six-row, spring variety). These cultivars were selected based on their nutritional properties, commercial importance and chemical diversity, as well as for being representative of crops from Tibet. After sieving and removing impurities, an appropriate amount of distilled water was sprayed on highland barley and stored in a polyethylene bag at 4°C for 24 h, so that the moisture content of HB was adjusted to 15%. Pearling rate was obtained by the ratio of HB grain weights before and after pearling. Four kinds of HB grains with different PR were obtained using wheat pearling machine (RCMTK, Henan Rongcheng Mechanical Engineering, China), which were 0%, 4%, 8% and 12% respectively, followed by milled in a cyclone mill (FW-400AD, XINBODE, China) to obtain the HBF. Wheat flour was purchased from local supermarket.

Preparation of noodles

The noodles formula was made of mixed flour (the ratio of HBF and wheat flour was 3:7), distilled water, 1.32% salt and 5% wheat gluten. Salt was dissolved in the distilled water, and the solution was mixed with flour using a dough-mixer (KENWOOD, England). Then the dough was put into a polyethylene bag for 15 min at 30°C. Noodles sheets passed through the sheething rolls of noodle machine (BJM-6, Deqing Bajie Electric Appliance, China) for 7–9 times to obtain. The dimensions of the noodle strands were 2 mm in width and 1.8 mm in thickness.

Grain characteristics and nutritional characteristics of HBF

Thousand kernels weight (TKW) of HB was determined with TKW tester (SC-A, Hangzhou Wanshen Detection Technology, China). The falling number was measured by the method of Shao (2019). A scanning electron microscope (SEM) (S–3400N, Hitachi, Japan) was used to observe grain microstructure. The TKW of HB was determined with TKW tester (SC-A, Hangzhou Wanshen Detection Technology, China). The nutritional, processing, functional and edible qualities of three highland barley flour (HBF) with different pearling rates were assessed in this study. The grain moisture content, hardness and grain size of the samples were measured by the single grain characteristic tester (4100, Perten, Sweden). Samples of HBF were collected and analyzed the nutritional characteristics. Crude protein (N×6.25) (46-11A), crude fat (30 – 10), ash (08 – 01), total starch (76 – 13), mineral elements (40 – 70) and amino acids (07 – 01) were analyzed according to AACCL methods. Dietary fiber content was determined using the assay kit (Megazyme International Ltd., Ireland). β-glucan content was determined using the megazyme mixed-linked β-glucan kit (Megazyme International Ltd., Ireland). γ-aminobutyric acid (GABA) was extracted as described by Baum (1996). Sample (0.6 mL) to be tested was placed in an ice bath, and 0.4 mL of boric acid buffer solution with a concentration of 0.2 M (pH 9.0) was added to terminate the reaction, followed by 6% phenol and sodium hypochlorite solution (5.25% effective chlorine). After full oscillation, the absorbance value was measured at 630 nm after 10 min reaction in boiling water bath and 20 min cooling in ice bath. All results were expressed based on a dry basis.

Thermomechanical, pasting and gelatinization properties
Thermal mechanical properties were measured by a Mixolab2 (Chopin, France) with a modified Chopin + protocol (Han et al., 2013). Changes in the viscosity of different PR were characterized by the rapid viscosity analyzer (RVA) (RVA-Tec Master, Perten, Australia). Flour samples and distilled water were mixed in aluminium canisters and stirred well. The programmed was set as follows: temperature held at 50°C for 1 min, then heated to 95°C in 3 min 42 s, and held for 2.5 min at 95°C. After that, the temperature was cooled to 50°C within 3 min 48 s and held for 2 min at 50°C. In vitro digestibility of starch were studied as reported by Gao (2019). Differential scanning calorimetry (DSC) (Q2000, Waters, USA) was used to determine the gelatinization properties according to the method of Allan with some modifications (Allan et al., 2018).

In vitro starch digestibility

The digested starch was classified into rapidly digestible starch (RDS), slowly digestible starch (SDS), and resistant starch (RS). Measurements and samples were made by the method of Alvarez (2020).

Determination of total phenolic content (TPC), total flavonoids content, anthocyanin content (AC) and antioxidant properties

A Micro Total Antioxidant Capacity (T-AOC) Assay Kit (Solarbio BC1315, China) was used to determine the total antioxidant capacity (TAC). Total phenolic content (TPC), total flavonoids content, anthocyanin content (AC), radical scavenging activities, including four common radicals, DPPH, ABTS+, hydroxyl radical (OH−) and superoxide (O2−) were determined by adapting previous methods (Zhang et al., 2020; Brand-Williams et al., 1995; Stratil et al., 2006; Xu et al., 2010; Guedes et al., 2013).

Quality evaluation of highland barley noodles

Determination of cooking loss and the optimum cooking time were referred to the method of AACC method (66−50, 44−15). The water absorption (g/100 g) was evaluated by subtracting the initial weight of noodle (30 g) from the boiled weight and dividing by the initial weight. The method of Ye (2016) was used to assess the textural properties with a Texture Analyzer (TA-XT Plus/50, Stablemicvo, England).

Statistical analysis

Statistical analyses were performed using Minitab 8.0, and Tukey’s post hoc test was used to detect significant differences. The figures were plotted using Origin 9.6, and means were considered significantly different at a p < 0.05 threshold.

Results And Discussions

Grain characteristics of HB

Three highland barley cultivars were pearled, and the PR varied from 0–12%. As shown in Fig. 1, the outer layers were removed gradually as the PR increased, but the tissues removed from kernel were inhomogeneous under abrasion. At 4% PR, 60%-70% seed capsules (highlighted with white arrow) and some of the aleurone layer (highlighted with red arrow) along the crease of kernel was removed. When the PR reached up to 8%, more aleurone layer was removed with the detachment of more than 80% seed capsules. At 12% PR, the seed capsules were almost completely scraped off.

It can be seen from Table 1 that moisture content decreased significantly with the increases of PR. This may be due to the loss of water caused by mechanical action in the pearling process, and the longer the pearling time, the more water loss. But the degree of water reduction declined at 12% PR due to the grain was moistened before pearling, led to the water failed to enter the endosperm and aleurone layer near the endosperm. Grain hardness has great influence on milling and processing quality. The grain hardness of BHB and QB13 with higher original grain hardness decreased significantly with the increases of PR, while QB27 with lower hardness had no significant change, possible because the thin and fragile skin of HB with higher hardness, loose combination of epidermis and endosperm, and easy to pearl. The results showed that the harder the kernel, the easier it was to remove the bark, and the trends of the thousand kernels weight and grain size were similar, that is, it gradually decreased with the increases of pearling degree. The falling number reflects the activity of α-amylase and is inversely proportional to the enzyme activity. The falling number increased notably when the PR was 4%, while increased slightly when the PR was 8%, which possibly because the gradient distribution of α-amylase in HB bran, and the enzyme content in the bran gradually decreases from outside to inside (Brier et al., 2015). Pearling treatment removed bran rich in enzymes, reduced the activity of α-amylase, and improved edible and storage quality of HBF.
Table 1: Effect of pearling rate (PR) on highland barley (HB) grain characteristics and α-amylase activity.

<table>
<thead>
<tr>
<th>Sample</th>
<th>PR (%)</th>
<th>Moisture content (%)</th>
<th>Hardness (%)</th>
<th>TKW (g)</th>
<th>Grain size (mm)</th>
<th>Falling number (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>QB13</td>
<td>0</td>
<td>10.29 ± 0.01c</td>
<td>73.67 ± 0.74a</td>
<td>22.20 ± 0.07a</td>
<td>2.26 ± 0b</td>
<td>223 ± 12d</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>9.92 ± 0.04d</td>
<td>71.40 ± 0.76bc</td>
<td>21.61 ± 0.22ab</td>
<td>2.20 ± 0.02bc</td>
<td>268 ± 7c</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>8.96 ± 0.07h</td>
<td>69.66 ± 0.45def</td>
<td>21.39 ± 0.30abc</td>
<td>2.15 ± 0.06cd</td>
<td>300 ± 5bc</td>
</tr>
<tr>
<td></td>
<td>12</td>
<td>8.70 ± 0.04i</td>
<td>68.04 ± 0.06f</td>
<td>20.93 ± 0.52bcd</td>
<td>1.95 ± 0.04f</td>
<td>301 ± 7b</td>
</tr>
<tr>
<td>QB27</td>
<td>0</td>
<td>10.45 ± 0.02b</td>
<td>72.32 ± 0.48ab</td>
<td>20.90 ± 0.30bcd</td>
<td>2.36 ± 0.01a</td>
<td>340 ± 4a</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>9.81 ± 0.01d</td>
<td>70.94 ± 0.37bcd</td>
<td>20.44 ± 0.28cde</td>
<td>2.25 ± 0.01b</td>
<td>345 ± 1a</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>9.45 ± 0.02e</td>
<td>69.36 ± 0.14def</td>
<td>20.18 ± 0.11de</td>
<td>2.16 ± 0.01cd</td>
<td>341 ± 7a</td>
</tr>
<tr>
<td></td>
<td>12</td>
<td>9.26 ± 0.10f</td>
<td>69.26 ± 0.23def</td>
<td>19.81 ± 0.09e</td>
<td>2.06 ± 0.01e</td>
<td>361 ± 10a</td>
</tr>
<tr>
<td>BHB</td>
<td>0</td>
<td>11.10 ± 0.08a</td>
<td>73.74 ± 0.25a</td>
<td>22.29 ± 0.35a</td>
<td>2.40 ± 0.08a</td>
<td>214 ± 22d</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>9.29 ± 0.15f</td>
<td>70.64 ± 1.56cde</td>
<td>22.01 ± 0.82a</td>
<td>2.25 ± 0.01b</td>
<td>283 ± 24bc</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>9.14 ± 0.06fg</td>
<td>69.21 ± 1.13ef</td>
<td>20.90 ± 0.51bcd</td>
<td>2.14 ± 0.03cde</td>
<td>287 ± 20bc</td>
</tr>
<tr>
<td></td>
<td>12</td>
<td>9.01 ± 0.04gh</td>
<td>68.97 ± 0.4ef</td>
<td>20.85 ± 0.43bcd</td>
<td>2.09 ± 0.02de</td>
<td>276 ± 12bc</td>
</tr>
</tbody>
</table>

TKW: thousand kernels weight. Total starch data are the mean ± standard deviation of triplicates. Different lowercase letters within a column indicate statistical differences (P ≤ 0.05).

**Nutritional characteristics of HBF**

Ash content of three HBF was significantly lower than that of control group, as it can be associated to the distribution of ash (Table 2). The variation in fat content among three HBF – that is, the decrease in QB27 and increased firstly and then decreased in QB13 and BHB, which may be explained distribution differences between the varieties. Protein content was almost similar within the varieties with no statistically. The starch content increased significantly when the PR was 4%, which may be attributable to the removal of peel and seed coat, resulting in the enrichment of starch in HBF. As the PR increased, total dietary fiber (TDF) and insoluble dietary fiber (IDF) gradually decreased, due to the pericarp and seed capsule are rich in xylans, cellulose and lignin which is the main source of IDF in HB, and the minor content in the aleurone layer and endosperm (Brouns et al., 2012). No considerable effect on soluble dietary fiber (SDF) was found with and without pearling, which is due to the high content of SDF in aleurone layer. Significant differences were observed with pearling process regarding the contents of calcium, iron and phosphorus and the treatments without pearling showed higher contents.
**Table 2**

<table>
<thead>
<tr>
<th>Sample</th>
<th>PR (%)</th>
<th>Ash (%)</th>
<th>Fat (%)</th>
<th>Protein (%)</th>
<th>TS (%)</th>
<th>TDF (%)</th>
<th>SDF (%)</th>
<th>IDF (%)</th>
<th>Ca (mg/kg)</th>
<th>P (mg/100 g)</th>
<th>Fe (mg/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>QB13</td>
<td>0.02c</td>
<td>0.03d</td>
<td>0.21b</td>
<td>5.47abc</td>
<td>0.58a</td>
<td>0.33ab</td>
<td>4.42a</td>
<td>0.82abc</td>
<td>13.77± 4a</td>
<td>369± 4a</td>
<td>27.3± 1.1f</td>
</tr>
<tr>
<td>4</td>
<td>0.06d</td>
<td>0.12a</td>
<td>0.01bcd</td>
<td>1.29ab</td>
<td>0.37ab</td>
<td>0.92bc</td>
<td>7.03± 0.59c</td>
<td>478± 10b</td>
<td>338± 1b</td>
<td>21.8± 2.1g</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>0.09d</td>
<td>0.21cd</td>
<td>0.14d</td>
<td>3.78ab</td>
<td>1.19bcd</td>
<td>0.25cd</td>
<td>7.01± 0.25cd</td>
<td>447± 4cd</td>
<td>326± 11bc</td>
<td>22.1± 2.0g</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>0.16f</td>
<td>0.12cd</td>
<td>0.00d</td>
<td>4.14ab</td>
<td>0.75cd</td>
<td>0.13bc</td>
<td>8.96± 0.86f</td>
<td>433± 1d</td>
<td>311± 6cd</td>
<td>18.9± 1.8g</td>
<td></td>
</tr>
<tr>
<td>QB27</td>
<td>0.15e</td>
<td>0.06b</td>
<td>0.64a</td>
<td>3.62bc</td>
<td>2.78ab</td>
<td>1.00bc</td>
<td>14.22± 0.79a</td>
<td>450± 6c</td>
<td>291± 18de</td>
<td>49.2± 1.1c</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>0.03ef</td>
<td>0.16b</td>
<td>0.09ab</td>
<td>0.45ab</td>
<td>1.2cd</td>
<td>0.71abc</td>
<td>12.55± 0.43bc</td>
<td>439± 1cd</td>
<td>292± 16de</td>
<td>37.9± 1.1e</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>0.13f</td>
<td>0.08bc</td>
<td>0.02bc</td>
<td>0.53ab</td>
<td>0.55def</td>
<td>0.41bc</td>
<td>11.30± 0.40cd</td>
<td>397± 4e</td>
<td>267± 6f</td>
<td>31.5± 1.7f</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>0.09g</td>
<td>0.04e</td>
<td>0.26cd</td>
<td>2.88a</td>
<td>0.38f</td>
<td>0.15c</td>
<td>9.58± 0.04ef</td>
<td>372± 6f</td>
<td>232± 1g</td>
<td>30.4± 0.8f</td>
<td></td>
</tr>
<tr>
<td>QB27</td>
<td>0.24a</td>
<td>0.12b</td>
<td>0.31e</td>
<td>3.63c</td>
<td>2.47abc</td>
<td>0.42ab</td>
<td>12.30± 0.87c</td>
<td>392± 1e</td>
<td>312± 6cd</td>
<td>92.4± 3.3a</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>0.03b</td>
<td>0.11bcd</td>
<td>0.17e</td>
<td>5.27abc</td>
<td>0.84de</td>
<td>0.3ab</td>
<td>11.84± 0.44cd</td>
<td>360± 13f</td>
<td>293± 10de</td>
<td>60.1± 4.4b</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>0.08c</td>
<td>0.08e</td>
<td>0.18e</td>
<td>4.47ab</td>
<td>0.44de</td>
<td>0.01a</td>
<td>10.73± 0.02de</td>
<td>362± 3f</td>
<td>278± 3ef</td>
<td>60.5± 1.1b</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>0.13cd</td>
<td>0.25de</td>
<td>0.32e</td>
<td>0.78ab</td>
<td>0.68ef</td>
<td>0.67bc</td>
<td>9.28± 0.14f</td>
<td>314± 10g</td>
<td>259± 4f</td>
<td>43.7± 3.5d</td>
<td></td>
</tr>
</tbody>
</table>

TS: total starch; TDF: total dietary fiber; SDF: soluble dietary fiber; IDF: insoluble dietary fiber. Data are the mean ± standard deviation of triplicates. Different lowercase letters within a column indicate statistical differences (P < 0.05).

### β-glucan and γ -aminobutyric acid (GABA) content

The increasing of PR resulted in a decreased in the content of β-glucan in HBF (Fig. 2A), which is opposite to published results of Zhao (2020). β-glucan is mainly concentrated in highland barley aleurone layer, and its content in pericarp and endosperm is low (Onipke Oluwatoyin et al., 2015). Highland barley bran is rich in GABA, which can be used as raw materials for developing GABA functional products such as anti-fatigue and lowering blood pressure (Hayakawa et al., 2004). When the PR is greater than 4%, the removal of aleurone layer leads to a significant decrease in the content of β-glucan in highland barley flour. The GABA content increased first and then decreased but not obvious, and the highest content was observed when the PR was 4% (Fig. 2B), indicating that appropriate pearling treatment could enrich the content of GABA.

### Thermomechanical, gelatinization and pasting properties

Thermomechanical properties of HBF were presented in Table 3 and Fig. 3. An increase in PR substantially changed the water absorption, development time and stability time, and the unpearled HBF showed a slight higher level. This may be due to the reduction of bran particles in HBF with the removal of the outer cortex. Bran had higher swelling power and water retention capacity than flour, leading to a higher water absorption (Wu et al., 2015). Compared with unpearled HBF, the development time of the pearled HBF was significantly shortened, which may be attributed to the high fiber content in the outer cortex, and the increase of hydroxyl in the fiber molecules, thus increasing the interaction between hydrogen bonds. Manuel et al. also observed an increased in development time when add the extruded bran into wheat flours (2011). In addition, fiber and other flour components competed with the protein to absorb water and interfered with the development of the protein network, causing the longer development time of unpearled HBF. It has been reported that the incorporation of sugar beet fiber into the dough matrix greatly competes for water with starch affecting pasting (Rosell et al., 2010). Softening degree reflected the strength of the protein network structure, with inversely proportional to the protein strength (Mozza et al., 2017). There was no significant difference in the softening degree of dough, and the value of setback increased with the increasing of pearling rates. This may be explained by the fact that bran has an obstructing effect on the intermolecular rearrangement of starch after gelatinization (Xu et al., 2018). With the increase of pearling rate, the reduction of bran content in HB reduced the stability of starch and made starch prone to stale. Cooking stability increased with the PR increasing, indicating that pearling treatment could improve the cooking resistance of HBF (Noort et al., 2010).

The starting temperature (T<sub>s</sub>), peak temperature (T<sub>p</sub>) and ending temperature (T<sub>e</sub>) of HBF of the three varieties had no significant changes (Table 3). The water bound by dietary fiber was reduced without the bran, which increased the water transmission rate in the gelatinization system and accelerated the gelatinization process of starch. Thus, the starch not gelatinized increased in HBF, leading to the decrease of ΔH value.
The content of RS and SB were potent indicators of glycemic index of food. Previous studies have reported that the increase of RS and SB has a positive impact on reducing the risk of cardiovascular and cerebrovascular diseases and improving the intestinal environment (Noula et al., 2016). As shown in Table 4, a significant decrease in RS and an increase in SB were observed with the increase of PR (indicating peeling treatment), which could slow down the digestion rate of starch. The content of RS was the highest when PR of QB27 and BHB was 4%, while 8% of QB13. Whereas, the total starch hydrolysis index and pasting properties of HBF were enlisted in Table 3. Peak viscosity (PV) indicates the highest viscosity achieved during gelatinization of starch under the presence of water (Coccaro et al., 2010). PV value presented an upward trend with the increase of PR. This was possibly because the removal of outer layers not only lowered the water retention ability and improved the ability of the pasted and eaten water (Gao et al., 2017). Roughly speaking, PV, breakdown (FB) and setback viscosity (BS) of three cultivars HBF increased, which was consistent with the previous research results (Bai et al., 2016), which could be ascribed to the content of bran with low PR was high, thus weakening the network structure formed by starch itself. The value of PV, TV, RVA and DSC were not only lowered the water retention ability and improved the ability of the pasted and eaten water, but also increased the gelatinization enthalpy (PV), peak viscosity, TV, breakdown, RVA and DSC values. Table 3 showed the effect of peeling on the pasting properties of four cultivars of HBF. The Table 4 below showed the conversion of starch hydrolysis rate and pasting properties of HBF.
the digestion and absorption of starch by blocking the adsorption site of digestive enzymes or interacting with digestive enzymes (Ye et al., 2018). Wenwen Yu et al. reported that barley proteins retarded the digestion of starch degraded by α-amylase which could bind with water-insoluble protein and with starch granules, leading to reduced starch hydrolysis (2018).

### Antioxidant properties

Several methods have been used to comprehensively evaluate the antioxidant properties of HB. The total phenol and anthocyanin content were found to be significantly affected by the factors of HB cultivar and PR (Fig. 4). The HB PR was 4% had the highest total phenol content (TPC), which indicated that the phenolic compounds in HB were enriched when the PR was 4%. This arises due to the phenols were mainly concentrated in aleurone layer, which began to be removed with the increase of PR. In case of anthocyanin, BHB with 0% PR had significantly higher than all the other samples. TPC has a direct effect on total antioxidant capacity (TAC), which consistent with the trend of antioxidant active substances such as anthocyanin and flavonoids content of QB13 and BHB were not quite significant. Compared with the control group, flavonoids content of QB27 decreased significantly. Nevertheless, no significant differences were noted between samples with different PR. TAC showed a negative correlation with PR, which consistent with the trend of antioxidant active substances such as anthocyanin and β-gluten. The inhibition rates of DPPH-decreased by 17.63%, 48.77% and 0.9% of QB13, QB27 and BHB, respectively. The ABTS·+ scavenging activity of QB13, QB27 and BHB (control groups) were 25.03, 21.23 and 31.48, and they decreased to 11.27, 17.25 and 25.70 after pearling process (PR 12%). Similarly, significant increases appeared in the inhibition rates of OH− and O2−. The changes of these radicals were consistent with the results obtained for total antioxidant capacity and some antioxidant substances. The differences of avonoids contents observed for QB13 and BHB were not quite significant. Compared with the control group, avonoids removed with the increase of PR. In case of anthocyanin, BHB with 0% PR had signicantly higher than all the other samples. TPC has a direct effect on total antioxidant capacity (TAC) (Awika et al., 2003), but the trend of TAC of HBF is inconsistent with that of TPC, which may be influenced by other antioxidant substances. The differences of flavonoids contents observed for QB13 and BHB were not quite significant. Compared with the control group, flavonoids content of QB27 decreased significantly. Nevertheless, no significant differences were noted between samples with different PR. TAC showed a negative correlation with PR, which consistent with the trend of antioxidant active substances such as anthocyanin and β-gluten. The inhibition rates of DPPH-decreased by 17.63%, 48.77% and 0.9% of QB13, QB27 and BHB, respectively. The ABTS·+ scavenging activity of QB13, QB27 and BHB (control groups) were 25.03, 21.23 and 31.48, and they decreased to 11.27, 17.25 and 25.70 after pearling process (PR 12%). Similarly, significant increases appeared in the inhibition rates of OH− and O2−. The changes of these radicals were consistent with the results obtained for total antioxidant capacity and some antioxidant substances in this study.

### Quality evaluation of highland barley noodles

As shown in Table 5, PR had significant effect on cooking characteristics except the cooking loss. When the PR was 4%, the water absorption of HB noodles decreased sharply. This might be because the pearling treatment reduced the dietary fiber content and damaged starch in HBF. Importantly, the break rate of QB13, QB27 and BHB (PR 0%) obviously decreased from 51.7%, 53.3% and 38.3–35.0%, 15.0% and 6.7% (PR 12%) respectively, indicated the improvement of noodles quality. The cooking time of QB13, QB27 and BHB were 2.25min, 3.15min and 3.15min when the PR was 12%, which was the shortest cooking time. The shorter cooking time as well as the lower water uptake means good noodle quality (Izydorczyk et al., 2003). Thereby, a more compact and denser protein network was formed. However, the differences of QB13 were not statistically significant.

<table>
<thead>
<tr>
<th>Sample</th>
<th>PR (%)</th>
<th>RDS (%)</th>
<th>SDS (%)</th>
<th>RS (%)</th>
<th>HI (%)</th>
<th>GI (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>QB13</td>
<td>0</td>
<td>50.91 ± 0.53c</td>
<td>34.85 ± 0c</td>
<td>14.23 ± 0.53de</td>
<td>61.07 ± 6.64def</td>
<td>73.24 ± 3.65def</td>
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<td>4</td>
<td>43.88 ± 1.03d</td>
<td>33.38 ± 2.01c</td>
<td>22.74 ± 0.98b</td>
<td>57.42 ± 2.18f</td>
<td>71.24 ± 1.20f</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>41.12 ± 2.95d</td>
<td>33.28 ± 3.84c</td>
<td>25.59 ± 0.88a</td>
<td>62.23 ± 2.49cdef</td>
<td>73.88 ± 1.36cdef</td>
</tr>
<tr>
<td></td>
<td>12</td>
<td>37.10 ± 0.61e</td>
<td>50.38 ± 1.02a</td>
<td>12.53 ± 0.41f</td>
<td>60.37 ± 1.71def</td>
<td>72.86 ± 0.94def</td>
</tr>
<tr>
<td>QB27</td>
<td>0</td>
<td>76.13 ± 0.17a</td>
<td>10.80 ± 0.67g</td>
<td>13.07 ± 0.5ef</td>
<td>68.16 ± 1.66bcde</td>
<td>77.13 ± 0.91bcde</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>65.84 ± 1.76b</td>
<td>19.51 ± 2.33ef</td>
<td>14.65 ± 0.57cd</td>
<td>62.24 ± 0.05cdef</td>
<td>74.43 ± 0.03cdef</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>63.73 ± 0.70b</td>
<td>25.98 ± 0.10d</td>
<td>10.30 ± 0.60h</td>
<td>59.38 ± 4.96ef</td>
<td>72.31 ± 2.72ef</td>
</tr>
<tr>
<td></td>
<td>12</td>
<td>42.76 ± 3.51d</td>
<td>48.44 ± 3.12ab</td>
<td>8.80 ± 0.38i</td>
<td>59.43 ± 4.39ef</td>
<td>72.34 ± 2.41ef</td>
</tr>
<tr>
<td>BHB</td>
<td>0</td>
<td>73.08 ± 1.02a</td>
<td>16.31 ± 1.39ef</td>
<td>10.61 ± 0.36h</td>
<td>85.02 ± 4.46a</td>
<td>86.39 ± 2.45a</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>65.9 ± 0.27b</td>
<td>18.17 ± 0ef</td>
<td>15.92 ± 0.27c</td>
<td>77.56 ± 6.75ab</td>
<td>82.29 ± 3.71ab</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>62.24 ± 1.53b</td>
<td>26.46 ± 1.92d</td>
<td>11.31 ± 0.39gh</td>
<td>71.54 ± 5.16bc</td>
<td>78.99 ± 2.84bc</td>
</tr>
<tr>
<td></td>
<td>12</td>
<td>50.60 ± 2.09c</td>
<td>43.98 ± 3.36b</td>
<td>5.42 ± 1.27j</td>
<td>69.57 ± 2.18bcd</td>
<td>77.91 ± 1.2bcd</td>
</tr>
</tbody>
</table>

RDS: rapidly digestible starch; SDS: slowly digestible starch; RS: resistant starch; HI: hydrolysis index; GI: Glycemic index. Data are the mean ± standard deviation of triplicates. Different lowercase letters within a column indicate statistical differences (P ≤ 0.05).
Table 5
Effect of pearling rate (PR) on quality of highland barley noodles

<table>
<thead>
<tr>
<th>Sample</th>
<th>PR (%)</th>
<th>WA (%)</th>
<th>CL (%)</th>
<th>BR (%)</th>
<th>CT (min)</th>
<th>TS (g)</th>
<th>TD (mm)</th>
<th>Hardness (g)</th>
<th>Gumminess (%)</th>
<th>Chewiness (%)</th>
<th>Resilience (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>QB13</td>
<td>0</td>
<td>58.2 ± 0.6bc</td>
<td>7.54 ± 0.81a</td>
<td>51.7 ± 2.4a</td>
<td>3.05 ± 0.07d</td>
<td>8.58 ± 0.14f</td>
<td>1.65 ± 0.25g</td>
<td>394 ± 56cd</td>
<td>70.5 ± 4.8d</td>
<td>29.2 ± 9.1cd</td>
<td>0.077 ± 0.005bcdc</td>
</tr>
<tr>
<td>4</td>
<td>54.8 ± 2.0a</td>
<td>7.31 ± 0.03a</td>
<td>35.0 ± 3.5bc</td>
<td>2.45 ± 0.07e</td>
<td>13.30 ± 0.08ef</td>
<td>3.93 ± 0.04f</td>
<td>465 ± 66bc</td>
<td>68.7 ± 7.8d</td>
<td>30.8 ± 8.4cd</td>
<td>0.081 ± 0.003bc</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>56.8 ± 1.2c</td>
<td>4.98 ± 0.52ab</td>
<td>37.5 ± 3.5bc</td>
<td>2.35 ± 0.07ef</td>
<td>17.21 ± 0.34de</td>
<td>4.82 ± 0.07ef</td>
<td>430 ± 31bc</td>
<td>70.6 ± 9.7d</td>
<td>34.2 ± 9.0cd</td>
<td>0.077 ± 0.008bc</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>54.6 ± 2.4c</td>
<td>5.94 ± 1.30ab</td>
<td>35.0 ± 0.0bc</td>
<td>2.25 ± 0.07f</td>
<td>19.43 ± 0.35cde</td>
<td>6.24 ± 0.07bc</td>
<td>471 ± 32bc</td>
<td>63.7 ± 1.9d</td>
<td>23.7 ± 3.8d</td>
<td>0.098 ± 0.009a</td>
<td></td>
</tr>
<tr>
<td>QB27</td>
<td>0</td>
<td>63.3 ± 0.6a</td>
<td>6.21 ± 0.38ab</td>
<td>53.3 ± 4.7a</td>
<td>3.15 ± 0.07cd</td>
<td>16.09 ± 1.38e</td>
<td>5.26 ± 0.06def</td>
<td>366 ± 20cd</td>
<td>72.6 ± 9.4d</td>
<td>40.1 ± 6.9d</td>
<td>0.073 ± 0.002d</td>
</tr>
<tr>
<td>4</td>
<td>61.9 ± 1.4ab</td>
<td>5.35 ± 3.00ab</td>
<td>30.0 ± 4.7bcd</td>
<td>3.20 ± 0.00bc</td>
<td>23.88 ± 0.09bcd</td>
<td>6.40 ± 0.40bcdc</td>
<td>434 ± 41bc</td>
<td>80.4 ± 11.3cd</td>
<td>35.8 ± 7.4c</td>
<td>0.079 ± 0.006bcd</td>
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<tr>
<td>8</td>
<td>56.9 ± 0.9bc</td>
<td>3.40 ± 2.69bc</td>
<td>28.3 ± 2.4cd</td>
<td>3.30 ± 0.00ab</td>
<td>28.82 ± 1.46ab</td>
<td>7.24 ± 0.10bc</td>
<td>585 ± 8b</td>
<td>132.8 ± 1.2a</td>
<td>98.8 ± 9.1a</td>
<td>0.088 ± 0.002abc</td>
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<td>12</td>
<td>55.7 ± 2.8c</td>
<td>6.06 ± 1.97ab</td>
<td>15.0 ± 2.4ef</td>
<td>3.15 ± 0.07cd</td>
<td>32.55 ± 7.82a</td>
<td>8.96 ± 0.56a</td>
<td>581 ± 52b</td>
<td>110.5 ± 7.0ab</td>
<td>74.6 ± 19.4ab</td>
<td>0.091 ± 0.001abc</td>
<td></td>
</tr>
<tr>
<td>BHB</td>
<td>0</td>
<td>61.3 ± 0.4ab</td>
<td>5.84 ± 0.44ab</td>
<td>38.3 ± 2.4b</td>
<td>3.30 ± 0.00ab</td>
<td>19.89 ± 0.80cde</td>
<td>4.54 ± 0.69f</td>
<td>240 ± 16d</td>
<td>62.3 ± 6.1d</td>
<td>32.3 ± 20.8cd</td>
<td>0.076 ± 0.005bcd</td>
</tr>
<tr>
<td>4</td>
<td>54.1 ± 0.5c</td>
<td>6.26 ± 0.52ab</td>
<td>23.3 ± 9.4de</td>
<td>3.35 ± 0.07a</td>
<td>19.80 ± 2.40cde</td>
<td>5.5 ± 0.11cde</td>
<td>390 ± 48cd</td>
<td>83.3 ± 11.2cd</td>
<td>41.0 ± 6.6cd</td>
<td>0.079 ± 0.004bcd</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>55.0 ± 0.0c</td>
<td>5.74 ± 0.58ab</td>
<td>13.3 ± 4.7f</td>
<td>3.25 ± 0.07abc</td>
<td>20.40 ± 0.41cde</td>
<td>7.01 ± 1.30cde</td>
<td>464 ± 83bc</td>
<td>79.4 ± 8.0cd</td>
<td>48.4 ± 4.7bcd</td>
<td>0.078 ± 0.004bcd</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>53.6 ± 4.5c</td>
<td>5.23 ± 0.01ab</td>
<td>6.7 ± 0.0f</td>
<td>3.15 ± 0.07cd</td>
<td>24.55 ± 1.60bc</td>
<td>9.06 ± 1.00a</td>
<td>778 ± 107a</td>
<td>103.2 ± 1.1bc</td>
<td>60.4 ± 11.1bc</td>
<td>0.093 ± 0.006abc</td>
<td></td>
</tr>
</tbody>
</table>

WA: water absorption; CL: cooking loss; BR: break rate; CT: cooking time; TS: tensil strength; TD: tension distance. Data are the mean ± standard deviation of triplicates. Different lowercase letters within a column indicate statistical differences (P ≤ 0.05).

Principal component analysis and correlation analysis

Principal component analysis was applied to HBF and HBF noodles in order to visualize the effect of pearling on the qualities, and quality indicators including nutritional, physicochemical and antioxidant characteristics. PC1 and PC2 accounted for 42.9% and 24.4% of the total variance, respectively (Fig. 5A). In the PC1 versus PC2 scatter plot, all samples of QB13 and QB27 were primarily distributed among the negative PC2 values, whereas the BHB samples were primarily distributed with positive PC2 values. From the loading plot, the difference between BHB flour and the other two types of HBF was primarily associated with differences in anthocyanin, hydrolysis index, tension distance, total starch and scavenging effects on hydroxyl radical. Furthermore, these three varieties of samples shifted towards negative PC1 values as the PR increased, and the primary contributors to this shift corresponded to tension distance, breakdown value, hardness and resilience. The correlation analysis results (Fig. 5B) indicated that some of the nutritional, physicochemical and antioxidant properties of the flours were correlated.

Conclusion

Three HB grains of pearled and unpearled were investigated as well as HBF and HBF noodles to evaluate the differences in their qualities. It has been observed that PR had significant effects on HB kernels. With the increases of PR, the hardness, thousand kernels weight and grain size of HB grains decreased. Pearling enriched some nutrients of HB and made some nutrients lose at the same time, in terms of the content of ash, fat, protein and total starch. The content of total dietary fiber, soluble and insoluble dietary fiber decreased with the increase of PR, which may result in the delay of starch hydrolysis and the reduction of glycemic index. Furthermore, pearling improved the gelatinization viscosity and significantly changed the thermomechanical properties of HBF dough. Thus, it could be said that the pearling is a successful method to improve the processing properties. Despite enriched some functional substances such as GABA and total phenol, the TAC of HBF was reduced and the inhibition of radicals inclined to some extent. Besides, the promoting effect in processing and cooking qualities pearled and unpearled HBF noodles had been confirmed in this study. Anyhow, further investigations about pearling method in gluten-free products are still necessary to obtain good quality food.

Declarations

Author Contribution

Qinana Zheng carried out the experiments, wrote the main manuscript, and corrected the manuscript; Yan Song carried out the experiments; Feiyang Xiong carried out the experiments; Zheng Wang carried out the experiments; Shuangfeng Guo carried out the experiments; Rong Ma carried out the experiments; Guanquan Zhang conceived the idea, supervised the work; All authors reviewed the manuscript.
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Data Availability
The data used in this study are available from the corresponding author upon reasonable request.

Declaration of Competing Interest
The authors report no declarations of interest.

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References


**Figures**

![Figure 1](image1)

**Figure 1**

The scanning electron microscopy (SEM) (× 400) of highland barley (HB) grains. Seed capsules are highlighted with white arrow and the aleurone layer are highlighted with red arrow.
Figure 2

Effect of pearling rate (PR) on β-glucan (A) and γ-aminobutyric acid (B) content of highland barley flour (HBF). Different lowercase letters indicate significantly different at level $P \leq 0.05$.

Figure 3

Thermomechanical curve recorded in the mixolab system for highland barley (HB) grains. A: zangqing 13 (QB13); B: zangqing 27 (QB27); C: black highland barley.
Figure 4

Total phenol content (A), anthocyanin (B), flavoloids content (C), total antioxidant capacity (D) and savenging effects on free radicals of HBF (E: DPPH radical; F: ABTS radical; G: hydroxyl radical; H: superoxide radical). Different lowercase letters indicate significantly different at level $P \leq 0.05$.

Figure 5

Principal component analysis (A) and Pearson's correlation coefficients (B) of nutritional, physicochemical and antioxidant characteristics of HBF and HBF noodles made from different pearling rates grains. SDS, slowly digestible starch; TS, total starch; SB, setback viscosity; BD, breakdown; TD, tension distance;
SDF, soluble dietary fibre; HI, hydrolysis index; GI, Glycemic index; CT, cooking time; GABA, γ-aminobutyric acid; WA, water absorption; RDS, rapidly digestible starch; TP, total phenol content; Pro, protein content; CL, cooking loss; TA, total antioxidant capacity; RS, resistant starch; IDF, insoluble dietary fibre; DT: development time; ΔH, gelatinization enthalpy; BR, break rate; FC, flavoloids content.

**Supplementary Files**

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