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Effect of pearling on nutritional value of highland barley flour and processing characteristics of noodles

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A R T I C L E I N F O

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A B S T R A C T

Highland barley is increasingly recognized as its nutritional benefits but its structure restricts the development and utilization in the food industry. The quality of highland barley products may be impacted by pearling, an essential step before the hull bran is consumed or further processed. The nutrition, function and edible qualities of three highland barley flour (HBF) with different pearling rates were assessed in this study. The content of resistant starch was the highest when the pearling rate of QB27 and BHB was 4%, while 8% of QB13. Un-pearled HBF showed higher DPPH, ABTS and superoxide radicals inhibition rates. The break rates of QB13, QB27 and BHB obviously decreased from 51.7%, 53.3% and 38.3% to 35.0%, 15.0% and 6.7% respectively at 12% pearling rate. PLS-DA model further attributed the improvement of pearling on noodles quality to the alteration of resilience, hardness, tension distance, breaking rate and water absorption of noodles.

1. 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). The content of protein is higher than those in hulled barley protein and it is more soluble, emulsifiable and stable, however, its foamability and foam stability are lower than that in wheat protein. 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. (2015) have proved that dietary HB food not only effectively adjusted postprandial amino acid levels of the people with abnormal glucose tolerance, but also improved their insulin sensitivity. Recently, β-glucan has been shown to have anti-aging, anti-cancer and immune regulation effects, which implied a potential prospect of HB (Ashraf et al., 2021). γ-aminobutyric acid (GABA) is an abundant four-carbon non-protein free amino acid that is primarily metabolized via decarboxylation of glutamate or degradation of polyamine (Zhang et al., 2018). GABA has many proven beneficial effects such as decreasing blood pressure, lowering the lipid and inhibiting the proliferation of cancer cells (Chung et al., 2009). Phenolic substances in HB exist in bound and free forms, which are present in cereals as antioxidants that contribute to reducing the risk of cancer.

Not only nutritional bases but also organizational structure affects the commercialization of HB. Generally, the multilayer organizational structure of HB restricts its industrialization and further commercialization. Thus, in order to gain satisfactory final products, a few studies have employed pearling treatment in HB processing to separate endosperm from the outer tissues with unfavorable processing quality. However, excessive pearling was usually carried out to ensure the taste of products, while a large amount of nutrients lost during the process. Gamel and Abdel-Aal (2012) investigated barley wholegrain and milling fractions in terms of phenolic acids composition, scavenging capacity against DPPH and ABTS radicals and inhibition of human LDL oxidation in vitro. They found that the outer layers fraction showed higher scavenging capacity against ABTS and DPPH radicals and inhibitory effects toward LDL oxidation compared with the endosperm fractions. Mehfooz et al. (2017) incorporated barely husk in chapatti and evaluated its compositional, thermal, textural and sensory characteristics. They found an increase in the content of dietary fiber and minerals, but the color of the products darker and the taste was affected to some extent. Therefore, the effects of pearling on HB flour and cooking characteristics remain to be fully elucidated.

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The present study treated three diverse HB cultivars at 4 kinds of pearling rate (PR) and investigate the evolution in nutritional value, processing quality and noodles quality of HB depending on PR. The objective of the present study is to give a possible way that pearling treatment influences the quality of HB noodles. The results of present study can be helpful to find an appropriate PR that will overcome the dilemma of palatability and provide a scientific basis for development, utilization and deep processing of HB.

2. Materials and methods

2.1. 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 5 %. Pearling degree 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.

2.2. 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. The dough passed through the sheeting rolls of noodle machine (BJM-6, Deqing Baijie Electric Appliance, China) for 7–9 times to obtain the noodles sheets. The dimensions of the noodle strands were 2 mm in width and 1.8 mm in thickness.

2.3. 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 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 AACC methods. Dietary fiber content was determined using the assay kit (Megazyme International ltd., Ireland). β -glucan content was determined using the megazyme mixed-linkage β-glucan kit (Megazyme International ltd., Ireland). γ-aminobutyric acid (GABA) was measured as follows: 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.

2.4. Pasting, gelatinization and thermomechanical properties

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. Differential scanning calorimetry (DSC) (Q2000, Waters, USA) was used to determine the gelatinization properties according to the method of Allan et al. (2018) with some modifications. Thermal mechanical properties were measured by a Mixolab2 (Chopin, France) with a modified Chopin + protocol.

2.5. 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-Ramirez et al. (2020).

2.6. 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 determinate 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 (O_2·−) were determined by adapting previous methods (Enujiugha et al., 2012; Guedes et al., 2013; Lin et al., 2018; Moza & Gujral, 2016; Yang et al., 2018; Zhao et al., 2008).

2.7. 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 textural properties was assessed using a Texture Analyzer (TA-XT Plus/50, Stablemicvo, England).

2.8. Statistical analysis

Statistical analyses were performed using Minitab 8.0, and Tukey's post hoc test was used to detect significant differences. The data sets were imported in MetaboAnalyst (version 4.0) to perform the principal component analysis (PCA), the partial least squares-discriminate analysis (PLSDA), the variable importance in projection (VIP) scores and the heat map visualization. The figures were plotted using Origin 9.6 and GraphPad Prism 7, and means were considered significantly different at a $P \leq 0.05$ threshold.

3. Results and discussions

3.1. Grain characteristics of HB

Three HB cultivars were pearled, and the PR varied from 0 % to 12 %. As shown in Fig. S1, the outer layers were removed gradually as the PR increased, but the tissues removed from kernel were inhomogeneous under abrasion. At 4 % PR (Fig. S1, A2, B2, C2), a majority of 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 % (Fig. S1 A3, B3, C3), more aleurone layer was removed with the detachment of more seed capsules. At 12 % PR (Fig. S1 A4 B4, C4), the seed capsules were almost completely scraped off.

It could be seen from Table 1 that moisture content decreased significantly with the increases of PR. This might 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 being moistened before pearling, which led to the water failed to enter the endosperm and aleurone layer near the endosperm. Grain hardness had a great influence on milling and processing quality (Table 1). The grain hardness of BHB and QB13, which had higher initial grain hardness, significantly decreased as PR increased, whereas QB27, which had lower initial hardness, did not significantly change during PR. This could be explained by the fact that HB with higher hardness had thin and fragile skin, a loose combination of epidermis and endosperm, and were easy to pearl. The results showed that the harder the kernel, the easier it was to remove the bark. The trends of the thousand kernels weight and grain size were similar, that is, it gradually decreased with the increases of pearling degree. Hagberg (1960) invented the "falling number" test to gauge how quickly starch-induced α-amylolysis caused wheat flour to liquefy. The International Association for Cereal Chemistry (ICC, 107/1) and the American Association of Cereal Chemists (AACC, 56-81.03) had approved it as a standard method for determining α-amylase activity, and the International Organization for Standardization (ISO, ISO 3093:2009) had adopted it for determining cereal quality. A low falling number reflected the high activity of α-amylase, the starch paste quickly hydrolyzed and liquefied, which resulted the stirrer to drop within fewer seconds (Shao et al., 2019). The falling number increased notably when the PR was 4 %, while increased slightly when the PR was 8 % (Table 1), which possibly because the gradient distribution of α-amylase in HB bran, and the enzyme content in the bran gradually decreased from outside to inside (Brier et al., 2015). All in all, pearling treatment removed bran rich in enzymes, reduced the activity of α-amylase, and improved edible and storage quality of HBF.

3.2. *Nutritional characteristics*

Ash content of three pearled HBF was significantly lower than that of un-pearled, as it could be associated to the distribution of ash (Table 1). The fat content decreased in QB27 depending pearling rate, while it increased firstly and then decreased in QB13 and BHB (Table 1), which might be explained by distribution differences between the varieties. Protein content was almost similar within the varieties with no statistically (Table 1). The starch content increased significantly when the PR was 4 % (Table 1), which might 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 (Table 1), due to that the pericarp and seed capsule contained a large amount of xylans, cellulose and lignin, while aleurone layer and endosperm contained a small amount of that (Brouns et al., 2012). No considerable effect on soluble dietary fiber (SDF) was found with and without pearling (Table 1), which was due to the high content of SDF in aleurone layer (Limberger-Bayer et al., 2014). Finally, pearling treatment significantly decreased the content of calcium, iron and phosphorus in QB13, QB27 and BHB.

Table 1
Effect of pearling rate (PR) on highland barley grain and proximate components of highland barley flour.

	QB13	QB27	BHB									
PR (%)	0	4	8	12	0	4	8	12	0	4	8	12
Highland barley grain												
MC (%)	10.29 ± 0.01c	9.92 ± 0.04d	8.96 ± 0.07 h	8.70 ± 0.04i	10.45 ± 0.02b	9.81 ± 0.01d	9.45 ± 0.02e	9.26 ± 0.10f	11.10 ± 0.08a	9.29 ± 0.15f	9.14 ± 0.06 fg	9.01 ± 0.04gh
Hardness (%)	73.67 ± 0.74a	71.40 ± 0.76bc	69.66 ± 0.45def	68.04 ± 0.06f	72.32 ± 0.48ab	70.94 ± 0.37bcd	69.36 ± 0.14def	69.26 ± 0.23def	73.74 ± 0.25a	70.64 ± 1.56cde	69.21 ± 1.13ef	68.97 ± 0.4ef
TKW (g)	22.20 ± 0.07a	21.61 ± 0.22ab	21.39 ± 0.30abc	20.93 ± 0.52bcd	20.90 ± 0.30bcd	20.44 ± 0.28cde	20.18 ± 0.11de	19.81 ± 0.09e	22.29 ± 0.35a	22.01 ± 0.82a	20.90 ± 0.51bcd	20.85 ± 0.43bcd
GS (mm)	2.26 ± 0.00b	2.20 ± 0.02bc	2.15 ± 0.06 cd	1.95 ± 0.04f	2.36 ± 0.01a	2.25 ± 0.01b	2.16 ± 0.01 cd	2.06 ± 0.01e	2.40 ± 0.08a	2.25 ± 0.01b	2.14 ± 0.03cde	2.09 ± 0.02de
FN (s)	223 ± 12d	268 ± 7c	300 ± 5bc	301 ± 7b	340 ± 4a	345 ± 1a	341 ± 7a	361 ± 10a	214 ± 22d	283 ± 24bc	287 ± 20bc	276 ± 12bc
Highland barley flour												
Ash (%)	3.38 ± 0.02c	3.08 ± 0.08d	3.05 ± 0.09d	2.47 ± 0.16f	2.79 ± 0.15e	2.54 ± 0.03ef	2.44 ± 0.13f	2.01 ± 0.09 g	4.65 ± 0.24a	4.31 ± 0.03b	3.42 ± 0.08c	3.29 ± 0.13 cd
Fat (%)	2.04 ± 0.21b	2.38 ± 0.12a	1.59 ± 0.21 cd	1.56 ± 0.12 cd	1.95 ± 0.06b	2.04 ± 0.16b	1.81 ± 0.08bc	1.19 ± 0.04e	1.99 ± 0.12b	1.73 ± 0.11bcd	1.21 ± 0.08e	1.41 ± 0.25de
Protein (%)	9.75 ± 0.03d	10.62 ± 0.01bcd	9.82 ± 0.14d	9.77 ± 0.00d	10.55 ± 0.64a	10.74 ± 0.09ab	10.46 ± 0.02bc	10.01 ± 0.26 cd	9.07 ± 0.31e	8.86 ± 0.17e	8.68 ± 0.18e	8.76 ± 0.32e
TS (%)	66.9 ± 5.47abc	72.95 ± 1.29ab	68.99 ± 3.78ab	70.28 ± 4.14ab	64.18 ± 3.62bc	69.09 ± 0.45ab	71.07 ± 0.53ab	74.39 ± 2.88a	59.38 ± 3.63c	67.07 ± 5.27abc	72.57 ± 4.47ab	70.26 ± 0.78ab
TDF (%)	24.28 ± 0.58a	22.77 ± 0.37ab	20.85 ± 1.19bcd	18.91 ± 0.75 cd	23.68 ± 2.78ab	19.76 ± 1.2 cd	17.97 ± 0.55def	15.09 ± 0.38f	21.73 ± 2.47abc	18.42 ± 0.84de	18.21 ± 0.44de	15.66 ± 0.68ef
SDF (%)	7.42 ± 0.82abc	7.03 ± 0.92bc	7.01 ± 0.13bc	6.50 ± 0.13bc	7.12 ± 1.00bc	7.52 ± 0.71abc	6.67 ± 0.41bc	6.11 ± 0.15c	7.75 ± 0.42ab	7.67 ± 0.3ab	8.87 ± 0.01a	6.86 ± 0.67bc
IDF (%)	13.77 ± 0.33ab	12.44 ± 0.59c	11.85 ± 0.25 cd	8.96 ± 0.86f	14.22 ± 0.79a	12.55 ± 0.43bc	11.30 ± 0.40 cd	9.58 ± 0.04ef	12.30 ± 0.87c	11.84 ± 0.44 cd	10.73 ± 0.02de	9.28 ± 0.14f
Ca (mg/kg)	543 ± 4a	478 ± 10b	447 ± 4 cd	433 ± 1d	450 ± 6c	439 ± 1 cd	397 ± 4e	372 ± 6f	392 ± 1e	360 ± 13f	362 ± 3f	314 ± 10 g
P (mg/100 g)	369 ± 4a	338 ± 1b	326 ± 11bc	311 ± 6 cd	291 ± 18de	292 ± 16de	267 ± 6f	232 ± 1 g	312 ± 6 cd	293 ± 10de	278 ± 3ef	259 ± 4f
Fe (mg/kg)	27.3 ± 1.1f	21.8 ± 2.1 g	22.1 ± 2.0 g	18.9 ± 1.8 g	49.2 ± 1.1c	37.9 ± 1.1e	31.5 ± 1.7f	30.4 ± 0.8f	92.4 ± 3.3a	60.1 ± 4.4b	60.5 ± 1.1b	43.7 ± 3.5d

MC: Moisture content; TKW: thousand kernels weight; GS: Gain size; FN: Falling number; TS: total starch; TDF: total dietary fibre; SDF: soluble dietary fibre; IDF: insoluble dietary fibre. Data are the mean ± standard deviation of triplicates. Different lowercase letters within a column indicate statistical differences ($P \leq 0.05$).

3.3. β-glucan and γ -aminobutyric acid (GABA) content

Pearling treatment decreased the content of β -glucan in HBF (Fig. 2A). Generally, β-glucan was mainly concentrated in highland barley aleurone layer, while its content in pericarp and endosperm was low (Onipe Oluwatoyin et al., 2015). When the PR was>4 %, the removal of aleurone layer significantly decreased in the content of β-glucan in HBF. The GABA content increased first and then decreased but was not obvious, and the highest content was observed when the PR was 4 %. (Fig. 2B) The amount of GABA reduced when the PR was higher than 4 %, indicating its proportion in the endosperm layer was less than that in the aleurone layer, which implied a prospect in developing GABA functional products such as anti-fatigue and lowering blood pressure. Jin et al. (2014) also reported that they obtained a barley bran enriched in GABA (948 mg/kg) under optimal conditions.

3.4. Pasting, gelatinization and thermomechanical properties

Pasting, gelatinization and thermomechanical properties of HBF were enlisted in Table S1 and Fig. 1. Peak viscosity presented an upward trend with the increase of PR. This was partly attributed to that the removal of outer layers not only lowered the water retention ability but also improved the ability of the paste to absorb water. Pearling treatment increased trough viscosity (TV), break down (BD), final viscosity (FV) and setback viscosity (SB) of QB13 and BHB, which was consistent with the previous research results, which could be ascribed to the content of bran with low PR was high, thus weakening the network structure formed by starch itself (Boita et al., 2016).

As illustrated in Fig. 1(D–F), pearling did not significantly change the starting temperature (T_o), peak temperature (T_p) and ending temperature (T_c) of HBF of the three varieties. The ΔH value decreased slightly ($P \geq 0.05$) except QB13 at 8 % PR, which could be attributed to the increase of not gelatinized starch (Zheng et al., 2022). Pearling treatment decreased the water bound to the dietary fiber, which might increase the water transmission rate in the gelatinization system and accelerate the gelatinization process of starch (Wang et al., 2022).

Thermomechanical properties of HBF were presented in Fig. 1(G–I). An increase in PR substantially decreased the water absorption, development time and stability time, which might be due to the reduction of bran particles in HBF with the removal of the outer cortex. Jiang et al. (2021) had reported that bran had higher swelling power and water retention capacity than flour, which led to a higher water absorption. Compared with un-pearled HBF, the development time of the pearled HBF was significantly shortened, which might 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

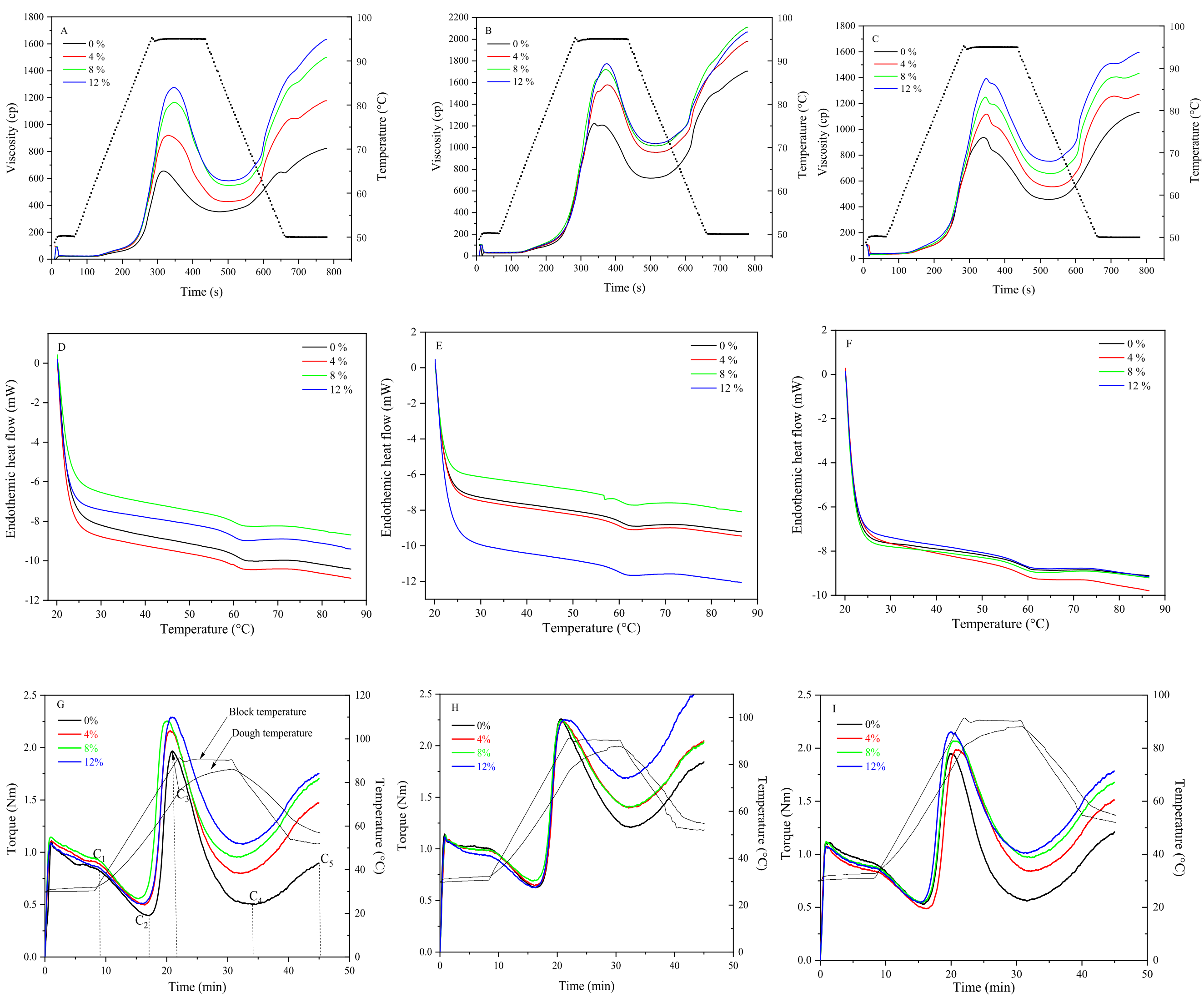

Fig. 1. RVA profiles (A-C: QB13, QB27 and BHB), DSC thermographs of gelatinization profiles (D-F: QB13, QB27 and BHB) and thermomechanical profiles (G-I: QB13, QB27 and BHB) of highland barley flour.

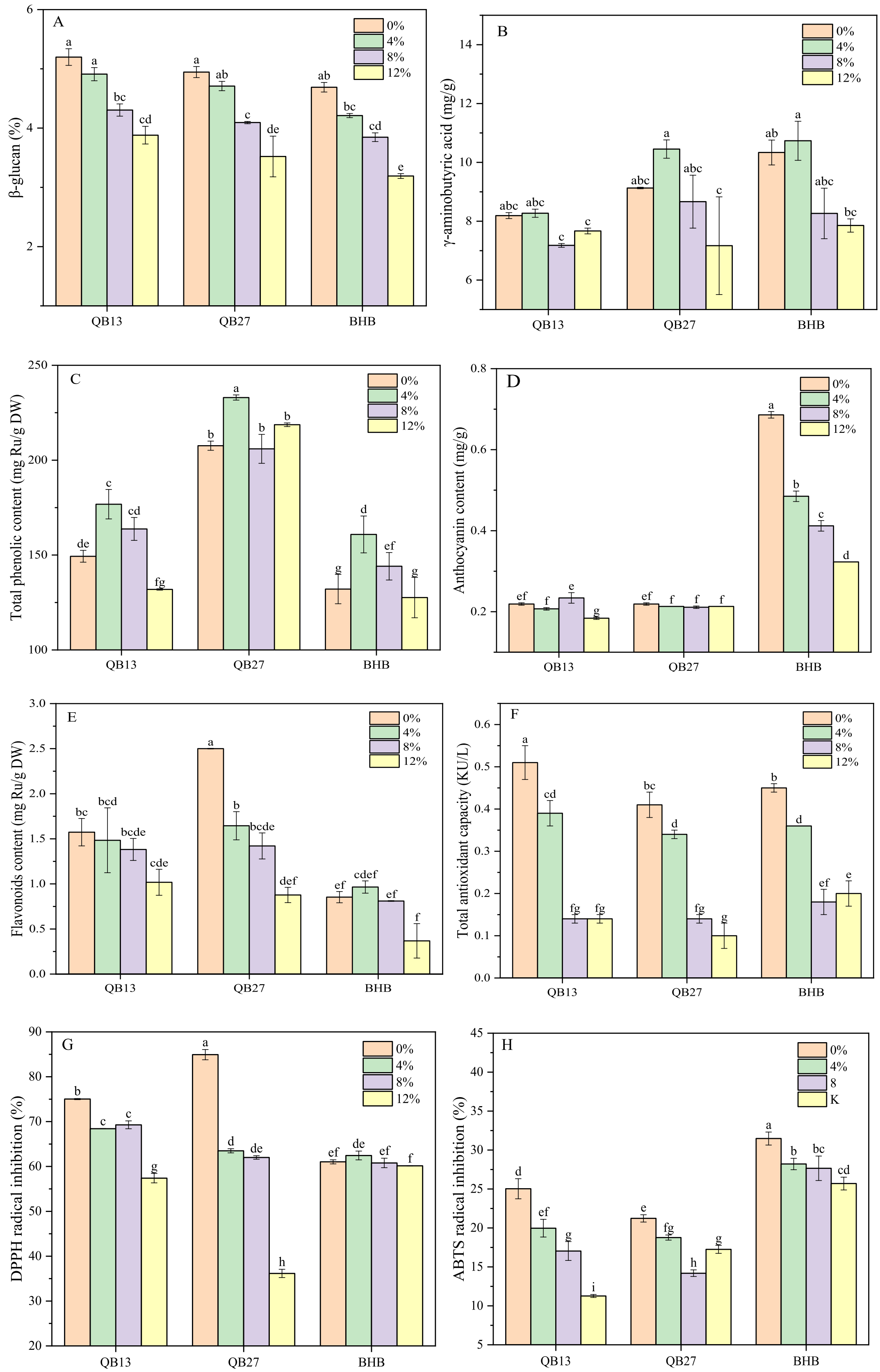

Fig. 2. Effect of pearling rate (PR) on β-glucan (A), γ-aminobutyric acid (B), total phenol content (C), anthocyanin (D), flavoloids content (E), total antioxidant capacity (F) and savenging effects on free radicals: DPPH radical(G), ABTS radical (H), hydroxyl radical (I) and superoxide radical (J) of highland barley flour. Footnote: Different lowercase letters indicate significantly different at level P ≤ 0.05.

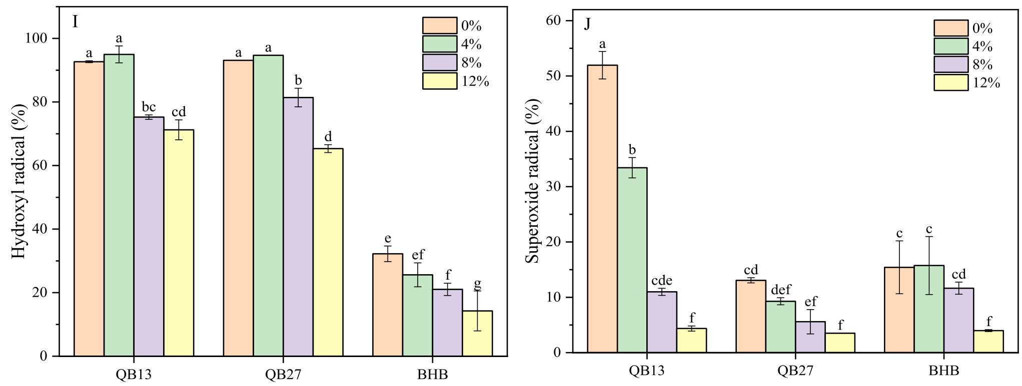

Fig. 2. (*continued*).

(Penella et al., 2008). Gomez et al. (2011) also observed an increase in development time when adding the extruded bran into wheat flour. 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 un-pearled 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. There was no significant difference in the softening degree of dough, and the value of setback increased with the increase of PR (Table S1). This might be explained by the fact that bran had an obstructing effect on the intermolecular rearrangement of starch after gelatinization (Xu et al., 2018). With the increase of PR, 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 (Table S1), indicating that pearling treatment could improve the cooking resistance of HBF.

3.5. *In vitro starch digestibility*

The content of SDS and RS were potent indicators of glycemic index of food. Previous studies have reported that the increase of SDS and RS had a positive impact on reducing the risk of cardiovascular and cerebrovascular diseases and improving the intestinal environment (Moza & Gujral, 2016). As shown in Table 2, a significant decrease in RDS and an increase in SDS was observed with the increase of PR, indicating pearling treatment could slow down the digestion rate of starch, which might be due to the partial gelatinization and recrystallization of starch. The content of RS was the highest when the PR of QB27 and BHB was 4 %, while 8 % of QB13. The result could be accounted for by variations in distribution amongst the varieties. Zeynep and Dilara (2019) reported that starch source, granule structure and amylose-amylopectin ratio, etc. could influence the starch resistance to digestion. Whereas, downward trends were observed when the PR exceeds the value. Overall, pearling treatment decreased the total starch HI and GI (Table 2), which might be related to the protein, fat, phenols and other active substances in HB that could inhibit the digestion and absorption of starch by blocking the adsorption site of digestive enzymes or interacting with digestive enzymes (Ye et al., 2018). Yu et al. (Yu et al., 2018) 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.

3.6. *Antioxidant properties*

Several methods had 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. 2 C- D). The HBF with 4 % PR 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 fact that the phenols were mainly concentrated in aleurone layer, which was generally removed with the increase of PR. Moreover, BHB with 0 % PR had a significantly higher level of anthocyanin than all the other samples. TPC had a direct effect on total antioxidant capacity (TAC), but the trend of TAC of HBF was inconsistent with that of TPC, which might be influenced by other antioxidant substances. There was no significant difference in the content of flavonoids between QB13 and BHB (Fig. 2 E).

Table 2
Effect of pearling rate (PR) on digestive characteristics of highland barley flour.

Sample	PR (%)	RDS (%)	SDS (%)	RS (%)	HI (%)	GI (%)	
QB13	0		50.91 ± 0.53c	34.85 ± 0c	14.23 ± 0.53de	61.07 ± 6.64def	73.24 ± 3.65def
	4		43.88 ± 1.03d	33.38 ± 2.01c	22.74 ± 0.98b	57.42 ± 2.18f	71.24 ± 1.20f
	8		41.12 ± 2.95d	33.28 ± 3.84c	25.59 ± 0.88a	62.23 ± 2.49cdef	73.88 ± 1.36cdef
	12		37.10 ± 0.61e	50.38 ± 1.02a	12.53 ± 0.41 fg	60.37 ± 1.71def	72.86 ± 0.94def
QB27	0		76.13 ± 0.17a	10.80 ± 0.67 g	13.07 ± 0.5ef	68.16 ± 1.66bcde	77.13 ± 0.91bcde
	4		65.84 ± 1.76b	19.51 ± 2.33ef	14.65 ± 0.57 cd	63.24 ± 0.05cdef	74.43 ± 0.03cdef
	8		63.73 ± 0.7 0b	25.98 ± 0.1 0d	10.30 ± 0.60 h	59.38 ± 4.96ef	72.31 ± 2.72ef
	12		42.76 ± 3.51d	48.44 ± 3.12ab	8.80 ± 0.38i	59.43 ± 4.39ef	72.34 ± 2.41ef
BHB	0		73.08 ± 1.02a	16.31 ± 1.39ef	10.61 ± 0.36 h	85.02 ± 4.46a	86.39 ± 2.45a
	4		65.9 ± 0.27b	18.17 ± 0ef	15.92 ± 0.27c	77.56 ± 6.75ab	82.29 ± 3.71ab
	8		62.24 ± 1.53b	26.46 ± 1.92d	11.31 ± 0.39gh	71.54 ± 5.16bc	78.99 ± 2.84bc
	12		50.60 ± 2.09c	43.98 ± 3.36b	5.42 ± 1.27j	69.57 ± 2.18bcd	77.91 ± 1.2bcd

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 ($P \leq 0.05$).

Pearling treatment significantly decreased the flavonoids content of QB27, while pearling did not significantly change that of QB13 and BHB. TAC showed a negative correlation with PR, which was consistent with the trend of antioxidant active substances such as anthocyanin and β-gluten (Fig. 2 F). The inhibition rates of DPPH decreased by 17.63 %, 48.77 % and 0.9 % of QB13, QB27 and BHB, respectively (Fig. 2 G). 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 PR (12 %). Similarly, significant increases appeared in the inhibition rates of OH − and O_2− (Fig. 2 H- J). The changes of these radicals were consistent with the results obtained for total antioxidant capacity and some antioxidant substances in this study. It has been reported that the phenolic extracts from the husk and bran presented higher total FRAP, ABTS and DPPH values than other parts of millet, which could be explained by the higher contents of phenolic compounds such as p-coumaric acid and ferulic acid (Zhang et al., 2021).

3.7. Pearling improved the quality of highland barley noodles

PR significantly altered the cooking characteristics of noodles except the cooking loss. When the PR was 4 %, the water absorption of highland barley noodles (HBN) decreased sharply, which was related to the fact that the pearling reduced the dietary fiber content and damaged starch in HBF (Fig. 3 A). Importantly, the break rate of QB13, QB27 and BHB (PR 0 %) obviously decreased from 51.7 %, 53.3 % and 38.3 % (PR 0 %) to 35.0 %, 15.0 % and 6.7 % (PR 12 %) respectively, indicating an improvement of noodles quality. The cooking time of QB13, QB27 and BHB were 2.25 min, 3.15 min and 3.15 min when the PR was 12 %, which was the shortest cooking time (Fig. 3 B). The shorter cooking time as well as the lower water uptake meant good noodle quality. Hardness increased with the increase of PR, which was probably due to the decrease in water absorption causing a decrease in the softness of the dough. The highest hardness in three HBN resulted in the highest resilience. On the other hand, PR significantly increased the gumminess and chewiness of QB27 and BHB (Fig. 3 C- F). The increment might be related to the absence of fiber, which could compete with proteins in water (Na-Nakorn et al., 2021). Thereby, a more compact and denser protein network was formed. However, the effect of PR on QB13 was not statistically significant. The higher tensile strength and the longer tension distance presented a compact structure and better cooking characteristics. Three cultivars all showed the highest tensile strength and the longest tension distance at 12 % PR (Fig. 3 G- H), which meant pearling could improve the cooking characteristics.

3.8. Associations between nutrition and processing qualities

PLS-DA model was applied to analyze the effect of PR on final HBN quality. As shown in Fig. 4 A, 12 % PR more significantly changed the quality of noodles than 4 % and 8 % PR. Variable Importance on Projection (VIP) values were calculated to estimate the importance of each variable in the PLS model. R2 and Q2 of PLS-DA cross validation were 0.93 and 0.82, respectively, which indicated that the PLS-DA model was valid and not overfitted, therefore validated the VIP values obtained from this model. Variables with VIP > 1 were the most relevant variable of noodle quality. VIP value (Fig. 4 B) indicated that the improvement of pearling on HBN quality was attributed to the alteration of resilience, hardness, tension distance (TD), breaking rate (BR) and water absorption (WA) of the final noodles. Therefore, we further analyzed the relationship between the indexes with VIP > 1 and the nutritional or processing qualities, aiming to investigate the possible mechanism that pearling improved the quality of noodles. As shown in Fig. 4 C-D, resilience was significantly positively correlated ($r > 0.8$, $P \leq 0.05$) with the content of SDS, and negatively correlated ($r > 0.8$, $P \leq 0.05$) with the content of IDF. The hardness of HBN has a highly significant correlation ($P \leq 0.05$) with development time. TD showed high correlation ($r > 0.8$, $P \leq 0.05$) with the content of dietary fiber, Ca, fat, P, β- glucan, superoxide value, development time, setback value, △H, peak viscosity, trough viscosity and breakdown. BR might decrease by dietary fiber, Ca, β- glucan, development time and △H and increase by setback value, peak viscosity and breakdown ($r > 0.8$, $P \leq 0.05$). High correlations ($r > 0.8$, $P \leq 0.05$) were also found between WA of HBN with stability time. Of note was that just SDS performed a strong positive correlation with the resilience (performed the highest VIP value) of noodles, which might imply a prospect of SDS in the improvement of noodles quality. Interestingly, (Mingming et al., 2021) had employed SDS to increase the quality of wheat noodles. Indeed, the formation of SDS might be attributed to the temperature alteration accompanying pearling, the later might cause the starch suffering fractional gelatinization which might facilitate conversion of the internal structure in the amorphous region and recrystallization of the starch (Anderson et al., 2002). With the SDS content increases, the water absorption rate of the corresponding noodles decreases, and the hardness and resilience were significantly increased. The texture of noodles was mainly related to high molecular weight glutenin and low molecular weight glutenin form aggregates through cross-linking in the dough sheet. The starch was embedded into the skeleton and form a stable network. Starch absorbed water and occupied a large part of the gluten network, which made it obviously affect the quality of noodles (Liu et al., 2021). During the cooking period, starch granules expanded and gelatinized along with the dissolution of starch molecules, while higher content of SDS meant a higher contents of long chains, which could make the structure not easy to break during gelatinization, and maintain the starch granule structure of gelatinized starch, thus improve the noodles quality.

4. Conclusion

Three HB grains of pearled and un-pearled were investigated as well as HBF and HBF noodles to evaluate the effects of pearling on the final noodles quality. 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 GABA, total phenol of HB and made ash, fat, TDF, IDF and Ions (i.e., calcium, iron and phosphorus) lose at the same time. Furthermore, pearling improved the gelatinization viscosity and the thermomechanical properties of HBF dough. Thus, it could be said that pearling was a successful method to improve the processing properties. Besides, PLSDA model revealed the fact that the improvement of pearling on HBN quality was attributed to the alteration of resilience, hardness, tension distance (TD), breaking rate (BR) and water absorption (WA) of the final noodles. Interestingly, just SDS performed a strong positive correlation with the resilience (performed the highest VIP value) of noodles, which might imply a prospect of SDS in the improvement of noodles quality. Thus, extra work needed to be conducted to investigate the potential function of SDS in future. In conclusion, this study indeed confirmed the promoting effect of pearling on HBF processing and cooking qualities.

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CRediT authorship contribution statement

Qianna Zheng: Conceptualization, Methodology, Software, Writing – original draft, Writing – review & editing, Visualization. **Zheng Wang:** Data curation, Formal analysis, Writing – original draft. **Feiyang Xiong:** Visualization, Investigation. **Yan Song:** Software, Validation. **Guoquan Zhang:** Conceptualization, Supervision, Project administration.

Declaration of Competing Interest

The authors declare that they have no known competing financial

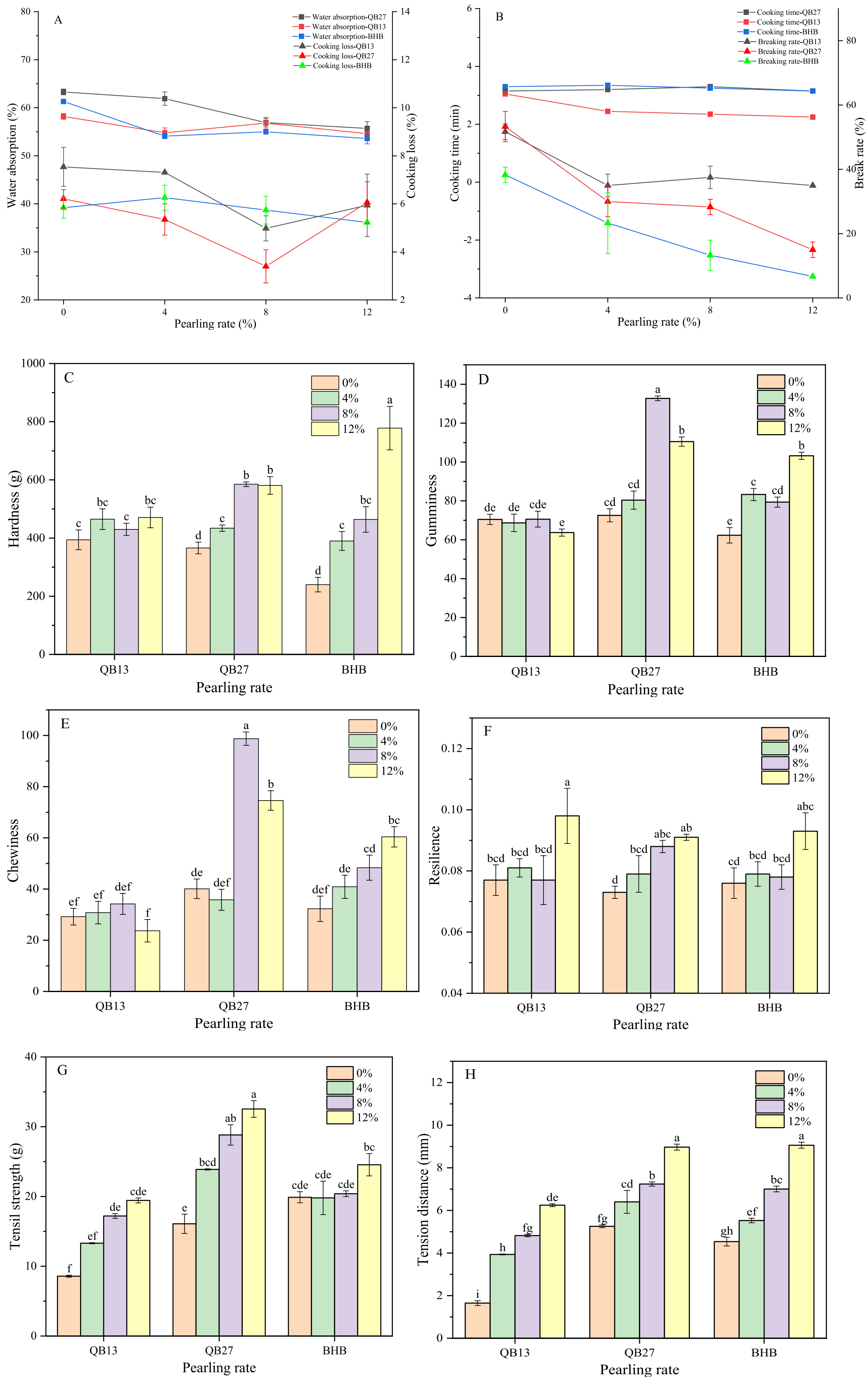

Fig. 3. Effect of pearling rate (PR) on highland barley noodles. (A) Water absorption and cooking loss; (B) Cooking time and breaking rate; (C) Hardness; (D) Guminess; (E) Chewiness; (F) Resilience; (G) Tensil strength; (H) Tension distance. Footnote: Different lowercase letters indicate significantly different at level P ≤ 0.05.

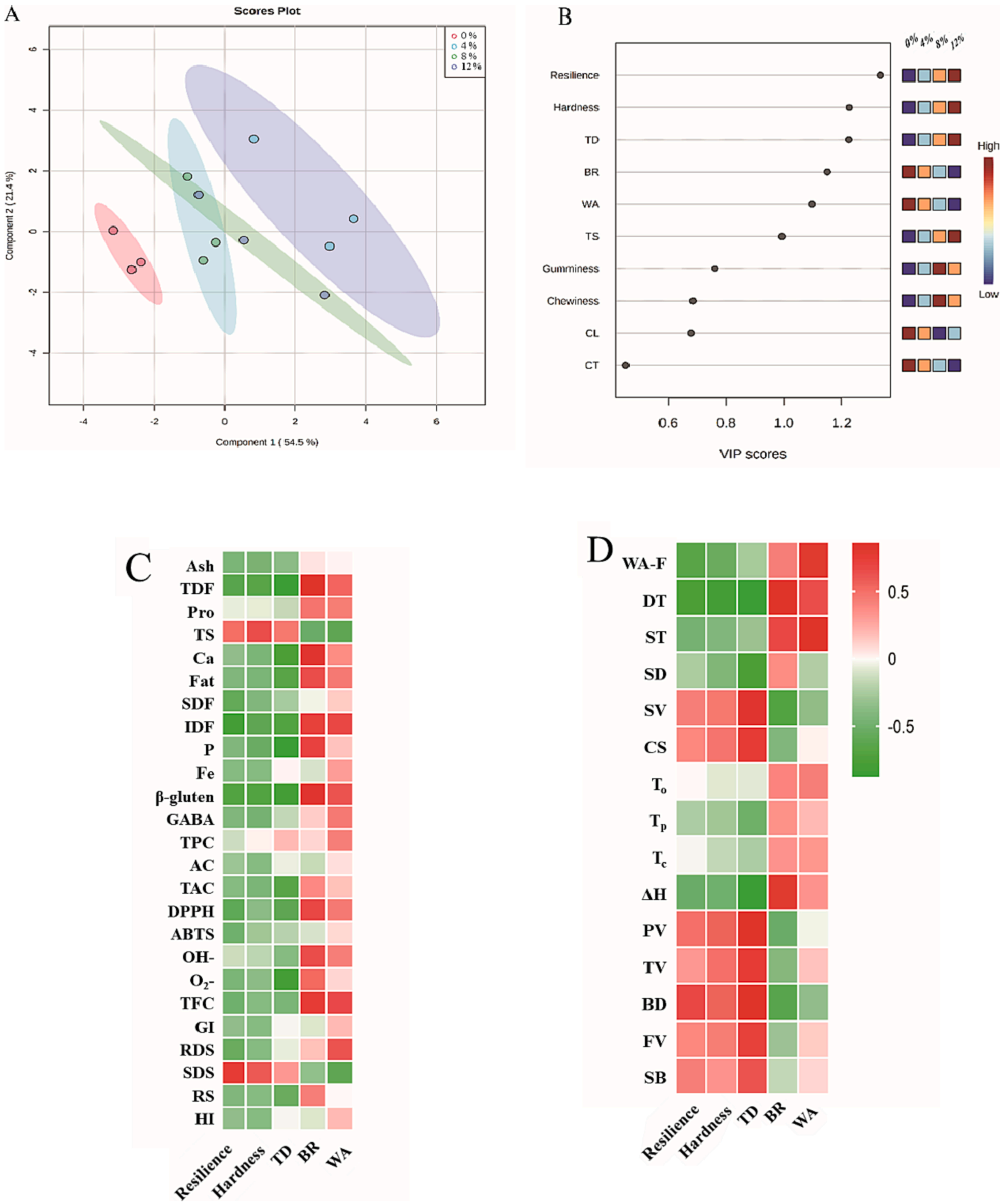

Fig. 4. Associations between nutrition, processing qualities of highland barley flour and highland barley noodles (HBN) qualities. (A) PLSDA score plot; (B) VIP scores in PLSDA; (C) Correlation analysis between nutrition content and HBN qualities; (D) Correlation analysis between processing qualities and HBN qualities. Footnote: TDF, total dietary fibre; Pro, protein content; TS, total starch; SDF, soluble dietary; IDF, insoluble dietary fibre; GABA, γ-aminobutyric acid; TPC, total phenol content; AC, anthocyanin content; TAC, total antioxidant capacity; TFC, total flavonoids content; GI, Glycemic index; RDS, rapidly digestible starch; SDS, slowly digestible starch; RS, resistant starch; HI, hydrolysis index; WA-F, water absorption of HBF; DT, development time; ST, stability time; SD, softening degree; SV, setback value; CS, cooking stability; To, onset temperature; Tp, peak temperature; Tc, cease temperature; ΔH, gelatinization enthalpy; PV, peak viscosity; TV, trough viscosity; BD, breakdown; FV, final viscosity; SB, setback viscosity; TD, tension distance; BR, breaking rate; WA, water absorption of HBN.

interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The authors are unable or have chosen not to specify which data has been used.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.fochx.2023.100596.

References

Allan, M. C., Rajwa, B., & Mauer, L. J. (2018). Effects of sugars and sugar alcohols on the gelatinization temperature of wheat starch. *Food Hydrocolloids, 84*, 593–607. https://doi.org/10.1016/j.foodhyd.2018.06.035

Alvarez-Ramirez, J., Vernon-Carter, E. J., Carrera-Tarela, Y., Garcia, A., & Roldan-Cruz, C. (2020). Effects of candelilla wax/canola oil oleogel on the rheology, texture, thermal properties and in vitro starch digestibility of wheat sponge cake bread. *LWT-Food Science and Technology, 130*, Article 109701. https://doi.org/10.1016/j.lwt.2020.109701

Anderson, A. K., Guraya, H. S., James, C., & Salvaggio, L. (2002). Digestibility and pasting properties of rice starch heat-moisture treated at the meltin temperature (T-m). *Starch-Starke, 54*(9), 401–409. https://doi.org/10.1002/1521379x(200209)54:9<401::aid-star401>3.0.co;2-z

Ashraf, Z. U., Shah, A., Gani, A., Gani, A., & Noor, N. (2021). Nanoreduction as a technology to exploit β-Glucan from cereal and fungal sources for enhancing its nutraceutical potential. *Carbohydrate Polymers, 258*, Article 117664. https://doi.org/10.1016/j.carbpol.2021.117664

Bai, Y. P., Zhou, H. M., Zhu, K. R., & Li, Q. (2021). Effect of thermal processing on the molecular, structural, and antioxidant characteristics of highland barley β-glucan. *Carbohydrate Polymers, 271*(2), Article 118416. https://doi.org/10.1016/j.carbpol.2021.118416

Bhatty, R. S. (1999). The potential of hull-less barley. *Cereal Chemistry, 76*(5), 589–599. https://doi.org/10.1094/CCHEM.1999.76.5.589

Boita, E., Oro, T., Bressiani, J., Santetti, G. S., Bertolin, T. E., & Gutkoski, L. C. (2016). Rheological properties of wheat flour dough and pan bread with wheat bran. *Journal of Cereal Science, 71*, 177–182. https://doi.org/10.1016/j.jcs.2016.08.015

Brier, N. D., Hemdane, S., Dornez, E., Gomand, S. V., Delcour, J. A., & Courtin, C. M. (2015). Structure, chemical composition and enzymatic activities of pearlings and bran obtained from pearled wheat (*Triticum aestivum L.*) by roller milling. *Journal of Cereal Science, 62*, 66–72. https://doi.org/10.1016/j.jcs.2014.12.009

Brouns, F., Hemery, Y., Anson, R. P., & Mateo, N. (2012). Wheat aleurone: Separation, composition, health aspects, and potential food use. *Critical Reviews in Food Science and Nutrition, 52*, 553–568. https://doi.org/10.1080/10408398.2011.589540

Chung, H. J., Jang, S. H., Cho, H. Y., & Lim, S. T. (2009). Effects of steeping and anaerobic treatment on GABA (γ-aminobutyric acid) content in germinated waxy hull-less barley. *LWT-Food Science and Technology, 42*(10), 1712–1716. https://doi.org/10.1016/j.lwt.2009.04.007

Enujiugha, V. N., Talabi, J. Y., Malomo, S. A., & Olagunju, A. I. (2012). DPPH radical scavenging capacity of phenolic extracts from African Yam Bean (*Sphenostylis stenocarpa*). *Food and Nutrition Sciences, 3*(1), 7–13. https://doi.org/10.4236/fns.2012.31002

Gamel, T. H., & Abdel-Aal, E.-S.-M. (2012). Phenolic acids and antioxidant properties of barley wholegrain and pearling fractions. *Agricultural and Food Science, 21*(2), 118–131. https://doi.org/10.23986/afsci.4727

Gomez, M., Jimenez, S., Ruiz, E., & Oliete, B. (2011). Effect of extruded wheat bran on dough rheology and bread quality. *LWT-Food Science and Technology, 44*(10), 2231–2237. https://doi.org/10.1016/j.lwt.2011.06.006

Guedes, A. C., Amaro, H. M., Giao, M. S., & Malcata, F. X. (2013). Optimization of ABTS radical cation assay specifically for determination of antioxidant capacity of intracellular extracts of microalgae and cyanobacteria. *Food Chemistry, 138*(1), 638–643. https://doi.org/10.1016/j.foodchem.2012.09.106

Hagberg, S. (1960). A rapid method for determining alpha-amylase activity. *Cereal Chemistry, 37*(2), 218–222. https://www.cerealsgrains.org/publications/cc/backissues/1960/Documents/chem37_218.pdf.

Jiang, F., Ren, Y., Du, C., Nie, G., Liang, J., Yu, X., & Du, S. K. (2021). Effect of pearling on the physicochemical properties and antioxidant capacity of quinoa (*Chenopodium quinoa Willd.*) flour. *Journal of Cereal Science, 102*. https://doi.org/10.1016/j.jcs.2021.103330

Jin, W. J., Kim, M. J., & Kim, K. S. (2014). Utilization of barley or wheat bran to bioconvert glutamate to γ-aminobutyric acid (GABA). *Journal of Food Science, 78*(9), C1376-C1382. doi: 10.1111/1750-3841.12234.

Limberger-Bayer, V. M., Francisco, A. D., Chan, A., Oro, T., Ogliari, P. J., & Barreto, P. L. M. (2014). Barley β-glucans extraction and partial characterization. *Food Chemistry, 154*, 84–89. https://doi.org/10.1016/j.foodchem.2013.12.104

Lin, S., Guo, H., Gong, J., Lu, M., Lu, M. Y., Wang, L., … Wu, D. T. (2018). Phenolic profiles, β-glucan contents, and antioxidant capacities of colored Qingke (Tibetan hulless barley) cultivars. *Journal of Cereal Science, 69–75*. https://doi.org/10.1016/j.jcs.2018.04.001

Liu, L., Wang, X., Ying, L., & Sun, C. (2015). Postprandial differences in the amino acid and biogenic amines profiles of impaired fasting glucose individuals after intake of highland barley. *Nutrients, 7*(7), 5556–5571. https://doi.org/10.3390/nu7075238

Liu, S., Liu, Q., Li, X., Obadi, M., & Xu, B. (2021). Effects of dough resting time on the development of gluten network in different sheeting directions and the textural properties of noodle dough. *LWT-Food Science and Technology, 141*, Article 110920. https://doi.org/10.1016/j.lwt.2021.110920

Mehfooz, T., Ali, T. M., Arif, S., & Hasnain, A. (2017). Effect of barley husk addition on rheological, textural, thermal and sensory characteristics of traditional flat bread (chapatti). *Journal of Cereal Science, 79*, 376–382. https://doi.org/10.1016/j.jcs.2017.11.020

Mingming, Q., Xueyuan, W., & Chengye, M. (2021). The properties of pea slowly digestible starch noodles. *IOSR Journal of Agriculture and Veterinary Science, 14*, 25–28. https://iosrjournals.org/iosr-javs/papers/Vol14-issue3/Series1/C1403012528.pdf.

Moza, J., & Gujral, H. S. (2016). Starch digestibility and bioactivity of high altitude hulless barley. *Food Chemistry, 194*, 561–568. https://doi.org/10.1016/j.foodchem.2015.07.149

Na-Nakorn, K., Hamaker, B. R., & Tongta, S. (2021). Physicochemical and rheological properties of cooked extruded reformed rice with added protein or fiber. *LWT-Food Science and Technology, 151*(1), Article 112196. https://doi.org/10.1016/j.lwt.2021.112196

Onipe Oluwatoyin, O., Daniso, B., & Jideani Afam, I. O. (2015). Composition and functionality of wheat bran and its application in some cereal food products. *International Journal of Food Science and Technology, 50*, 2509–2518. https://doi.org/10.1111/ijfs.12935

Penella, J. S., Collar, C., & Haros, M. (2008). Effect of wheat bran and enzyme addition on dough functional performance and phytic acid levels in bread. *Journal of Cereal Science, 48*, 715–721. https://doi.org/10.1016/j.jcs.2008.03.006

Rosell, C. M., Santos, E., & Collar, C. (2010). Physical characterization of fiber-enriched bread doughs by dual mixing and temperature constraint using the Mixolab. *European Food Research and Technology, 231*(4), 535–544. https://doi.org/10.1007/s00217-010-1310-y

Shao, Y., Tsai, M.-H., He, Y., Chen, J., & Wilson, C. (2019). Reduction of falling number in soft white spring wheat caused by an increased proportion of spherical B-type starch granules. *Food Chemistry, 284*, 140–148. https://doi.org/10.1016/j.foodchem.2019.01.006

Wang, C. C., Yang, Z., Xing, J. J., Guo, X. N., & Zhu, K. X. (2022). Effects and underlying mechanisms of insoluble dietary fiber and ferulic acid on the crumb structure of steamed bread. *Food Hydrocolloids, 125*, Article 107448. https://doi.org/10.1016/j.foodhyd.2021.107448

Xu, X., Xu, Y., Wang, N., & Zhou, Y. (2018). Effects of superfine grinding of bran on the properties of dough and qualities of steamed bread. *Journal of Cereal Science, 81*, 76–82. https://doi.org/10.1016/j.jcs.2018.04.002

Yang, X. J., Dang, B., & Fan, M. T. (2018). Free and bound phenolic compound content and antioxidant activity of different cultivated blue highland barley varieties from the Qinghai-Tibet plateau. *Molecules, 23*, 879. https://doi.org/10.3390/molecules23040879

Ye, J., Hu, X., Luo, S., McClements, D. J., Liang, L., & Liu, C. (2018). Effect of endogenous proteins and lipids on starch digestibility in rice flour. *Food Reasearch International, 106*, 404–409. https://doi.org/10.1016/j.foodres.2018.01.008

Yu, W., Zou, W., Dhital, S., Wu, P., Gidley, M. J., Fox, G. P., & Gilbert, R. G. (2018). The adsorption of α-amylase on barley proteins affects the in vitro digestion of starch in barley flour. *Food Chemistry, 241*, 493–501. https://doi.org/10.1016/j.foodchem.2017.09.021

Zeynep, T. C., & Dilara, N. E. (2019). Resistant starch. *In Encyclopedia of Food Chemistry, 571–575*. https://doi.org/10.1016/B978-0-08-100596-5.22407-4

Zhang, M., Xu, Y., Xiang, J., Zheng, B., Yuan, Y., Luo, D., & Fan, J. (2021). Comparative evaluation on phenolic profiles, antioxidant properties and α-glucosidase inhibitory effects of different milling fractions of foxtail millet. *Journal of Cereal Science, 99*, Article 103217. https://doi.org/10.1016/j.jcs.2021.103217

Zhang, R., Li, Q., Zhu, L., Liu, C., & Li, Y. X. (2018). Study on the γ-Aminobutyric acid (GABA) in highland barley monascus beer. *Journal of Food Science and Biotechnology, 37*, 1148–1152. https://doi.org/10.3969/j.issn.1673-1689.2018.11.005

Zhao, H., Wei, F., Dong, J., Jian, L., Jian, C., Shan, L., … Kong, W. (2008). Evaluation of antioxidant activities and total phenolic contents of typical malting barley varieties. *Food Chemistry, 107*(1), 296–304. https://doi.org/10.1016/j.foodchem.2007.08.018

Zheng, Y., Chai, Z., Kong, X., Chen, S., Ye, X., & Tian, J. (2022). Effect of annealing treatment on the physicochemical properties and enzymatic hydrolysis of different types of starch. *Food Chemistry, 403*, Article 134153. https://doi.org/10.1016/j.foodchem.2022.134153