Effects of roasting on barley β-glucan, thermal, textural and pasting properties

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Abstract

Different hulled barley cultivars were subjected to roasting in hot sand (280°C) and the effects on β-glucan solubility, physicochemical, thermal and pasting properties were studied. Grain hardness, bulk density, L/B ratio and thousand kernel weight were significantly lowered upon roasting. The geometric mean diameter significantly increased, the CIE L* a* b* colour values a* and b* significantly increased while L* and ΔE were significantly decreased. The roasted barley flour had significantly higher water absorption, water solubility and oil absorption capacity. The cultivars DWR-28 and RD-2508 had the highest total β-glucan content and roasting affected in different extent the total β-glucan content and extractability depending on the cultivars. Roasting significantly increased the insoluble β-glucan with a concomitant decrease in the amount of soluble β-glucan. In addition, roasting significantly affected the pasting and thermal properties of the flours, together with an increase in the damage starch content. Therefore, roasting induces large variations in the ratio soluble to insoluble β-glucan content and also in the physical characteristics of a range of hulled barley cultivars.

Keywords: Barley, β-glucan, Damage starch, roasting

1. Introduction

Barley (Hordeum vulgare L.) is an ancient and important cereal grain and occupies about 9.4% of the total area under cereal production (FAO, 2007). The predominant type of cultivated barley is hulled, having a tough fibrous husk, which is used as a malting and brewing grain. The other type is the hulless or naked barley in which the hull is easily removed during threshing similar to wheat. In the Western world, barley has been mainly used for feed and alcohol production. However, its high content in dietary fiber has motivated the interest in increasing the consumption of barley based foods. The use of barley as a human food should be encouraged because it has one of the highest levels (2-10%) of β-glucan. The β-glucans behave as a peculiar fiber because are present in both soluble and insoluble forms and around 54% of total β-glucan is soluble in water and classified as soluble fiber (Anker-Nilssen et al., 2008). Therefore, β-glucans have the health benefits associated to insoluble fibers like ability to relieve constipation. Soluble β-glucans are recognized as healthy polymers due to their benefits in cholesterol lowering and glycemic index reduction, effects that are beneficial in the prevention and management of
various diet related diseases, such as diabetes and cardiovascular disease (Jenkins et al., 2000).

A simple way of increasing the consumption of barley is by including barley in food products with attractive sensory characteristics. However, the physiological effect of the food supplemented with barley largely depends on the barley variety and the processing treatments applied to the grains (Izydorczyk et al., 2000). Roasting is a simple and convenient process that uses dry heat for short periods of time for improving grain characteristics. Roasted grains exhibit improved texture, enhanced crispiness and volume due to puffing (Hoke et al, 2007). Roasting also improves colour, extends shelf life, enhances flavor and reduces the antinutrient factors of cereals and legumes (Gahalawat and Sehgal, 1992). Moreover, roasting of grains leads to the gelatinization of starch and denaturation of proteins thus improve the digestibility of cereals and legumes (Caldwell et al, 2000). However, no information is available about the effect of roasting on thermal, textural and pasting properties of barley and its effect on the β-glucan content and the ratio of the two types of β-glucans.

It is likely that the thermal treatment of the barley grains modifies the characteristics of the starches and the content and properties of the β-glucans, which have great influence in determining the utilization of barley for food purposes. The objectives of the present investigation were to empirically investigate the changes during roasting of barley grains, regarding the changes in physico-chemical, textural, pasting and thermal properties of common hulled barley cultivars. Special attention was paid to the variation in total, soluble and insoluble β-glucan content upon roasting hulled barley from different cultivars.

2. Material and methods

Common hulled barley cultivars (PL-172, PL-426, RD-2503, RD-2508, RD-2035, RD-2052, RD-2552 (six rowed) and DWR-28 (two rowed) were procured from Central State Seed Farm, Sriganganagar, Rajasthan, India. All chemicals used were of analytical grade, β-glucan and starch damage assay kit were provided by Megazyme International, Ireland and Termamyl 120L (Thermostable α-amylase) was procured from Novozyme, Denmark.
Each test was performed in triplicates on dry weight basis. The Milli Q water (Millipore, France) was used in all analytical tests.

2.1 Roasting of barley:

Hulled barley (400g) at a moisture content of 10% was roasted in hot sand at 280±5°C for 20 seconds. Roasted barley after cooling was dehusked in a rice polisher (Paras and Gujral, 2009) and ground in the Newport Super Mill (Newport, Australia) to pass through 60 (BSS) sieve to obtain roasted barley flour.

2.2 Physical characteristics barley:

The bulk density expressed as gram per liter (g/l) was evaluated by measuring the weight of known volume of control and roasted barley sample. Length, breadth and width of control and roasted grains were measured by the help of Vernier-caliper.

Puffing index = bulk density of control/ bulk density of roasted barley.

Geometric mean diameter (GMD) of control and roasted samples were measured using Vernier Caliper. Geometric mean of the spatial dimensions (length, breadth and thickness) was calculated as equivalent diameter = \((L \times B \times T)^{1/3}\)

2.3 Hardness of control and roasted grains

The hardness of the dehusked grain (control and roasted) was determined on a texture analyzer (Model TA-HDi, Stable Microsystem, Surrey, U.K). The barley grains (control and roasted) were compressed 1mm using a probe with 25mm diameter. A 50 kg load cell was used and the pre, post test and test speeds were 1.5, 10 and 1mm sec\(^{-1}\), respectively.

2.4 Colour of flour

Colour measurement of flour was carried using a Hunter Colorimeter fitted with optical sensor (Hunter Associates Laboratory Inc. Restan VA., USA ) on the basis of CIE L*, a*, b* colour system. The colour difference (∆E) was calculated as:

\[ \Delta E = [(\Delta L^*) + (\Delta a^*) + (\Delta b^*)]^{1/2} \]

2.5 Water absorption capacity, water solubility index and oil absorption

Water absorption capacity of flour (control and roasted) was measured by the centrifugation method of Anderson et al. (1969). Flour (3 g) was dispersed in 25 ml of distilled water taken in pre-weighed centrifuge tubes. The dispersion was stirred for 10 min followed by centrifugation for 25 min at 3000g. The supernatant was collected by allowing
the tube to stand inverted for 10 min. The supernatant obtained was dried in hot air oven for 24 h at 105°C. The results were expressed as % water solubility index.

The oil absorption capacity was determined according to method of Lin et al. (1974). Flour (0.5g) was mixed with 10 ml of refined oil (Soybean Refined Oil, Fortune brand, India) in pre-weighed centrifugal tube and vortexed for 10 min. The tubes were centrifuged for 25 min at 3000g. The oil was drained off by inverting for 10 min and centrifuge tubes were weighed.

2.6 Quantification of total, insoluble and soluble β-glucan

The total, insoluble and soluble β-glucan was quantified according to the method reported by McCleary and Glennie (1985) using ‘β-glucan assay kit’ (Megazyme International Ireland Ltd., Wicklow, Ireland). For mixed linkage total β-glucan, flour (0.5g on dry weight) was taken in polypropylene tubes and 1ml of ethanol (50% v/v) was added followed by sodium phosphate buffer (5ml, 20mM, pH 6.5) and mixed well with the help of vortex mixer. The tubes were incubated in boiling water bath and cooled to 40°C. Enzyme, lichenase (10U) was added, tubes were incubated for 1 h at 40°C with intermediate vortex mixing. The volume of each tube was adjusted to 30 ml with water, the content of tubes was mixed thoroughly, and centrifuged at 1000g for 10 min. Aliquot (0.1ml), was transferred in three test tubes. Sodium acetate buffer (0.1 ml, 50mM, pH 4.0) was added to one of these tubes (reaction blank) and in rest two tubes 0.2U β-glucosidase was added and incubated at 40°C for 15 min. After incubation, 3.0 ml glucose oxidase proxidase determine reagent was added in all tubes and incubated at 40°C for 20 min. The absorbance was noticed at 510 nm by spectrophotometer (Shimadzu, UV-2450, Kyoto, Japan). Standard glucose solution was used as standard and calculation carried out.

For determination of water soluble β-glucan flour was suspended in 10 ml aqueous ethanol (80% v/v) and incubated in steam water bath for 5 min to inactivate enzymes. After cooling the tubes to room temperature, centrifugation was done at 12000g for 10 min and ethanol drained off. The pellet was suspended in 10 ml water and incubated at 65°C for 30 min, followed by centrifugation at 6000g for 10 min. The supernatant was recovered and pellet was further extracted with 10 ml and ultimately with 5 ml water. The supernatant obtained in each step were pooled and estimated for soluble β-glucan as described by McCleary and Glennie (1985). The β-glucan in residues was defined as insoluble β-glucan.
2.7 β-glucan extractability

Extraction of β-glucan was carried out as reported by Bhatti (1995), barley flour (10g) mixed with NaOH and extracted for 1h at room temperature and further centrifuged at 6000g (REMI, C 24, Mumbai, India) for 15 min. The residue was again extracted with NaOH for 1h and centrifuged at 6000g for 15 min. The supernatant were pooled and pH adjusted to 6.5 with HCl. Calcium chloride (70 mg/100 ml) and Termamyl 120L (0.1 ml/100ml) was added. The contents were incubated at 96°C for 1 h with shaking and suspension was cooled to room temperature (25°C) and the pH adjusted to 4.5 with HCl. The supernatant was again centrifuged at 6000g for 15 min and the pellet discarded. Ethanol was added to 50% final concentration and kept overnight at 4°C, centrifuged again at 6000g for 15 min. The crude gum was resuspended in water and washed with 50% ethanol twice, centrifuged again, the pellet was homogenized in water and freeze dried (Heto, LL 3000, Denmark).

2.8 Pasting properties

Pasting properties of flours (control and roasted) were studied using a Rapid Visco Analyzer (Newport Scientific Pty Ltd., Australia) using the Standard profile 1. Flour (3g on 14% moisture basis) was taken in the canister and 25 ml water was added. The suspension was mixed thoroughly with plastic paddle to prevent lump formation before RVA analysis that involved a heating step of 50 to 95°C at 6°C/min, a holding phase at 95°C for 5 min, a cooling step from 95°C to 50°C at 6°C/min and a holding phase at 50°C for 2 min. The peak viscosity, breakdown viscosity, final viscosity, setback viscosity, peak time and pasting temperature were reported.

2.9 Thermal properties

The thermal characteristics of barley flours (control and roasted) were analyzed using a Differential Scanning Calorimeter (DSC, Mettler Toledo, Switzerland) equipped with a thermal analysis data station and robotic device to handle the aluminum pan. The sample (5 mg, dry weight basis) was loaded into a 40 µl aluminum pan and distilled water was added (flour to distilled water ratio was 1:2.3). The sample was hermetically sealed and allowed to stand for 1 hr at room temperature before heating in DSC. The DSC analyzer was calibrated using indium and an empty aluminum pan was used as reference. The sample was heated at a rate of 10°C / min from 30 to 100 °C, onset temperatures (T₀), peak
temperature ($T_p$), endset temperature ($T_c$) and enthalpy of gelatinization ($\Delta H_{gel}$) were calculated automatically. The gelatinization range ($R$) was ($T_c - T_0$), the peak height index (PHI) was calculated by the ratio $\Delta H_{gel} / \Delta H_{gel}$. The degree of gelatinization (DG) was calculated as reported by Holm et al. (1988) and results were reported in percent degree of gelatinization.

$$\text{Degree of gelatinization} (\%) = \left[ 1 - \frac{\Delta H_{gel} \text{ of roasted sample}}{\Delta H_{gel} \text{ of control sample}} \right] \times 100$$

2.10 Damaged starch content

Starch damage was measured enzymatically using the ‘Starch Damage Assay Kit’ (Megazyme International Ireland Ltd., Wicklow, Ireland). The results were reported as % damage starch.

2.11 Statistical Analysis

Analysis of variance (ANOVA) was carried out and Fishers least significant difference (LSD) test was used to describe means with 95% confidence. The Pearson correlation coefficients were calculated by SPSS statistical software (SPSS Inc., Chicago, Illinois, USA) at a probability level of $p<0.05$.

3. Result and discussion

3.1. Effect of roasting on physical properties of barley

The thousand kernel weight (TKW) of roasted barley grain varied significantly ($p<0.05$) among the cultivars and ranged from 32.8 to 53.3 g (Table 1). The highest and the lowest TKW was observed for DWR-28 and PL-426, respectively. After roasting, the TKW was significantly ($p<0.05$) lowered in all the cultivars. The highest and the lowest decrease was observed in PL-426 and RD-2503, respectively (Table 1). Similar result was also reported by Mariotti et al. (2006) for puffed barley.

The bulk density of roasted barley significantly varied among cultivars also after roasting, being the bulk density significantly ($p<0.05$) lowered. The decrease in bulk density after roasting can be attributed to loss of integrity between starch-starch and starch-protein matrix and or due to the formation of spaces in starchy endosperm (Chandrasekhar and Chattopadhyay, 1990). The roasting of barley grain also significantly decreased the L/B ratio, the highest and lowest decrease was observed in PL-172 and RD- 2052 cultivar, respectively. A positive correlation ($R= 0.60$) was noticed between L/B ratio and bulk density of roasted barley.
The roasting of barley significantly increased the geometric mean diameter (GMD) likely due to expansion of grain derived from the disorganization of starchy endosperm and expansion of cavities present in endosperm or formation of spaces in endosperm (Mariotti et al., 2006). The puffing index, indicator of volume of puffed grain (Hoke et al., 2007), significantly varied among cultivars and ranged from 1.9 to 2.4. The highest puffing index was observed for RD-2552 and PL-172 while the lowest was observed for RD-2508 and RD-2052 cultivars. A negative correlation (R= -0.78) existed between the puffing index and bulk density of roasted barley.

3.2 Effect of roasting on grain hardness

The hardness is very important because energy requirement during milling depends upon the hardness of grain (Moss et al., 1980). The grain hardness is influenced by the size, direction of applied force, moisture content, chemical composition and heat treatment given to the grain (Mridula et al., 2007). The hardness of the dehusked roasted grain significantly varied among the cultivars, and it decreased significantly (p<0.05) as a consequence of the roasting. Decrease in hardness upon roasting was also reported by Murthy et al. (2008) for wheat. This effect could be attributed to the fact that surface gelatinization of starch took place and fissures developed on the grain upon further heating, resulted in the reduced hardness (Mridula et al., 2008).

3.3 Effect of roasting on colour characteristics of flour

Color parameters were significantly different among cultivars, and roasting or thermal treatment affected significantly the color of the flour (Table 1). The L* value indicates the lightness, 0-100 representing dark to light. The statistical analysis revealed that the L* of flour significantly (p<0.05) varied among cultivars (Table 1), the highest being for RD-2552 and the lowest being for DWR-28 cultivars. After the roasting of barley the L* value was significantly (p<0.05) lowered. The a* value gives the degree of the red green colour, with a higher positive a* value indicating more redness, whereas the b* value indicates the degree of yellow blue colour, with higher positive b* value indicating more yellow. The highest and the lowest a* value was observed for DWR-28 and RD-2035 cultivars, respectively. The roasting caused a significant (p<0.05) increase in a* and b* values of all cultivars. The total colour difference (∆E) of flour significantly (p<0.05) varied among cultivars and ranged from 83.7 to 87.4. The roasting of barley significantly
decreased the ∆E for all the cultivars with the highest and the lowest for DWR-28 and RD-2508 cultivars, respectively. This result agrees with previous finding in roasted wheat (Murthy et al., 2008). A possible explanation to the results observed in the color parameters (L*, a* and b*) is the Maillard reaction (Rufian-Henares et al., 2009) and browning reactions that produce brown pigments with low and high molecular weight in advance stage of the browning reaction (Hofmann, 1998).

3.4 Effect of roasting on water absorption capacity, water solubility index and oil absorption capacity

The water absorption capacity (WAC) of roasted barley flours did not significantly vary among the cultivars, but significant differences were observed on the oil absorption capacity (OAC) and in the water solubility index (WSI) (Table 1). A significant (p<0.05) positive correlation (R= 0.72) was exhibited by WSI and OAC. The thermal treatment affected those parameters (WAC, WSI, OAC) inducing a significant increase in all the cultivars studied. Mariotti et al. (2006) reported similar results for water absorption capacity for puffed barley; and also Griffith and Castell-Perez (1998) reported an increase in the WAC, OAC and WSI in different cereals and legume after roasting.

The formation of a porous structure in the endosperm and the capillaries formed might be responsible of the increase in the absorption; also the presence of higher level of damaged starch has been suggested as possible (Mariotti et al, 2006). Starch had the tendency to become soluble after different cooking treatment (Jones et al., 2000).

3.5 Effect of roasting on total, insoluble and soluble β-glucan

Roasting affected in different extent the total β-glucan content depending on the cultivar (Fig 1a), observing a significant decrease in the total β-glucan content of some cultivars. The highest total β-glucan was observed for DWR-28 (5.47%) and RD-2035 (5.41%) in control and roasted barley, respectively. The lowest total β-glucan was observed for RD-2508 cultivar in both roasted and control barley. The soluble β-glucan ranged from 1.95 to 3.07% in control barley while it was significantly lowered after roasting (Fig. 1b). The highest and the lowest decrease in soluble β-glucan were observed for RD-2035 (25.3%) and RD-2552 (4.9%) cultivars, respectively. Izydorczyk et al. (2000) reported that hydrothermal treatments did not increase the amount of soluble β-glucan in different barley cultivars. The insoluble β-glucan ranged from 2.0 to 3.0% in control barley flour (Fig. 1c),
the highest and the lowest being for PL-172 and RD-2508 cultivars, respectively. Roasting significantly increased the insoluble β-glucan in all the barley cultivars.

A significant (p<0.05) positive correlation was observed between total and insoluble β-glucan of control barley (R = 0.73). Upon roasting, total β-glucan exhibited a significant positive correlation (R = 0.82) with insoluble β-glucan while the correlation with soluble β-glucan was lower (R = 0.45).

3.6 Effect of roasting on β-glucan extractability

The β-glucan extractability significantly varied among the cultivars in control and roasted barley (Fig.2). The highest and the lowest β-glucan extractability were observed for PL-172 and PL-426, respectively in control and roasted barley. After roasting, β-glucan extractability only showed significant increase in RD-2035 and PL-172. Bhatty (1995) reported similar results for β-glucan extractability in barley and oat bran.

β-glucan extractability (control barley) was positively correlated with water absorption capacity (R = 0.70, p<0.05).

3.7 Effect of roasting on pasting properties of flour

The pasting properties of barley flour obtained after roasting significantly varied among cultivars (Table 2). A sharp decrease in peak viscosity and breakdown viscosity (BDV, measurement of the cooked starch to disintegration) was noticed after roasting. BDV showed a significant positive (p<0.05) correlation (R= 0.64) with puffing index.

The roasting of barley significantly (p<0.05) decrease the final viscosity and the setback viscosity (SB), with the exception of RD-2552 that showed an increase in the SB viscosity after roasting. The time required to reach peak viscosity did not vary significantly among the cultivars. However, the roasting of barley significantly increased the peak time (PT). In addition, roasting of barley significantly increased the pasting temperature. Similar results were also reported for pasting properties in roasted oat (Cenkowski et al., 2006). Therefore, it seems that starch is partially gelatinized during roasting, despite the limiting water available for the starch. It has been reported that the loosely packed starch granules with high level of damaged starch easily hydrate and swell more rapidly in the presence of heat and consequently produce less peak viscosity (Mariotti et al., 2006), thus the increase in damaged starch might explain the results obtained.
It should remark that some interesting correlations were found among physical parameters and the content of β-glucans. Total β-glucan showed significant (p<0.05) positive correlation with peak and final viscosity (R = 0.74, 0.67 and 0.61, respectively). Insoluble β-glucan showed a positive correlation with peak and trough viscosity (R = 0.74 and 0.61 respectively). After roasting the β-glucan did not show correlation with the pasting parameters (peak, final and trough viscosity) as exhibited by control flour.

The peak viscosity, TV and breakdown showed significant (p<0.05) positive correlation (R= 0.75, 0.74 and 0.72, respectively) with β-glucan extractability. Zhang et al. (1998) reported that the non-starchy polysaccharide such as β-glucan affected the pasting properties of barley flour.

### 3.8 Effect of roasting on thermal properties

The thermal properties, onset temperature and peak temperature of barley flour significantly (p<0.05) varied among cultivars (Table 3). The endset temperature (T_e) of the roasted barley did not significantly vary among the cultivars. Upon roasting, significant (p<0.05) decrease was observed in T_o among all cultivars, whereas roasting did not affect the T_e significantly.

The enthalpy of gelatinization (ΔH_{gel}) ranged from 0.16 to 0.74 J/g with the highest being for DWR-28 and the lowest being for RD-2052. Significant decrease was observed in ΔH_{gel} when the barley was roasted. The degree of gelatinization ranged from 86.2 to 97.6% in the roasted barley. Upon roasting, significant increase was observed in the gelatinization range. The peak height index (PHI) significantly decreased in all the cultivar after roasting.

Upon roasting the barley starch was either gelatinized completely or partially depending upon type of heat treatment and grain properties. During gelatinization inter and intramolecular hydrogen bonds are broken. This results in a loosening up of the compact granular structure and allows different degrees of swelling and absorption of water. The roasting leads to gelatinization of the starch, which agrees with the observed decrease in ΔH_{gel}, although the starch that remained either ungelatinized or partially gelatinized showed a slight higher ΔH_{gel} in roasted as compared to other samples. Holm et al. (1988) reported that the degree of gelatinization (DG) ranged from 22-65% for rolled cereals, lower values than the ones obtained in the present study, although discrepancies could be attributed to difference in thermal treatment applied to grains. In fact, differences
in the effect of thermal and hydrothermal treatments have been reported. Khunae et al. (2007) reported increase in $T_o$ and decrease in $\Delta H_{gel}$ of rice starches upon hydrothermal treatment. Granfeldt et al. (2000) reported a decrease in $T_o$ and $\Delta H_{gel}$ for roasted oat and steamed barley flakes.

Some correlations were also established among the DSC parameters and pasting properties. A significant ($p<0.05$) positive correlation ($R= 0.64$) was exhibited between through viscosity and endset temperature. Moreover, peak time of RVA showed a significant ($p<0.05$) positive correlation with $T_o$, $T_c$ and $R$ of DSC, ($R= 0.70$, $0.77$ and $0.79$, respectively). Also, setback viscosity showed a significant positive correlation with peak height index ($R= 0.64$) of DSC. Special attention should be paid to the correlations observed with the ß-glucan extractability (control barley) that was positively correlated with endset ($R = 0.63$, $p<0.05$), gelatinization temperature range ($R = 0.85$, $p<0.01$) and negatively correlated with onset temperature ($R = -0.81$, $p<0.05$). Moreover, after roasting these correlations were lowered.

3.9 Effect of roasting on starch damage

During the milling of grain some starch particles get mechanically damaged and the level of damaged starch depends upon the texture of grain, type of seed, and force applied during milling (Hoseney, 1994). The level of damage starch affects the flour characteristics like water absorption capacity. The damage starch content in roasted barley is an index of the extent of modification of the structure of the native starch granules by the thermal processing. Therefore, the level of the damage starch in the roasted barley from different cultivars was determined. The level of damage starch significantly varied among the cultivars and ranged from 2.1 to 3.1% with highest and lowest being for RD-2052 and PL-172, respectively in control flour (Figure 3), probably the difference was due to the difference in the hardness of grain. However, after roasting the damage starch ranged from 28.8 to 43.1%. The substantial increase in the level of damaged starch in the roasted barley could be ascribed to gelatinization and bursting of starch granules due to higher temperature. Mariotti et al. (2006) reported similar results for control and roasted barley.

Conclusions
The study revealed that large variations were found in the physical characteristics, thermal and pasting properties of a range of barley cultivars. Roasting of barley significantly affect the physical properties of barley cultivars, together with the thermal and pasting properties. The thermal treatment induced partial starch gelatinization and provoked a significant increase of the damage starch.

β-glucan extractability remained unaffected after roasting, only two cultivars (RD-2035 and PL-172) showed an increase in the extractability. Roasting affected in different extent the total β-glucan content depending on the cultivar, observing a significant decrease of the total β-glucan content in some cultivars. The greatest effect was observed on the ratio of both types of β-glucans (soluble and insoluble), since roasting induced a significant increase in the insoluble β-glucans with a simultaneous decrease in the soluble β-glucan content. Therefore, roasting could be used as an strategy for modifying the ratio of soluble to insoluble β-glucans content and the grain barley properties.

Acknowledgement

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References


Indiastat http://www.Indiastat.com/India/showdata.asp


Table 1. Physical properties of different barley cultivars and color and physicochemical properties of their flours

<table>
<thead>
<tr>
<th>Cultivars</th>
<th>DWR-28</th>
<th>RD-2503</th>
<th>RD-2508</th>
<th>RD-2035</th>
<th>RD-2052</th>
<th>RD-2552</th>
<th>PL-172</th>
<th>PL-426</th>
</tr>
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<tbody>
<tr>
<td>Thousand kernel weight (g)</td>
<td>53.3(^{\text{a}})</td>
<td>42.2(^{\text{c}})</td>
<td>37.5(^{\text{b}})</td>
<td>39.1(^{\text{c}})</td>
<td>40.5(^{\text{d}})</td>
<td>45.6(^{\text{f}})</td>
<td>37.2(^{\text{b}})</td>
<td>32.8(^{\text{a}})</td>
</tr>
<tr>
<td>Bulk density (g/l)</td>
<td>265.0(^{\text{a}})</td>
<td>286.7(^{\text{c}})</td>
<td>296.2(^{\text{d}})</td>
<td>270.5(^{\text{b}})</td>
<td>326.7(^{\text{f}})</td>
<td>265.8(^{\text{a}})</td>
<td>269.3(^{\text{b}})</td>
<td>269.7(^{\text{b}})</td>
</tr>
<tr>
<td>L/B ratio</td>
<td>1.8(^{\text{a}})</td>
<td>1.9(^{\text{a}})</td>
<td>1.9(^{\text{a}})</td>
<td>1.8(^{\text{a}})</td>
<td>2.1(^{\text{b}})</td>
<td>2.0(^{\text{a}})</td>
<td>1.8(^{\text{a}})</td>
<td>1.8(^{\text{a}})</td>
</tr>
<tr>
<td>Geometric mean diameter (GMD)</td>
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<td>5.6(^{\text{b}})</td>
<td>5.8(^{\text{c}})</td>
<td>5.5(^{\text{a}})</td>
<td>5.7(^{\text{b}})</td>
<td>5.7(^{\text{b}})</td>
<td>5.9(^{\text{d}})</td>
<td>6.0(^{\text{c}})</td>
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<td>Puffing index</td>
<td>2.3(^{\text{d}})</td>
<td>2.1(^{\text{c}})</td>
<td>1.9(^{\text{a}})</td>
<td>2.3(^{\text{d}})</td>
<td>1.9(^{\text{a}})</td>
<td>2.4(^{\text{e}})</td>
<td>2.4(^{\text{e}})</td>
<td>2.0(^{\text{b}})</td>
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<td>Grain hardness (N)</td>
<td>49.8(^{\text{a}})</td>
<td>51.8(^{\text{a}})</td>
<td>31.3(^{\text{a}})</td>
<td>39.7(^{\text{a}})</td>
<td>28.0(^{\text{a}})</td>
<td>43.8(^{\text{a}})</td>
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<td>L*</td>
<td>82.8(^{\text{a}})</td>
<td>85.9(^{\text{b}})</td>
<td>85.4(^{\text{b}})</td>
<td>85.2(^{\text{b}})</td>
<td>84.5(^{\text{b}})</td>
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<td>85.1(^{\text{b}})</td>
<td>85.9(^{\text{b}})</td>
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<td>a*</td>
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<td>2.6(^{\text{b}})</td>
<td>2.1(^{\text{a}})</td>
<td>2.4(^{\text{a}})</td>
<td>2.3(^{\text{a}})</td>
<td>2.2(^{\text{a}})</td>
<td>2.2(^{\text{a}})</td>
</tr>
<tr>
<td>b*</td>
<td>11.9(^{\text{g}})</td>
<td>10.4(^{\text{d}})</td>
<td>11.0(^{\text{f}})</td>
<td>10.1(^{\text{c}})</td>
<td>10.8(^{\text{e}})</td>
<td>10.4(^{\text{d}})</td>
<td>9.9(^{\text{b}})</td>
<td>9.6(^{\text{a}})</td>
</tr>
<tr>
<td>(\Delta E)</td>
<td>83.7(^{\text{a}})</td>
<td>86.5(^{\text{b}})</td>
<td>86.1(^{\text{b}})</td>
<td>85.8(^{\text{b}})</td>
<td>85.2(^{\text{b}})</td>
<td>87.4(^{\text{c}})</td>
<td>85.7(^{\text{b}})</td>
<td>86.5(^{\text{b}})</td>
</tr>
<tr>
<td>Water absorption capacity (g/g)</td>
<td>4.4(^{\text{a}})</td>
<td>4.4(^{\text{a}})</td>
<td>4.6(^{\text{a}})</td>
<td>4.4(^{\text{a}})</td>
<td>3.9(^{\text{a}})</td>
<td>4.5(^{\text{a}})</td>
<td>4.4(^{\text{a}})</td>
<td>4.1(^{\text{a}})</td>
</tr>
<tr>
<td>Oil absorption capacity (g/g)</td>
<td>2.6(^{\text{b}})</td>
<td>2.3(^{\text{b}})</td>
<td>2.2(^{\text{b}})</td>
<td>2.5(^{\text{b}})</td>
<td>2.4(^{\text{b}})</td>
<td>2.3(^{\text{b}})</td>
<td>2.4(^{\text{b}})</td>
<td>2.0(^{\text{b}})</td>
</tr>
<tr>
<td>Water solubility index (%)</td>
<td>13.8(^{\text{c}})</td>
<td>12.6(^{\text{c}})</td>
<td>11.6(^{\text{e}})</td>
<td>13.8(^{\text{c}})</td>
<td>12.5(^{\text{c}})</td>
<td>11.5(^{\text{d}})</td>
<td>12.0(^{\text{b}})</td>
<td>13.1(^{\text{d}})</td>
</tr>
</tbody>
</table>

a, b, c, d, e, f and g superscripts are significantly (p<0.05) different row wise in different cultivars. Subscripts denote the percentage increase (↑) or decrease (↓) from control barley.
Table 2. Pasting properties of roasted barley flours from different cultivars

<table>
<thead>
<tr>
<th>Cultivars</th>
<th>Peak viscosity (cP)</th>
<th>Breakdown viscosity (cP)</th>
<th>Final viscosity (cP)</th>
<th>Setback viscosity (cP)</th>
<th>Peak time (min)</th>
<th>Pasting temperature (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>DWR-28</td>
<td>523b 11.8</td>
<td>66a 92.0</td>
<td>1064d 150.2</td>
<td>644d 41.3</td>
<td>6.9a 12.4</td>
<td>94.0a 14.3</td>
</tr>
<tr>
<td>RD-2503</td>
<td>478a 71.1</td>
<td>72a 88.5</td>
<td>957b 53.7</td>
<td>552b 46.0</td>
<td>7.0a 12.3</td>
<td>91.8a 9.3</td>
</tr>
<tr>
<td>RD-2508</td>
<td>473a 62.5</td>
<td>60a 88.2</td>
<td>910a 44.0</td>
<td>496a 43.1</td>
<td>7.0a 13.4</td>
<td>88.8a 6.2</td>
</tr>
<tr>
<td>RD-2035</td>
<td>685c 53.0</td>
<td>116d 76.9</td>
<td>1072d 43.7</td>
<td>501a 45.7</td>
<td>7.0a 10.4</td>
<td>93.3a 9.3</td>
</tr>
<tr>
<td>RD-2052</td>
<td>709d 53.2</td>
<td>84b 81.4</td>
<td>1346e 34.9</td>
<td>724e 27.6</td>
<td>7.0a 7.6</td>
<td>87.9a 6.5</td>
</tr>
<tr>
<td>RD-2552</td>
<td>726d 54.1</td>
<td>101c 64.7</td>
<td>1406f 152.2</td>
<td>785f 123.7</td>
<td>7.0a 10.0</td>
<td>89.3a 5.1</td>
</tr>
<tr>
<td>PL-172</td>
<td>869e 58.0</td>
<td>131e 84.0</td>
<td>1613g 130.6</td>
<td>876g 18.7</td>
<td>7.0a 12.0</td>
<td>86.2a 5.7</td>
</tr>
<tr>
<td>PL-426</td>
<td>459a 78.4</td>
<td>70a 92.4</td>
<td>988e 57.3</td>
<td>599e 46.9</td>
<td>7.0a 13.9</td>
<td>93.7a 15.5</td>
</tr>
</tbody>
</table>

a, b, c, d, e, f and g superscripts are significantly (p<0.05) different column wise in different cultivars. Subscripts denote the percentage increase (↑) or decrease (↓) in pasting properties from control barley flour.
Table 3. Thermal properties of roasted barley

<table>
<thead>
<tr>
<th>Cultivars</th>
<th>$\Delta$H (J/g)</th>
<th>Onset $T_o$ ($^\circ$C)</th>
<th>Peak $T_p$ ($^\circ$C)</th>
<th>Endset $T_c$ ($^\circ$C)</th>
<th>R ($T_c - T_o$)</th>
<th>Degree of gelatinization (%)</th>
<th>PHI</th>
</tr>
</thead>
<tbody>
<tr>
<td>DWR-28</td>
<td>0.77$^h$</td>
<td>52.1$^b$13.7</td>
<td>66.2$^d$</td>
<td>78.7$^a$</td>
<td>26.6$^f$139.6</td>
<td>86.2$^a$</td>
<td>0.05$^a$</td>
</tr>
<tr>
<td>RD-2503</td>
<td>0.69$^f$</td>
<td>51.9$^a$13.9</td>
<td>66.3$^d$</td>
<td>80.9$^a$</td>
<td>29.0$^g$193.6</td>
<td>87.8$^b$</td>
<td>0.05$^a$</td>
</tr>
<tr>
<td>RD-2508</td>
<td>0.60$^e$</td>
<td>54.2$^c$10.6</td>
<td>65.2$^b$</td>
<td>75.9$^a$</td>
<td>21.7$^e$151.4</td>
<td>86.5$^a$</td>
<td>0.06$^a$</td>
</tr>
<tr>
<td>RD-2035</td>
<td>0.22$^b$</td>
<td>56.5$^d$5.1</td>
<td>65.9$^c$</td>
<td>71.3$^a$</td>
<td>14.7$^e$138.0</td>
<td>96.0$^f$</td>
<td>0.02$^a$</td>
</tr>
<tr>
<td>RD-2052</td>
<td>0.16$^a$</td>
<td>56.8$^d$6.6</td>
<td>65.9$^c$</td>
<td>70.7$^a$</td>
<td>13.2$^b$141.6</td>
<td>97.6$^g$</td>
<td>0.02$^a$</td>
</tr>
<tr>
<td>RD-2552</td>
<td>0.74$^g$</td>
<td>57.8$^c$4.5</td>
<td>64.2$^a$</td>
<td>70.6$^a$</td>
<td>12.8$^e$149.6</td>
<td>88.5$^c$</td>
<td>0.12$^b$</td>
</tr>
<tr>
<td>PL-172</td>
<td>0.42$^d$</td>
<td>52.7$^b$11.4</td>
<td>64.3$^a$</td>
<td>72.5$^a$</td>
<td>19.7$^d$191.0</td>
<td>94.0$^d$</td>
<td>0.04$^a$</td>
</tr>
<tr>
<td>PL-426</td>
<td>0.34$^c$</td>
<td>52.6$^b$14.0</td>
<td>65.1$^b$</td>
<td>72.3$^a$</td>
<td>19.7$^d$149.5</td>
<td>94.6$^e$</td>
<td>0.03$^a$</td>
</tr>
</tbody>
</table>

a, b, c, d, e, f, g and h superscripts are significantly (p<0.05) different column wise in different cultivars. Subscripts denote the percentage increase ($\uparrow$) or decrease ($\downarrow$) in thermal properties from control barley flour.
Figure captions

Figure 1. Effect of roasting on total, soluble and insoluble β-glucan in different barley cultivars, mixed linkage total β-glucan (Fig.1a), soluble β-glucan (Fig.1b), insoluble β-glucan (Fig.1c), different superscripts (a to f) show significant difference (p<0.05) within cultivars and p, q superscripts show significant difference of roasting within a cultivar.

Figure 2. Effect of roasting on extractability of β-glucan in different barley cultivars, superscripts (a - f) are show the significant difference within cultivars and (p & q) superscripts show significant difference of roasting within a cultivars.

Figure 3. Effect of roasting on starch damage in different barley cultivars, superscripts (a - h) are show the significant difference within cultivars and (p & q) superscripts show significant difference of roasting within a cultivars.
Fig 1a.

Fig 1b

Fig 1c
Figure 1

Figure 2
Figure 3