Barley (*Hordeum vulgare*) is the fourth most important cereal grain in the world with India producing about 16.89 lakh tonnes per year. The predominant type of barley cultivated is hulled having a tough fibrous husk and is used as a malting and brewing grain and as cattle feed. Unfortunately, at present only about 2% of the total barley produced is utilized as a human food. Among cereals barley has one of the highest levels of β-glucan, which is known to have several health benefits like lowering blood cholesterol and glycemic index. Barley also contains many phenolic compounds that have antioxidant activity and function as reducing agents, free radical scavengers, single oxygen quencher and potential complexer of prooxidants. These bioactive compounds in barley help reduce the risk of chronic disease making it a functional grain therefore processing and utilization of barley into human foods should be encouraged. Barley is utilized in human foods after undergoing processes such as roasting, baking and extrusion and these processes affect the bioactive compounds in barley.

Eight commonly grown Indian hulled barley cultivars were evaluated for their dehusking, pearling, physico-chemical, β-glucan, pasting and thermal behavior. Dehusking and pearling time among the different barley cultivars varied from 46 to 84 sec and 239 to 1439 sec, respectively. Conditioning of barley samples at 14% moisture significantly lowered the dehusking and pearling time. Bulk density and thousand kernel weight of barley cultivars differed significantly and ranged from 38.24 to 54.54g and 547 to 653g/l, respectively. The protein and ash content varied significantly among cultivars and ranged from 8.75 to 13.45% and 1.15 to 1.51%, respectively. Particle size distribution of flours was significantly different among the cultivars with flour from RD-2552 and RD-2035 cultivars having the most even particle size distribution. The total color difference (ΔE) of whole barley flour was not significantly different among cultivars. The total, soluble and insoluble β-glucan ranged from 4.07 to 5.47%, 1.84 to 2.64% and 1.63 to 2.84%, respectively. The highest total, soluble and insoluble β-glucan was observed for DWR-28, RD-2503 and PL-172, respectively. The extractability of β-glucan varied...
significantly among cultivars and ranged from 89.1 to 95.5%. The peak and final viscosity of barley flours was significantly different among cultivars and ranged from 1261 to 2122 cP and 1628 to 2319 cP, respectively. The enthalpy ($\Delta H$) of gelatinization of barley flour varied from 4.45 to 7.08 J/g and gelatinisation temperature ($T_p$) varied from 64.23 to 66.26 °C.

The total phenolic content and antioxidant activity (DPPH free radical scavenging activity) varied significantly among different barley cultivars and ranged from 3070 to 4439µg ferulic acid equivalents/g and 17.01 to 24.92%, respectively. The polyphenol oxidase activity of the barley samples varied from 0.147 to 0.382 Δ475/min g. The total flavonoid content, reducing power and metal chelating activity of barley sample varied significantly among cultivars and ranged from 1387 to 2246µg catechin equivalents/g, 47.0 to 62.2 µmol ascorbic acid equivalents/g and 37.5 to 61.5%, respectively. The non-enzymatic browning index significantly differed among cultivars and ranged from 0.052 to 0.069/0.1g.

The eight barley cultivars were subjected to roasting in a traditional roaster (280°C±5) and studied for effects on β-glucan solubility, physico-chemical, thermal, pasting and antioxidant properties. The grain puffed upon roasting and grain hardness and total color difference were significantly lowered. Roasting brought about a decrease in the soluble β-glucan content in all the cultivars and this decrease ranged from 4.9 to 25.3%. However, a significant increase in insoluble β-glucan ranging from 2.7 to 28.6% was observed within the cultivars. Also, roasting lowered the ratio of soluble to insoluble β-glucan by 8.1 to 41.9%. Roasting significantly affected the pasting and thermal properties of the flours, together with an increase in the damage starch content that ranged from 28.8 to 43.1%.

A significant decrease in total phenolic content (8.5 to 49.6%) and total flavonoid content (24.5 to 53.2%) was observed after roasting. The antioxidant activity significantly increased by 16.8 to 108.2% upon sand and microwave roasting with the sand roasted barley exhibiting higher antioxidant activity. The reducing power and metal chelating activity significantly increased by upto 77.5% and 78.9%, respectively. The non-enzymatic browning index increased upto 315 to 774% and was higher for sand roasted
barley. Microwave roasting brought about a greater reduction of 45.1 to 76.8% in polyphenol oxidase activity.

The extrusion of barley samples was carried out at 15 and 20% feed moisture and 150 and 180°C extrusion temperature and the extrudates were evaluated for effects on physico-chemical properties, β-glucan extractability and antioxidant behavior. The highest expansion was observed for the extrudates extruded at 150°C extrusion temperature and 15% feed moisture (LTLM). The HTHM (180°C and 20%) extrudates exhibited the highest water absorption capacity. A significant increase in soluble β-glucan was observed upon extrusion at 180°C extrusion temperature and 15% feed moisture (HTLM). The ratio of soluble to insoluble β-glucan varied from 0.7 to 1.5 in the control barley but after extrusion cooking the ratio increased from 1.2 to 3.1. The β-glucan extractability increased by up to 8% after extrusion with extrudates from HTHM showing highest extractability. A significant decrease in the peak and final viscosity of the extrudates at all the extrusion conditions was observed. A significant decrease in total phenolic content (TPC) and total flavonoid content (TFC) was observed upon extrusion. The antioxidant activity (AOA) increased significantly upon extrusion and this increase was highest (36 to 69%) at 150°C extrusion temperature and 20% feed moisture. The increase in feed moisture and temperature significantly increased the metal chelating activity. The reducing power decreased significantly upon extrusion as compared to their corresponding control samples. Extrusion lead to an increase in the non-enzymatic browning (NEB) index which increased with increase in extrusion temperature.

PL-172 cultivar was selected to evaluate the chapatti making behavior of barley and wheat flour blends as it had high content of β-glucan and highest antioxidant potential. Wheat flour was replaced with barley flour in such a way so as to give 1.5, 3.0 and 4.5% β-glucan (equivalent to 28, 56 and 84% barley flour) in the wheat barley flour blends. β-glucan (1.5, 3.0 and 4.5%) incorporated wheat flour was also prepared by adding β-glucan extracted from barley into wheat flour. The chapatti making behavior of the wheat barley flour blends and β-glucan incorporated wheat flour was evaluated.

Incorporating barley flour and β-glucan increased dough water absorption capacity significantly. Chapattis prepared by replacing 28% wheat flour with barley flour had good sheeting and sensory properties however; replacement at higher levels made
sheeting difficult and reduced the sensory scores. Wheat flour that contained β-glucan at 4.5% level (equivalent to 84% replacement of wheat flour with barley flour) had good dough making and sheeting characteristics, received high sensory scores and was as good as 100% wheat flour chapatti. The retrogradation in chapattis after storage for 24 h at 4°C was also studied and it was observed that β-glucan prevented the extent of retrogradation which was evident from the lower enthalpy of retrogradation. Replacement of wheat flour with barley flour also increased the total phenolic content, antioxidant activity and total flavonoid content of the wheat barley flour blends. Baking of chapatti lead to decrease in total phenolic and flavonoid content but increased the antioxidant activity and non-enzymatic browning index.

Cookies were prepared by replacing wheat flour with barley flour at levels of 25 to 100%. Increasing levels of barley flour in the blends lead to significant decrease in spread factor and bake loss and increased the snap force and lightness (L*) of cookies. The total phenolic content and antioxidant activity increased with increasing levels of barley flour in the blends whereas baking lead to further increase in antioxidant activity, metal chelating activity and non-enzymatic browning index.

Conclusions:

- The total phenolic content and antioxidant activity is highest in the bran fraction of barley.
- Antioxidant activity and total phenolic content of barley significantly increased upon germination of barley for 24 h.
- Roasting of barley significantly decreased the ratio of soluble to insoluble β-glucan, however total β-glucan was not affected.
- Roasting of barley lead to significant decrease in total phenolic, total flavonoid content and polyphenol oxidase activity but significantly increased the antioxidant activity, reducing power, metal chelating activity and non-enzymatic browning index.
- Extrusion cooking increases the soluble β-glucan content in barley extrudates.
- The total phenolic content, flavonoid content and reducing power decreased upon extrusion but antioxidant activity, non-enzymatic browning index and metal chelating activity increased.
Summary and Conclusion

- Chapattis can be prepared by incorporating barley flour in wheat flour at a level of upto 28% without affecting sensory attributes.
- β-glucan can be added into wheat flour at levels of 4.5% and acceptable chapattis can be prepared.
- Barley flour incorporation in wheat flour was found to be more effective in preventing the staling of chapattis as compared to β-glucan.
- Acceptable cookies can be made by replacing refined wheat flour with whole barley flour upto 100% levels.
- Barley cultivar PL-172 has the highest β-glucan levels and antioxidant potential among the cultivars evaluated therefore it is recommended for processing into human foods.