CHAPTER-2

REVIEW OF LITERATURE

Barley (Hordeum vulgare L.) is an important cereal grain throughout the world but very little of this grain is used directly as a human food (only about 2%, Baik and Ullrich, 2008). Today there is an increase in the number of patients suffering from coronary heart diseases, cancer and diabetics world wide. Under such circumstances, requirement of functional foods will increase; food processors will tailor foods in such a way that they provide protection from diseases and promote health. As barley has been recognized as a functional grain its utilization in human foods will definitely increase. People are becoming more health conscious and they wish to consume foods that provide not only daily energy requirement and nutrients but also heath benefits (Izydorczyk, 2010). Food and Drug Administration (FDA) has allowed the labeling of foods containing barely as healthy food. (Brezinov-Belcredi et al., 2009).

2.1 Structure of grain and physical characteristics

Barley grain is a covered caryopsis like rice meaning that it is enclosed in a lignified covering consisting of leaf like structure termed as lemma and palea (Magness et al., 1971) which are firmly bound with endosperm and stay with endosperm even after threshing. Majority of the barley cultivated around the world is hulled type because it is more suitable for malting and this is where most of the barley produced is utilized. The hull of barley accounts for 10 to 20% of barley grain and the average husk content depends upon cultivars and growing conditions (Evers et al., 1999). Bhatt et al. (1975) reported husk content ranging from 10 to 13% in different barley cultivars whereas Zielinski and Kozlowska (2000) reported husk content ranging from 7.6 to 9.8 % in different barley cultivars. More recently, Du and Yu (2011) reported husk content ranging from 9 to 11% in six different barley varieties. On the other hand, in hull-less barley hull is not attached firmly to the endosperm and is easily removed during thrashing similar to wheat (Baik and Ullrich, 2008).

Bran is the next morphological fraction after husk that surrounds the endosperm and it accounts for 7 to 12% of the grain. The bran is rich in fat, protein and minerals
(MacGregor, 1993; MacGregor and Fincher, 1993). The germ (embryo) is situated at the attachment end of the caryopsis on its dorsal side and accounts for only 2 to 4% of the total kernel (Jadhav et al., 1998). It is a rich source of protein (34%) and lipid (13 to 17%) and most of the tocopherols are concentrated in this segment (Newman and Newman, 1991; MacGregor and Fincher, 1993).

The endosperm is the main morphological fraction and accounts for approximately 75% of the grain. The major portion of endosperm consists of starch and protein; starch in the form of granules is embedded in a protein matrix (Jadhav et al., 1998). The thousand kernel weight of barley grain is generally used for estimation of differences in grain mean mass between samples or cultivars and cultivars with higher weight indicate better filled grain (Zupfer et al., 1998). Thousand kernel weight is also an indicator of flour yield and quality (Villacres and Rivadeneira, 2005). Zupfer et al. (1998) reported that the thousand kernel weight of different barley cultivars ranged from 32.0 to 42.5g. Bhatti and Rossnagel (1998) reported thousand kernel weight of 27 to 40g for Japanese and Canadian barley, respectively. Andersson et al. (1999) reported that thousand kernel weight of barley ranged from 36 to 54g. The thousand kernel weight depends upon cultivar, environmental conditions and agricultural practices. A wide variation in thousand kernel weight has been reported by Yalcin et al. (2007) ranging from 26 to 47g in different barley cultivars.

Bulk density is also an indicator of grain quality and is affected by several factors such as moisture content, surface characteristics, protein content and shape and size of grain (Yamazaki and Briggle, 1969). Andersson et al. (1999) reported that bulk density of barley ranged from 661 to 732 g/l and Mariotti et al. (2006) observed a bulk density of 832.1 g/l for raw barley. Sharma and Gujral (2010a) reported that bulk density of different barley cultivars ranged from 0.547 to 0.657 g/ml.

### 2.2 Proximate composition of barley

The composition of any plant product depends upon the environmental conditions where the plant is grown, agricultural practices and soil conditions (Jadhav et al., 1998). Starch content in barley has been reported to be 60 to 64%, the amyllose content varies from 20 to 30% while in waxy barley amyllose is as low as 1% and in the high amyllose
barley it is upto 45% (Morrison et al., 1986; Henry, 1988; MacGregor and Fincher, 1993; MacGregor, 1993). Protein content of barley varied from 8 to 15% (MacGregor, 1993) whereas some authors have reported a protein content as high as 20% (Torp et al., 1981; Newman and Newman, 1991). The protein content largely depends upon the nitrogen content which is supplied to the plant during growth (Friedman and Atsmon, 1988). The lipid content of barley ranges from 2 to 3% and most of the lipids are concentrated in the bran and germ portion (Newman and McGuire, 1985; Morrison, 1993; Bhatta, 1993a). Non-polar type of lipids are the major part of lipid and the linoleic acid is the major fatty acid (Briggs, 1978; Price and Parsons, 1979). Andersson et al. (1999) evaluated different barley cultivars for their chemical composition and reported a starch content of 52.1 to 63.8%, protein 8.7 to 10.5%, fat 2.2 to 3.5%, dietary fiber 18.9 to 23.8% and ash 2.3 to 2.6%. Mahdi et al. (2008) reported a carbohydrate content of 73.5%, protein 12.5% and fat 2.3% in barley. Sullivan et al. (2010b) reported a total starch of 47.5 and 76.8% in hulled barley whole grain and flour, respectively. They also reported that the hulled barley grain contains 18.7% total, 2.6% soluble and 16.1% insoluble fibers while dehulled whole barley flour contains 3.5% total, 1.9% soluble and 1.6% insoluble fibers.

2.3 Dehusking and pearling of barley

Dehusking or dehulling is the first step before hulled barley can be utilized in human foods. The dehusked barley is then further subjected to pearling and milling. As compared to other cereals such as rice, the hull of barley is strongly attached to the pericarp therefore, dehusking is difficult. Hulled barley is utilized in malting therefore its dehulling behavior has received little attention especially in abrasive type polisher used for rice dehulling.

If refined barley flour is to be produced then pearling or bran removal is the next step after dehulling. Pearling is the successive peeling of grain to remove bran by the application of abrasion. Pearling removes residual adhering hull, pericarp, seed coat, aleurone and subaleurone layers, and the embryo (Jadhav et al., 1998; Baik and Ullrich, 2008). The degree of pearling depends upon the end use of barley, and pearling leads to pearled, pot or polished barley. After dehusking, further removal of the next kernel layer, the pericarp, produces pot barley (Jadhav et al., 1998; Sullivan et al., 2010a). Further
abraision, leading to formation of pearled barley, removes the seed coat, aleurone, and subaleurone layers. After pearling yield of grains is about 60 to 70% of the total weight of grain, the average being 67% (Kent, 1983). Chandra et al. (1999) reported that dehusking of barley can be carried out using a small polisher by abrasion of grains against an abrasive surface with the help of wire brush however, they did not study the dehusking behavior. Baik and Ullrich (2008) reported that the dehulling of barley removes small portion of bran, germ and endosperm along with the hull. Kiryluk et al. (2000) dehulled barley using a vertical shelling machine before subjecting it to roller milling. Panfili et al. (2008) carried out the dehusking of barley using FC2K-Otake dehuller. Gray et al. (2010) used the Satake abrasion mill for dehusking and pearling of barley and reported a dehusking time of 55 to 60 sec. Peeling and pearling of the barley can be carried out using a Buhler pearling machine (Buhler AG, Switzerland), peeling removes the outer layers of barley grain and this is followed by pearling, where the peeled grain are polished, thus removing further layers of the grain (Sullivan et al., 2010b). Sharma and Gujral (2010a) investigated the dehusking and pearling behavior of eight different hulled barley cultivars in a McGill rice polisher. They reported that the dehusking time varied from 46 to 84 sec and pearling time to remove 10% bran varied from 413 to 1439 sec. The pearling process is governed by size, shape, composition and hardness of grain (Pomeranz and Shands, 1974; Kent, 1983; Foster and Prentice, 1987). Pearling of barley for varying degree (upto 80% of the original weight) has been carried out by Yeung and Vasanthan (2001) and they reported a pearling time ranging from 13 to 56 min.

Dehusked and pearled barley is further subjected to milling into flour using different types of mills. Whole barley flour can be prepared by abrasion and hammer milling (Knuckles et al., 1992; Yoon et al., 1995), but care should be taken that the grain should not contain small portions of hull, as this will lead to increased ash and insoluble fiber content (Baik and Ullrich, 2008). It has been reported that the flour and bran produced by roller milling exhibits special characteristics and offers new application of barley in human foods. But as compared to wheat, barley can not be easily separated in refined flour and bran by roller milling because it behaves differently during conventional roller milling (Bhatty, 1993a, 1997). Barley bran is brittle and is easily broken in to small
fragments and contaminates white flour (Jadhav et al., 1998). An extraction rate of 70 to 74% has been achieved by Bhatty (1986) upon roller milling of two different barley cultivars using tempering moisture of 11 to 13%.

Many efforts have been made to optimize the milling conditions for the production of flour and bran and for evaluation of their mill streams. Klamczynski and Czuchajowska (1999) milled pearled barley using a Miag Multomat Roller Mill and obtained three milling fractions i.e. break flour, reduction flour, and bran. Dehulled barley grains conditioned to different moisture content and roller milled in a Brabender Quadrumat Junior Mill and produced 40% flours and 60% grits or middlings (Kiryluk et al., 2000). Four different barley cultivars were milled after conditioning at different moisture levels in a Buhler Roller Mill; it was observed that conditioning at 14.3% produced best results in terms of flour yield (Andersson et al., 2003). Roller milling of barley has been carried out to study the effect of pearling and conditioning on mill stream (Izydorczyk et al., 2003). Izydorczyk et al. (2005) carried out roller milling of different barley cultivars by conditioning them to moisture content of 16%.

2.4 Physico-chemical properties of barley flour

The water holding capacity (WHC)/water absorption index, water solubility index (WSI) and oil absorption capacity are considered as physico-chemical properties (Elleuch et al., 2011). The water holding capacity of barley flour depends upon presence of β-glucan (Bhatty, 1993a; Bhatty, 1997). Bhatty (1993a) obtained barley flour by roller milling and reported a water holding capacity of 2.5 ml/g. Further he reported that barley flour had higher water holding capacity as compared to wheat. Whole barley flour exhibited WHC, 2.5 ml/g and 1.1 ml/g for CDC Candle and CDC Dawn barley cultivars, respectively (Bhatty, 1997). Water holding capacity of flour largely depends upon the composition, particle size; determination method, presence and type of dietary fiber (Elleuch et al., 2011). Water absorption capacity of dough was increased significantly by addition of barley flour in wheat flour during bread making (Jacobs et al., 2008). Izydorczyk et al. (2005) reported that the inclusions of fiber rich fractions from barley increased the WAC substantially. Izydorczyk et al. (2008) studied the effect of addition of barley flour in wheat flour during bread making and found that increasing the level of
barley flour significantly increased the water absorption capacity. Skendi et al. (2009, 2010) observed that increasing the concentration of β-glucan increased the WAC of wheat flour dough during bread making. Fanisa et al. (1999) reported that the water holding capacity of barley flour is 272% and infrared processing of barley significantly increases the water holding capacity upto 429%. Puffing of cereals exerts significant effect on the WAC and exhibits increased WAC as compared to their corresponding control samples (Mariotti et al., 2006). Ainsworth et al. (2007) studied the effect of extruder screw speed (100 to 300 rpm) and addition of brewers spent grain and observed a significant increase in WAC. Altan et al. (2008) studied the effect of addition of tomato pomace in barley flour and observed an increase in water absorption index after extrusion cooking. Different size of barley grits were subjected to extrusion cooking at two different temperature (100 and 140°C) and it was observed that the extrusion cooking increased the water absorption index and further increasing the extrusion temperature significantly increased water absorption index (Al-Rabadi et al., 2011).

The water solubility index is an indicator of presence of water soluble component in the flour and it describes the rate and extent to which the particles dissolve in water. Principally, it depends upon the chemical composition and particle size of flour (Filli et al., 2010). Barley flour had more water solubility index as compared to wheat because it contains more water soluble components such as β-glucan. Therefore, incorporation of barley flour in wheat flour leads to increase in water solubility index (Brennan and Cleary, 2005; Izydorczyk and Dexter, 2008). WSI is also an indicator of the extent of gelatinization of starch (Kirby et al., 1988; Jones et al., 2000). WSI is considered as an indicator of soluble material produced and molecular breakdown during thermal processing (Ding et al., 2005; Ding et al., 2006). Marrotti et al. (2006) reported that WSI of raw barley was 7.5 % while after puffing of barley it was increased upto 30.2%. Lee and Inglett (2006a) studied the effect of hydrothermal treatment on barley flour and reported a water solubility index of 15.82% for control flour while after hydrothermal treatment it was increased by 20.20%. Extrusion cooking produces a large amount of small molecules by breakdown of starch and other macromolecules such as β-glucan leading to increase in WSI (Ainsworth et al., 2007; Altan et al., 2008; Oikonomou and Krokida, 2011; Zhang et al., 2011). Anisworth et al. (2007) studied the effect of addition
of brewers spent grain (BSG) in maize flour during extrusion cooking and reported a WSI ranging from 6.1 to 10.2% depending upon percentage addition of BSG. WSI ranged from 7.08 to 11.99 in extrudates prepared from barley flour-tomato pomace (Altan et al., 2008). Different barley flour fractions were extruded by twin screw extruder, these extrudates showed a WSI ranging from 6.45 to 8.94%, smaller fractions had highest WSI while the lowest was exhibited by larger particles (Al-Rabadi et al., 2011).

The oil absorption/holding capacity (OAC) is the amount of oil retained by flour after mixing with oil and incubation for a particular period of time followed by centrifugation. It depends upon the chemical characteristics and physical state of flour (Elleuch et al., 2011). It is also related to the overall charge density and to the hydrophilic nature of the constituents (Fleury and Lahaye, 1991). The non-polar side chains of proteins are considered to bind the hydrophobic chains of fat thus retaining more oil (Osman et al., 2000; Lee et al., 2006). The flour obtained after roller milling of barley exhibited oil holding capacity of 1.3 g/g (Bhattay, 1993a). Sharma and Gujral (2010a) reported that the oil holding capacity of whole barley flour ranged from 1.50 to 1.68 g/g. Sand roasting of barley significantly raised the oil absorption capacity of barley and it ranged between 1.99 to 2.63 g/g (Sharma et al., 2011).

2.5 Color characteristics

Bhattay (1993a) reported that the lightness of roller milled flour ranged from 78.8 to 86.7 for sixteen different barley cultivars. The production of food malt significantly decrease the lightness of flour (Bhattay, 1996), in this investigation he reported the lightness of control barley flour to be 83.1 while after malting it was lowered to 80.0. Different barley cultivars were dry milled in Quadrumat Junior Mill to obtain whole barley flour with 100% extraction rate and this whole flour exhibited the lightness value ranging from 83.1 to 84.7 (Bhattay, 1997). Different barley cultivars from Canada and Japan, were milled before and after pearling and analyzed for their composition and physico-chemical properties and they reported the lightness ranging from 78.9 to 86 (Bhattay and Rossnagel, 1998). In another study, Yeung and Vasanthan (2001) produced whole barley flour and reported the lightness value ranging from 87.0 to 87.7, redness value 1.3 to 1.4 and yellowness value 10.4 to 10.5 for two different barley cultivars.
Further they also reported that the pearling of barley lead to increase in lightness and decrease in redness and yellowness. Bellido and Béta (2009) reported color of different barley samples with the lightness value ranging from 66.68 to 81.11, redness value 1.49 to 1.90 and yellowness value 8.85 to 13.95. Sharma and Gujral (2010a) also reported the lightness value ranging from 88.6 to 89.6, redness 0.7 to 1.0 and yellowness 7.6 to 8.7 for whole barley flour from eight different barley cultivars.

Sand roasting is a popular method of processing of grains in India and this method improves the texture, enhances the flavor and extends the shelf life (Gahalawat and Sehgal, 1992; Hoke et al., 2007). Sand roasting is generally carried out at 280-300°C temperature and this significantly affects the color characteristics of barley due to Maillard browning (Hofmann, 1998; Gujral et al., 2011), decreases the lightness increases the redness and yellowness of flour (Sharma and Gujral, 2011). Duh et al. (2001) reported lightness values of 18.30 to 36.29, redness values of 0.71 to 2.34 and yellowness values of 2.14 to 14.70 for barley roasted under different temperature conditions. Murthy et al. (2008) investigated the effect of fluidized bed and sand roasting on wheat and reported the lightness value of 65.15, 59.89, 47.26, redness values 9.55, 8.54, 8.00 and yellowness values 30.63, 23.34, 16.68 for over roasted, optimum roasted and under-roasted wheat, respectively. Different oat cultivars were sand roasted, dehulled and ground to flour and color was evaluated and this revealed lightness values of 82.0 to 87.0, redness values of 1.6 to 3.0 and yellowness values of 11.3 to 14.2. (Gujral et al., 2011). Extrusion cooking also brings about changes in color which is due to the reaction between reducing sugar and amino acids through Maillard browning (Jadhav et al., 1998). The intensity of pigment formation largely depends upon the water activity, composition of food materials, reaction time and concentration of reactant (Manzocco et al., 2000; Rufian-Henares and Delgado-Andrade, 2009; Stojceska et al., 2009). Ainsworth et al. (2007) reported the lightness values of 51.7 to 62.5, redness values of -6.9 to -10.0 and yellowness values of 12.8 to 17.7 for extrudates prepared by addition of different concentration of brewer spent grain and extruded under different conditions. The extrudates prepared from barley exhibited the lightness of 65.85, redness of 2.70 and yellowness of 16.10 but upon addition of tomato pomace to the barley flour decreased the lightness and increased the redness and yellowness of extrudates (Altan et al., 2008).
extrudates prepared from medium barley grits and flour exhibited the lightness values of 75.25 and 74.47, redness values of 2.88 and 3.66, yellowness values of 14.67 and 16.44 (Altan et al., 2009a). Stojceska et al. (2009) studied the effect of addition of brewers spent grain in wheat flour and corn flour at 10% level and subjected this to extrusion cooking, the extrudates exhibited lightness between 58.0 to 63.9, redness between -5.1 to -3.9 and b* between 20.0 to 22.1.

Barley flour has been utilized for production of different baked products such as chapattis, breads and cookies (Gujral and Gaur, 2002; Gujral et al., 2003; Trogh et al., 2004; Gujral and Gaur, 2005; Sudha et al., 2007; Izydorczyk and Dexter, 2008; Skrbic et al., 2009; Skendi et al., 2009; Tiwari et al., 2011). Flat bread was made using the barley fiber rich fractions and lightness of bread ranged from 67.45 to 74.31, a* values ranged from 1.92 to 5.32 and b* value ranged from 19.83 to 26.87 (Izydorczyk et al., 2008). Yadav et al. (2008a) studied the effect of freeze thaw cycle on quality of chapatti and reported that the baking of chapatti significantly lowered the lightness. Gluten free bread was formulated using corn starch and other non-gluten cereals and also fiber from different sources including barley were added at 3, 6 and 9% replacement in formulation. The crust lightness was 65.48, 68.69 and 72.58 the redness was 7.22, 9.54 and 9.87 while the yellowness was 31.80, 34.84 and 32.78 (Sabanis et al., 2009). Kinner et al. (2011) prepared the bread with barley and reported that the crust color was darker while the crumb color was lighter.

Limited studies have been carried out with regards to the cookie making properties of barley flour. Bressa et al. (1996) prepared butter cookies from barley and reported the lightness ranging from 55.5 to 78.0 after different baking time. Summa et al. (2006) investigated the relationship between antioxidant activity and acrylamide formation in barley cookies. Barley bran was blended with wheat flour up to 40% for cookie making; the cookies prepared with these blends had total color difference of 47.40 to 51.72 (Sudha et al., 2007). Wheat flour was replaced with barley flour up to 70% and cookies were prepared and evaluated for their color characteristics, the lightness ranging from 56.2 to 59.4, redness ranging from 8.9 to 11.5 and yellowness ranging from 27.2 to 30.5 was reported (Frost et al., 2011).
2.6. Pasting properties

The viscosity of barley flour is an important parameter in food processing and it significantly affects the quality of the products (Gray et al., 2010). It has been reported that the viscosity of barley flours were comparable to wheat flours when analyzed with Rapid Visco Analyzer (RVA) (Eliasson, 1986). Viscosity may be influenced by composition of barley, cultivars and growing conditions (MacGregor and Fincher, 1993; Yoshimotoa et al., 2002). Hatcher et al. (2005) studied the pasting profile of barley flour from different cultivars and reported that addition of barley flour in wheat flour for noodle making increases or decreases pasting profile as compared to their corresponding control samples. It was reported that barley flour had peak viscosity of 3604 cP, trough viscosity of 1682 cP and final viscosity of 3411 cP (Koksel et al., 2004). Ragaee and Abdel-Aal (2006) investigated the effect of addition of flour from different cereals including barley flour in wheat flour and stated that the barley flour exhibit the peak viscosity (PV) 1355, final viscosity (FV) 1061, breakdown viscosity (BV) 989 cP. Zhou et al. (2008) studied the pasting profile of ten different barley cultivars and reported a large variation in peak, final and breakdown viscosity. In another study, whole barley flour from different barley cultivars was evaluated for their pasting behavior, and it was observed that the peak viscosity ranged from 381 to 3751 cP, breakdown viscosity from 282 to 2470 cP and final viscosity from 233 to 4765 cP (Gray et al., 2010). Whole barley flour exhibited peak viscosity of 3775 cP, final viscosity of 2490 cP and breakdown viscosity of 1570 cP (Sullivan et al., 2010b). Sharma and Gujral (2010a) studied the milling behavior and pasting properties of different barley cultivars and reported peak viscosity ranging from 1261 to 2122 cP, final viscosity 1628 to 2329 cP, breakdown viscosity 287 to 916 cP and pasting temperature 81.13 to 85.50°C. Lee et al. (2011) pearled barley to 23% of its original weight and ground it into flour, and evaluated its pasting properties, they observed that the Saessal cultivar had highest peak viscosity of 295.44 Rapid Visco Units (RVU) and final viscosity of 309.62 RVU.

The pasting properties are significantly affected by the application of heat and the degree of starch gelatinization and are governed by the type and severity of heat treatment (Becker et al., 2001; Altan et al., 2009b). Visco-Amylograph was used to study the pasting profile of puffed barley which exhibited peak viscosity of 950 Brabender
Units (BU) and a pasting temperature of 62.0°C (Mariotti et al., 2006). Barley rich in β-glucan has been subjected to steam jet cooking and the effect on oil barrier properties and pasting properties investigated, the cooked barley exhibited lack of characteristic peak viscosity and reduction in final viscosity as compared to native barley flour (Lee and Inglett, 2006a).

Different barley cultivars were roasted in hot sand at 280°C ±5 and investigated for their pasting and thermal behavior, a significant decrease in pasting viscosity was observed (Sharma et al., 2011). Similarly, ten different oat cultivars were sand roasted and evaluated for their pasting profile; roasted oat exhibited peak viscosity ranging from 418 to 1079 cP, final viscosity 1124 to 2240 cP, breakdown viscosity 38 to 319 cP and pasting temperature 92.0 to 94.5°C (Gujral et al., 2011). High amylose barley (HAB), waxy barley (WB) and normal barley (NB) were heated in microwave which resulted in a significant decrease in peak viscosity while the final viscosity of NB and HAB samples were higher and lower, respectively, as compared to their corresponding control samples (Emami et al., 2011). Extrusion cooking significantly lowers the pasting viscosity which is attributed to gelatinization of starch during the extrusion cooking due to high temperature along with high moisture and shear. The viscosity of paste largely depends upon the degree of gelatinization of starch and the molecular breakdown due to shear action of screw during extrusion (Carvalho et al., 2010).

Koksel et al. (2004) reported a sharp decrease in pasting profile of barley after extrusion cooking. Al-Rabadi et al. (2011) reported that increasing the temperature of extrusion decreased the peak viscosity significantly of extrudates prepared from barley flour and barley fines. The peak viscosity appeared due to presence of ungelatinized starch present in extrudates (Sopade et al., 2006). Moreover, higher final viscosity may be due to the higher leaching of macromolecules (Jacobs et al., 1995), and the formation of viscous paste (Ozcan and Jackson, 2005). Wheat flour was blended with β-glucan (Glucagel®) at different levels (2.5% and 5.0%) for bread making and these blends were studied for their pasting behavior, the peak, final and breakdown viscosity were decreased sharply depending upon the concentration of β-glucan (Brennan and Cleary, 2007). Symons and Brennan (2004a) studied the effect of incorporation of β-glucan rich fraction to wheat flour at 2.5 and 5.0% level and reported that the both level of
incorporation significantly lowered the pasting properties. The β-glucan was extracted from barley and incorporated in wheat starch and studied for pasting and thermal properties and it was reported that addition of β-glucan lead to sharp decrease in pasting properties (Symons and Brennan, 2004b) however, 1% incorporation of β-glucan did not affect pasting properties significantly. Ragaee and Abdel-Aal (2006) reported that the incorporation of barley flour at 15% level in soft wheat flour showed significant decrease in PV, FV and BV and PT while it increased the PV, FV and BD when incorporated in hard wheat flour.

Middlings from whole barley and pearled barley were incorporated in wheat flour up to 60% level and the peak viscosity ranging from 2031 to 2153 cP, final viscosity from 2097 to 2192 cP and breakdown viscosity from 1034 to 1074 cP was reported after addition of whole barley middlings while addition of pearled barley middling showed peak viscosity from 2059 to 2074 cP, final viscosity from 2165 to 2182 cP and breakdown viscosity from 1025 to 1031 cP (Sullivan et al., 2011).

2.7 Thermal properties

Two different barley cultivars pearled at 10 and 40% of their original weight were milled to flour and evaluated for their thermal properties using a Differential Scanning Calorimetry (DSC), the enthalpy of gelatinization ranged from 6.6 to 7.4 J/g, onset temperature 60.5 to 63.8°C and peak temperature 66.6 to 72.6°C (Klamczynski et al., 1998). Ahn et al. (2005) reported an enthalpy of gelatinization of 2.22 J/g, onset temperature of 60.8°C and peak temperature of 67.8°C for Merlin barley cultivar. Ao and Jane (2007) studied barley starches and reported enthalpy of gelatinization of 12.6 J/g and peak temperature of 62.6 °C. Peak gelatinization temperature of barley flour was reported to be 68.5°C (Altan et al., 2009b). Three different barley cultivars showed enthalpy of gelatinization ranging from 2.9 to 9.6 J/g, onset of gelatinization temperature ranging from 60 to 64°C, peak temperature ranging from 64.2 to 72.6°C (Emami et al., 2011). Whole barley flour from eight different cultivars were analyzed for their thermal properties and it was reported that the enthalpy of gelatinization ranged from 4.45 to 7.08 J/g, and temperature to peak ranged from 64.23 to 66.26 °C, conclusion temperature ranged from 69.05 to 71.45°C and onset temperature ranged from 59.55 to 71.17°C
Starches from eight different barley cultivars were isolated and studied for their thermal properties and it was reported that the enthalpy of gelatinization ranged from 3.69 to 4.87 J/g, and the peak temperature ranged from 63.56 to 68.30 °C (Gujral et al., 2012a).

Cereal foods are processed by the application of heat that causes the gelatinization of starch and denatures the proteins. When the heat processed cereals are analyzed on DSC, they exhibit a decrease in the enthalpy of gelatinization depends upon the severity of heat treatment (dry heat or moist heat) and composition of raw material. Infrared heating of barley after conditioning significantly affects the thermal properties and lowers the enthalpy of gelatinization upto 2.26 J/g (Fasina et al., 1999). Granfeldt et al. (2000) performed the thermal analysis of raw barley and barley flakes and reported that the raw barley had higher enthalpy of gelatinization (8.05 J/g) as compared to barley flakes (5.89 J/g). A large variation was also reported in the onset temperature of raw barley (52.6 °C) and barley flakes (39.7 °C) but peak temperature was not affected significantly. It has been reported that the jet cooking of barley flour lead to complete gelatinization of starch present in flour because no peak was observed in cooked flour determined by DSC however native flour exhibited a characteristic peak at 67 °C (Lee and Inglett, 2006a). Conditioning of barley at different moisture and further processing by infrared heating lead to a decrease in enthalpy of gelatinization depending upon time and power of heating (Emami et al., 2011). Sharma et al. (2011) studied the effect of sand roasting on thermal properties of different barley cultivars using DSC and pointed out that the roasting lead to a decrease in enthalpy of gelatinization. The flour from sand roasted barley exhibited enthalpy of gelatinization ranging from 0.16 to 0.77 J/g, onset temperature of 51.9 to 57.8°C and peak temperature of 64.2 to 66.3°C. Extrusion cooking of barley lead to a significant decrease in enthalpy of gelatinization and peak temperature depending upon extrusion conditions (Altan et al., 2009b).

Bread and chapatti (Indian flat bread) start to deteriorate immediately after baking due to loss of water and retrogradation of starch (Gujral et al., 2008; Purhagen et al., 2011a). Efforts have been made to extend the shelf life by addition of different gums and hydrocolloids during bread making (Gujral and Pathak, 2002; Mandala and Sotirakoglou, 2005; Shaikh et al., 2008). Different parameters such as firmness, springiness, water...
migration and retrogradation are used for measurement of staling of bread and chapatti (Shaikh et al., 2008; Ronda and Ross, 2011). Addition of barley β-glucan in wheat starch significantly affects the thermal characteristics exhibiting the enthalpy of gelatinization ranging from 7.43 to 9.07 J/g (Symons and Brennen, 2004b). Cleary and Brennen (2006) studied the effect of addition of different concentrations of β-glucan on thermal properties of pasta and reported that the enthalpy of gelatinization was significantly affected. Bread was prepared using two different concentration of Glucagel (a concentrated source of β-glucan, 2.5 and 5%) and evaluated for thermal properties, the onset temperature was significantly affected and a significant decrease in endset temperature was reported, however, peak temperature was not affected significantly. The enthalpy of gelatinization was significantly decreased after addition of Glucagel at both levels (Brennan and Cleary, 2007).

Skendi et al., (2010) studied the effects of incorporation of β-glucan in wheat flour for bread making and reported that the bread containing β-glucan did not show enthalpy of retrogradation. Bread prepared with added barley flour (heat treated and raw) was studied using DSC for its retrogradation behavior and it was observed that the barley flour affects the rate of staling (Purhagen et al., 2011a). Purhagen et al. (2011b) studied the effects of incorporation of different fibers in bread to delay the staling and reported that the addition of oat bran significantly retards the retrogradation.

2.8 β-glucan content

The mixed linkage (1→3), (1→4) β-glucan is a major component of cell wall of barley (Stone and Clarke, 1992; Buckeridge et al., 2004; Holtekjolen et al., 2006) and has attracted the attention of researchers and industrialist due to its unique characteristics. Structurally β-glucan is similar to cellulose but the β-(1→3) linkage makes the major difference between both (Jadhav et al., 1998). It is a liner polymer that is consists of cellotriosyl and cellotetraosyl units joined by β-(1→3) linkages. The presence of these β-(1→3) linkages leads to kinks in the straight chain polymer, allowing water to get in between the chains making beta-glucan soluble in water, thus beta-glucan is classified as a soluble dietary fiber (Collins et al., 2010). Solubility of β-glucan largely depends upon the number of β-(1→3) linkages (Gomez et al., 1997a, b; Fincher, 2009a, b). Most of the
water soluble barley β-glucan contains approximately 30% (1→3) and 70% (1→4) linkages, which are organized into blocks of two or three (1→4)-linked residues separated by single (1→3)-linked residues (Izydorczyk and Dexter, 2008; Izydorczyk, 2010; Wood, 2010). Unique feature of barley grain is that the β-glucan is uniformly distributed in the kernel while it is more concentrated in outer layers in oat grain, thus pearling or removal of outer layer does not affects the β-glucan content in barley (Fincher, 1975; Autio et al., 2006; Vasnathan and Temelli, 2008; Cui and Wang, 2009).

The concentration of β-glucan largely depends upon the cultivars and environmental conditions (Perez-Vendrell et al., 1996; Zhang et al., 2001; Zhang et al., 2002; Ehrenbergerov et al., 2008; Andersson and Borjesdotter, 2011; Dickin et al., 2011; Kinner et al., 2011). Amount of β-glucan ranges from 2 to 11% but generally fall between 4 to 6%, although it is reported to be as high as 17% in certain cultivars (Aman and Graham, 1987; Zhang et al., 2002; Brennan and Cleary, 2005). It has also been reported that the high amylose and amyllopectin cultivars had higher amount of β-glucan as compared to normal amylose and amyllopectin cultivars (Oscarsson et al., 1996; Xue et al., 1997).

Lehtonan and Aikasalo (1987) studied 50 cultivars of six rowed and 68 cultivars of two rowed barley for their β-glucan content and reported that the β-glucan in six rowed barley cultivars ranged from 2.8 to 4.3% while in two rowed barley ranged from 3.5 to 5.3%. Different hulled barley cultivars were studied for their total soluble and insoluble β-glucan and it was reported that the average total β-glucan in barley was 4.5% and 54% of the total was in the form of soluble β-glucan (Aman and Graham, 1987). Bhatta et al. (1991) examined hull-less barley for their β-glucan content and reported that the total and soluble β-glucan ranged from 3.9 to 5.4% and 1.0 to 2.7%, respectively. Knuckles et al. (1992) studied different barley cultivars for their total, soluble and insoluble β-glucan and reported that the total β-glucan ranged from 5.1 to 7.2%, soluble β-glucan 2.4 to 4.8% and insoluble β-glucan 2.3 to 3.2%. Oscarsson et al. (1996) reported that the β-glucan content ranged from 3.8 to 6.3% and 4.7 to 7.9% in different hulled and hull-less barley cultivars, respectively. It has been reported that the β-glucan ranged from 3 to 7% in non-waxy barley cultivars (Xue et al., 1997). Knuckles et al. (1997) produced bread with
barley flour and reported that the blend containing barley flour exhibits total, soluble and insoluble β-glucan of 0.31, 0.06 and 0.25%, respectively.

Klamczynski et al. (1998) studied different barley cultivars for their composition and pointed out that the β-glucan ranged from 3.3 to 5.7%. Marconi et al. (2000) reported that the β-glucan in two different barley cultivars ranged from 4.2 to 4.5%. Kalra and Jood (2000) reported total and soluble β-glucan ranged from 2.18 to 4.60% and 1.08 to 2.06%, respectively in three different Indian barley cultivars. In an other study, Jood and Kalra (2001) reported that the total β-glucan content in Indian barley cultivars ranged from 2.18 to 6.23%. Izydorczyk et al. (2001) reported that the total and soluble β-glucan ranged from 3.9 to 8.0% and 1.2 to 3.2%, respectively, in different barley cultivars. Average β-glucan content in barley commonly grown in Turkey is 3.6% (Genc et al., 2001). Storsley et al. (2003) studied the different hull-less barley cultivars and reported that the β-glucan content ranged from 3.64 to 7.96%. The average β-glucan content ranged from 3.09 to 4.05% in different winter and spring cultivars of hulled barley (Nielsen and Munck, 2003). Irakli et al. (2004) studied the structural feature and rheological properties of water soluble β-glucan from different barley cultivars and reported the total β-glucan ranged from 3.91 to 5.93%. Demirbas (2005) reported that the β-glucan content of barley grown in Turkey ranged from 3.2 to 4.6%, further he reported that barley grown in USA has highest average β-glucan content (7.2%) while that grown in Canada has the lowest (1.7%). Water soluble and insoluble β-glucan content in different barley cultivars was reported to range from 3.75 to 7.96% and 10.89 to 21.70%, respectively (Gajdosova et al., 2007). β-glucan content in 35 different hulled barley cultivars ranged from 2.64 to 8.05% and average β-glucan content was reported to be 3.95% (Panfilli et al., 2008). A large variation in total, soluble and insoluble β-glucan in barley cultivars ranging from 3.5 to 6.8%, 2.6 to 4.9% and 0.1 to 2.5% has been reported (Holtekjolen et al., 2008).

Eight different hulled barley cultivars grown under different temperature conditions were studied for their β-glucan content and it was reported that average total β-glucan content ranged from 4.3 to 6.6% while the soluble and insoluble β-glucan ranged from 0.6 to 3.3% and 2.5 to 5.1%, respectively (Anker-Nilssen et al., 2008). Liu et al. (2009) reported the total β-glucan was approximately 4% in whole grain before
pearling. Sullivan et al. (2010a) studied the effect of pearling on composition of barley grain and reported that the whole barley flour contained 3.27% β-glucan. Griffey et al. (2010) evaluated different hulled and hull-less cultivars after growing them for four years, and reported that the average β-glucan content was 4.0% for malting cultivars while 4.2% for hull-less cultivars. Lee et al. (2011) reported that the β-glucan content in five different Korean barley cultivars after pearling ranged from 5.2 to 8.4%. Dickin et al. (2011) reported that the β-glucan content in different naked barley cultivars grown in different environments ranged from 2.2 to 7.7%. Rieder et al. (2012) studied the effects of barley flour on bread quality and reported that the barley cultivars have total β-glucan of 5.3 to 5.6%.

Barley β-glucan content can be affected by processing treatments. It has been reported that processing conditions significantly affects the β-glucan content in barley (Izydorczyk et al., 2000; Molina-Cano et al., 2004; Koksel et al., 2004; Kanauchi and Bamforth, 2008; Sharma et al., 2011; Sharma and Gujral, 2012). Germination of barley significantly decreased the β-glucan content due to enhanced β-glucanase activity which degrades the β-glucan (Nielsen and Munck, 2003; Wang et al., 2004). However, the thermal processing of barley impacts differently on β-glucan. In India barley is utilized after roasting in sattu making, a traditional food used in refreshment drink in summer (Jood and Kalra, 2001; Sharma et al., 2011) and little attention has been given to study the effect of sattu making on β-glucan. Grain roasting and popping is an important unit operation for preparation of grain product with longer shelf life, better sensory quality and more retention of nutritional value. The roasting process has also been reported to have an affect on β-glucan (Jha, 2005; Gujral et al., 2011; Sharma et al., 2011).

A steep decrease in soluble β-glucan and increase in insoluble β-glucan without significantly affecting the total β-glucan has been reported by Sharma et al. (2011) upon roasting of barley. On the other hand, bulgur making and cooking of barley significantly increases or decreases the β-glucan content depending upon cultivars (Koksel et al., 1999). Basman and Koksel (2001) reported that during the baking of flat bread there was upto 6% loss in β-glucan as compared to raw material. Cavallero et al. (2002) reported that the baking of bread did not affect the total β-glucan significantly. Andersson et al. (2004) reported that the mixing during dough making and fermentation decreased the β-
glucan content. Process such as cooking and baking affect the physical state of β-glucan in terms of extractability, solubility and viscosity and also in the content of, total, soluble and insoluble β-glucan (Johansson et al., 2007). Izydorczyk et al. (2000) reported that the hydrothermal treatment along with enzymes and further sonication during the extraction improves the solubility thus increasing the amount of soluble β-glucan. Moreover, it is not necessary that the hydrothermal treatment increases the levels of soluble β-glucan but it exerts a positive effect on solubility of β-glucan however roasting did not show same effect. More recently, it has been reported that the baking decreased the amount of soluble β-glucan while cooking increased the soluble β-glucan (Johansson et al., 2007).

Extrusion cooking is very popular these days worldwide due to its many advantages such as fast process, versatility and low cost, also the products made by extrusion cooking have long shelf life due to low moisture (Chiu et al. 2011; Santillan-Moreno et al., 2011). Since the β-glucan is a functional component of barley therefore, to study the changes in β-glucan during extrusion cooking is very important. Effects of extrusion cooking on the nutritional quality and fiber in wheat, rye and barley have been reported by Wang and Klopfenstein (1993). Huth et al. (2000) reported the functional properties of barley dietary fiber upon extrusion cooking. It has been reported that the extrusion cooking leads to greater changes in dietary fiber profile (Vasanthan et al., 2002) however moderate extrusion conditions did not affect the dietary fiber composition (Singh et al., 2007). It has also been reported that the use of low shear type screw for extrusion of barley had insignificant effect while the extrusion using high shear screw lowered the amount of total β-glucan significantly (Koksel et al., 2004). Gill et al. (2002a, b) studied the effect of addition of extruded barley flour to wheat bread and evaluated the effect on fiber content. It has been reported that the extrusion cooking did not affect β-glucan content in barley and oats (Vranjes and Wenk, 1995; Yao et al., 2006). Moreover, Fadel et al. (1988) reported an insignificant increase in total β-glucan upon extrusion cooking. Recently, it has been reported that the total β-glucan significantly decreased upon extrusion cooking, however the insoluble β-glucan may increase, decrease or remain unchanged depending upon cultivars in oats (Yao et al., 2011). Temperature and applied shear action of screw during extrusion cooking may lead to increase in the soluble β-glucan (Wood et al., 1989; Brennan and Cleary, 2005)
2.9 β-glucan extractability

The beneficial physiological effects of β-glucan have been widely accepted therefore food and supplement industries are highly interested in extraction and purification of β-glucan for incorporation in foods (Vasanthan and Temelli, 2008). Such β-glucan extraction methods are desired which give the highest yield without affecting its molecular weight and depolymerization, because both these characteristics have pronounced effects on its physiological activity (Wood, 2010). There are two major methods by which β-glucan can be extracted or concentrated, one is dry fractionation and other is wet extraction (Ghotra et al., 2008).

In the dry fractionation, milling and sieving is carried out in such a way that the fractions separated by sieving contain higher levels of β-glucan. Dry fractionation involves various operations that include roller milling, hammer milling, abrasion milling, pearling, and shifting (Knuckles et al., 1992; Yoon et al., 1995; Kiryluk et al., 2000; Zheng et al., 2000; Izydorczyk and Dexter, 2008). However by these methods only approximately 30% β-glucan concentrates have been achieved (Vasanthan and Temelli, 2008). The alternative method for concentrating β-glucan is wet extraction, using this method β-glucan can be concentrated up to 95%. This method may be divided in four categories depending upon use of solutions, (i) aqueous thermo-mechanical treatment (ii) aqueous enzymatic treatments (iii) aqueous or aqueous alkali extraction (iv) aqueous alcohol based enzymatic treatment (Vasanthan and Temelli, 2008). There is also an alcohol free process of concentrating β-glucan that involves either heating or freezing the final solution after extraction with water eliminating the alcohol precipitation step (Potter et al., 2003; Morgan, 2003). However, during aqueous extraction, endogenous β-glucan degrading enzymes such as β-glucanase may be activated and it degrades or fragments the β-glucan thus lowering the molecular weight consequently lowering viscosity (Ghotra et al., 2008). These effects can be overcome by inactivating the enzymes, like by refluxing the flour in boiling ethanol (80% v/v) before extraction (McCleary and Glennie-Holmes, 1985; Beer et al., 1997). A number of extraction and purification studies have been carried out. Wood et al. (1977) first reported the extraction procedure of β-glucan. The yield, purity, structure and molecular weight is affected by the choice of extraction procedure. Concentration of β-glucan in gum extracted by aqueous enzymatic and
aqueous thermo-mechanical methods has been reported (Inglett, 1992, 2000). Morgan and Ofman (1998) extracted the β-glucan with water followed by repetitive freezing and thawing that leads to separation of solids that are rich in β-glucan upto 94%. Goering and Eslick (1989) reported that the β-glucan can be extracted by water and the endogenous enzymes inactivated by heating the slurry at 95 to 115°C for 1 to 2 h. Wang et al. (1996) reported that upto 75% β-glucan extractability can be achieved using the water as a solvent. Simple water extracted barley flour has comparatively lower β-glucan content (33%) (Cavallero et al., 2002). Oscarsson et al. (1996) reported that the extractability of β-glucan ranged from 28.6 to 57.7% for hulled and 36.7 to 69.0% for hull-less cultivars.

Burkus and Temelli (1998) investigated the effects of extraction conditions on yield and purity of β-glucan and they reported that the highest purity (81.3%) and yield (4.1%) can be achieved by boiling the extract of barley at pH 7. Woodward et al. (1983, 1988) extracted the β-glucan from barley flour with water at 40 and 65°C and precipitated it with 30% ammonium sulphate, further it was purified with α-amylase. Temelli (1997) used water for extraction at different pH (7 to 10) and temperature (40 to 55°C) and reported that the yield of gum ranged from 3.28 to 5.54% and purity 57 to 89%, the highest yield and purity was obtained at pH 7 and temperature 55°C. The temperature of extraction also affects the molecular weight and ratio of (1→4) and (1→3) of β-glucan (Storsley et al., 2003). Recently, it has reported that not only temperature and solvents but also pH, particle size, stirring rate and solvent to flour ratio affect the β-glucan extractability (Benito-Roman et al., 2011). Burkus and Temelli (1999) reported that the β-glucan content in extracted gum ranged from 55 to 72%. The sequential extraction of β-glucan has been carried out at 40, 65 and 95°C and it was reported that increasing the temperature increases the yield of β-glucan (McCleary, 1988). It has been reported that starch may be extracted along with β-glucan when the extraction is carried out beyond the starch gelatinization temperature therefore it is required to eliminate the starch from the extract using enzymes (Brennen and Cleary, 2005). Saulnier et al. (1994) used hot water for extraction of β-glucan and further removed the starch impurities using thermostable α-amylase. The β-glucan was extracted from different oat and barley flours with hot water containing thermostable α-amylase and studied for their molecular weight using flow-injection analysis and high-performance size-exclusion chromatography, and
it was observed that the extractable β-glucan was between 60 to 75% (Beer et al., 1997). Tejinder (2003) extracted the β-glucan from barley, and before extraction of flour with warm water, treated it with hot ethanol to inactivated β-glucanase activity, the extracted material contained 77.3 to 79.3% β-glucan and further this material was used for preparation of edible film. In a study carried out by Burkus and Temelli (2005) reported the proximate composition of β-glucan enriched gum extracted from barley and observed that the β-glucan content in gum was ranged from 78 to 83.3%. Ghotra et al. (2009) reported 82% recovery of β-glucan from barley β-glucan concentrate. Faraj et al. (2006) extracted the gum from barley using hot water and reported the content of β-glucan in gum to be 50.7% to 87.5%. Bhatty (1993b) studied the effect of solvent on β-glucan extractability of barley bran and reported that the highest yield of 64% β-glucan can be achieved by extraction with 20% sodium carbonate solution at pH 10. The β-glucan concentrates may be prepared by aqueous and alkali extraction of flours and these methods have been used at pilot plant level. Bhatty (1995) used alkali solution (0.25 and 1N) for extraction of β-glucan from barley bran at laboratory and pilot plant scale and reported the extractability upto 98%; he used the thermostable α-amylase for purification of β-glucan. A sequential solvent extraction and structural characterization of polysaccharides from the endosperm cell walls of barley grown in different environments has been carried out by Lazaridou et al. (2008), they sequentially extracted the β-glucan with water (65°C), saturated Ba(OH)₂, again with water at 25°C, and 1M NaOH and further purified by dialysis. They reported the Aspen parkland region with thick black soil (Hamiota, Manitoba, MB) contained the highest extractable β-glucan content. Saulnier et al. (1994) extracted the β-glucan from barley by sequential treatment with water at 40°C, at 90°C with thermostable α-amylase and 1M NaOH at room temperature; this sequential extraction method extracted almost all β-glucan present in grain. Different hull-less barley cultivars were milled into flour, bran and short fraction and analyzed for their extractable β-glucan. Flours from different barley cultivars varying in amylose content were studied for extraction of non starchy polysaccharide such as β-glucan and arabinoxylans, by sequentially extraction with water, alkaline [Ba(OH)₂], again with water, and finally with NaOH and it was reported that the Ba(OH)₂/H₂O and NaOH fractions contained more β-glucan than arabinoxylans (Izydorczyk et al., 2003).
It has been reported that the solubilization of β-glucan can be enhanced by the application of temperature; also the endogenous enzymes assist the extraction process except β-glucanase (Kanauchi and Bamforth, 2001). Vasanthan and Temelli (2002) reported that the yield of β-glucan ranged from 40 to 70% depending upon particle size of flour and solvent, they used water and solvent along with different enzymes. Goering (1991) also extracted the β-glucan from barley using different enzymes. Burkus and Temelli (2003) extracted β-glucan from barley by pilot plant extraction and laboratory scale procedure and reported a β-glucan extractability of 78.92 and 71.14%, respectively.

Gomez et al. (1997a) extracted β-glucan from barley samples by warm water at 65°C and thermostable α-amylase and it was further purified with proteinase-K to remove the protein impurities. Extraction of β-glucan can be carried out using alcohol and enzyme which is cost effective and provides high purity β-glucan, in this technique protein and starch materials are removed by enzymes and β-glucan remain as such and not solubilised thus the molecular weight of extracted β-glucan does not change (Vasanthan and Temelli, 2005).

It has been reported that the processing of barley and other grains significantly affects the β-glucan extractability (Johansson et al., 2007). Andersson et al. (2004) studied the effect of bread baking on β-glucan and reported that neither bread baking nor dough making affects the ratio of (1→4) to (1→3) linkage however β-glucan may be degraded by endogenous enzymes in barley or wheat flour used for baking. Baking of muffins increased the extractability of β-glucan though decrease in molecular weight was reported (Beer et al., 1997), baking of cookies and bread decreased β-glucan extractability and molecular weight of β-glucan (Kerkhoffis et al., 2003). The difference in extractability may depend upon the physical interaction between β-glucan and arabinoxylan components present in endospermic cell wall (Ebringerova et al., 2005). Robertson et al. (1997) reported that cooking and enzymatic treatment of barley flour increase the extractability significantly, they reported that the extractability ranged from 26.3 to 83.0% in control and treated samples. Sharma et al. (2011) studied the effects of sand roasting of barley on β-glucan extractability and reported that roasting did not affect the extractability due to short period of heating however in an another study Gujral et al. (2011) observed a significant increase in β-glucan extractability of oats upon sand
roasting. Cooking of porridge released more β-glucan while baking decreased the extractability (Johansson et al., 2007). On the other hand, the extractability increased upon baking of rye crisp bread (Andersson et al., 2008). It has been demonstrated that the β-glucanase treated muffins made from oats, exhibited increased β-glucan solubility/extractability but molecular weight decreased (Tosh et al., 2008). Tosh et al. (2010) investigated that the extrusion conditions significantly affects β-glucan extractability, they observed increased β-glucan solubility of extruded oats. Huth et al. (2000) reported that the moisture content of feed material significantly affected the β-glucan extractability as compared to the extrusion temperature. The heat treatment increased the extractability of β-glucan as well as viscosity of solution in barley (Ames et al., 2006). It has been reported that the β-glucan extractability can be improved by using higher temperature and moisture (autoclaving) (Izydorczyk et al., 2000). Burkus and Temelli (1998) also reported that the heat treatment enhances the amount of extractable β-glucan. Yiu et al. (1991) studied the effect of conventional and microwave cooking on solubility of β-glucan of oats and observed that conventional cooking lead to more solubilization of β-glucan as compared to microwave cooking. Increasing the temperature during extraction at pH 7 increased extractability of β-glucan of barley flour (Temelli, 1997; Kanauchi and Bamforth, 2001). It has been reported that the heat treatment also inactivates or slows down the activity of endogenous enzymes thus these may not degrades the β-glucan therefore resulting in more extractability (Doehlert et al., 1997). It has been reported that the solubility of β-glucan depends upon the storage conditions, Moriartey et al. (2010) demonstrated that the frozen storage of bread containing β-glucan, enhances the solubility of β-glucan as compared to refrigerated and room temperature stored breads. The extractability of β-glucan increased upto 38% after jet cooking without pH adjustment while it has been observed to be 63.5% after jet cooking at pH 11 (Rose et al., 2010).

2.10 Total phenolic content

Phenolic compounds are the compounds that contain one or more aromatic rings along with one or more hydroxyl group; these include flavonoids, phenolic acids, flavonols and amino phenolic compounds (Liu, 2004). Similar to fruits and vegetables,
grains also contains phenolic compounds and these compounds are largely concentrated in the outer most layers of the grain (Naczk and Shahidi, 2006; Liu, 2007; Madhujith and Shahidi, 2008). The phenolic compounds are basically produced by secondary metabolism in plants. The main functions of phenolic compounds include defense of plants against pathogens, predators and parasites; growth of plants and contribute in color development of plants (Jonnalagadda et al., 2010). Some phenolic compounds are specific to cereal grain and are not present in significant amounts in fruits and vegetables like ferulic acids and diferulates (Shahidi and Naczk, 1995; Bunzel et al., 2001). It is well known that the phenolic compounds have potent antioxidant properties and free radical scavenging capabilities (Shahidi and Wanasundara, 1992). They are known to exert various physiological effects in humans, such as preventing oxidative damage of lipid and low-density lipoproteins (Morton et al., 2000), inhibiting platelet aggregation (Daniel et al., 1999), and reducing the risk of coronary heart disease and cancer (Newmark, 1996; Valverde et al., 2000).

Barley is considered as a rich source of phenolic compounds among the cereals (Bendelow and LaBerge, 1979; Sharma et al., 2012). Barley contains many phenolic compounds in the free and bound form including benzoic and cinnamic acid derivatives, proanthocyanidins, quinines, flavonols, chalcones, flavones, flavanones, and amino phenolic compounds which are concentrated in the outer layers of the barley grain (Goupy et al., 1999). Ferulic acid and p-coumaric acid are known as phenolic compound abundantly found in whole grains including barley; this phenolic compound exists in free, bound and soluble-conjugated form (Maillard and Berset, 1995; Madhujith and Shahidi, 2009). The composition of phenolic compounds depends upon the grain type, cultivars and morphological fraction used for analysis (Kahkonen et al., 1999; Madhujith et al., 2006; Gorinstein et al., 2007). The extraction conditions and solvent also affects the amount of phenolic content (Bonoli et al., 2004; Naczk and Shahidi, 2004). Zielinski and Kozlowska (2000) studied the antioxidant activity and total phenolic content in different cereals including barley and its morphological fractions and reported that the total phenolic content ranged from 10.20 to 26.90 µg of catechin/mg of lyophilizate in whole barley while it was 27.96 to 36.81 µg of catechin/mg of lyophilizate for outer layers (bran). Bonoli et al. (2004) extracted barley flour using different solvents and reported
values of total phenolic content ranging from 0.13 to 0.68 mg gallic acid/g flour. The extraction conditions 80.2% methanol and 60.5°C temperature for 38.6 min were optimized using response surface methodology and the total phenolic content ranging from 13.58 to 22.93 mg of ferulic acid equivalents/g on the basis of lyophilized weight was reported (Madhujith and Shahidi, 2006). Total phenolic content ranging from 1.03 to 1.87 mg of gallic acid equivalents/g in different barley cultivars was reported (Zhao et al., 2006). Total phenolic content in different hulled and hullless barley cultivars has been reported to be between 966 and 1873 µg/g of barley flour (Holtekjolen et al., 2006). Madhujith et al. (2006) reported that the outer-most layers of barley had highest total phenolic content ranging from 0.17 to 6.26 mg ferulic acid equivalents/g defatted material. Choi et al. (2007) studied the antioxidant activity of different grains commonly consumed in Korea including barley and reported that barley contains 50 mg/100g total polyphenols. Six different barley cultivars were evaluated for their total phenolic content that ranged from 0.68 to 1.19 mg of ferulic acid equivalents/g of defatted material (Madhujith and Shahidi, 2007). Kim et al. (2007) investigated different colored barley for their antioxidant activity and reported that the total phenolic contents ranged from 191.6 to 403.8 µg/g. Fourteen malting barley cultivars were evaluated for antioxidant profile and it was reported that the total phenolic content ranged from 2.17 to 2.56 mg gallic acid equivalents/g db (Zhao et al., 2008). Madhujith and Shahidi (2009) reported a total phenolic content ranging from 2.63 to 4.51 mg ferulic acid equivalents/g defatted material in different barley cultivars. The total phenolic content ranging from 2.5 to 3.0 mg ferulic acid equivalents/g in barley has also been reported (Menga et al., 2010). Zilic et al. (2011) investigated the antioxidant properties of different cereals including different hull-less barley cultivars and reported that the total phenolic content ranged from 2.81 to 3.79 mg catechin equivalents/g.

The processing conditions significantly affects the total phenolic content in grains and they may increase or decrease depending upon the type of process and kind of food material (Dewento et al., 2002a, b; Altan et al., 2009c; Zhang et al. 2010; Gujral et al., 2011). Malting of barley may increase or decreased the total phenolic content depending upon cultivars, the total phenolic content in control barley ranged from 1.0 to 17.5 µg ferulic acid equivalents/g while after malting it ranged from 3.9 to 9.4 µg ferulic acid
equivalents/g (Goupy et al., 1999). The germination and malting process increased the total phenolic content in barley from 3.11 to 3.19 mg gallic acid equivalents in malt (Quinming et al., 2010). Effect of germination duration on antioxidant activity of different barley cultivars and their milling fractions has been studied and total phenolic content reported to range from 3070 to 4439 µg ferulic acid equivalents/g of flour and after germination it decreased (Sharma and Gujral, 2010b).

Roasting is a simple and convenient process that uses dry heat for short periods of time for improving grain characteristics. The roasting process is part of the malting process and is typically known as kilning and is done to produce characteristic flavor and color in the malt (Maillard et al., 1996; Goupy et al., 1999; Dvorakova et al., 2008). Roasting of grains is also done to produce snack foods. The roasting can be carried out either in hot sand, microwave oven or hot air oven depending upon choice of product (Omwamba and Hu, 2009; Omwamba and Hu, 2010; Gujral et al., 2011; Sharma et al., 2011).

The antioxidant activity of barley has been evaluated during kilning and the effects on insoluble bound phenolic acids of barley and malt were examined. It was reported that the total phenolic content ranged from 303.44 to 704.03 µg/g with the highest values observed for barley kilned at 80°C while the lowest exhibited by germinated barley (Maillard and Berset, 1995). Malting of barley significantly increased the total phenolic content from 0.98 to 1.87 mg gallic acid equivalents /g to 1.32 to 2.30 mg gallic acid equivalents/g (Maillard et al., 1996). Roasted barley exhibited the total phenolic content of 377.6 µg/g while it was 504.4 µg/g in control barley (Samaras et al., 2005). It has been reported that the killing process leads to a significant increased in total phenolic content in Gan4 (15.2%) and Hamelin (9.9%) cultivars of barley (Lu et al., 2007).

Omwamba and Hu (2009) roasted barley in hot air oven at 200 to 250°C for 50 to 70 min and reported total phenolic content ranging from 3.17 to 4.01 mg gallic acid equivalent/g. The antioxidant properties of infant cereal were studied and reported that the Milupa barley cereal exhibited total phenolic content of 800 mg ferulic acid equivalents/kg (Li et al., 2010). Roasting of barley was carried out using microwaves at different power and roasting conditions were optimized, the total phenolic content in
aqueous and acetone extracts were reported to be 3.52 and 6.92 mg gallic acid equivalents/g of extracts (Omwamba and Hu, 2010). It was reported that the cooking and roasting increased the total phenolic content while germination decreased total phenolic content in Mexican barley cultivars (Gallegos-Infante et al., 2010). Sharma and Gujral (2011) studied the effect of sand and microwave roasting on antioxidant properties of eight different barley cultivars and reported that microwave roasting decreased the total phenolic content by 24.4 to 49.6% while sand roasting by 8.5 to 32.9%.

Zielinski et al. (2001) studied the effect of extrusion cooking on different cereal grains and they reported that barley had total phenolic content of 6.48 µg/g; while after extrusion cooking at 200°C it was increased to 24.31 µg/g. Stojceska et al. (2009) reported that the total phenolic content can be decreased or increased after extrusion depending upon the conditions of extrusion. They reported a total phenolic content of 1.9 mM gallic acid equivalent/g in control sample while after extrusion it ranged from 1.4 to 2.1 mM gallic acid equivalent/g depending upon extrusion condition. Altan et al. (2009c) studied the effects of extrusion cooking on barley extrudates and reported that the extrusion cooking significantly lowered (46 to 60%) the total phenolic content depending upon extrusion conditions. On the other hand, the total phenolic content was reported to decrease upon extrusion cooking and it ranged between 1374 to 2194 µg ferulic acid equivalents/g while before extrusion it was ranged from 3070 to 4439 µg ferulic acid equivalents/g (Sharma et al., 2012).

There are no reports on evaluation of total phenolic content in cookies made by incorporating barley flour. It has been reported that the incorporation of barley flour in wheat flour during bread making at levels of 40%, increased or decreased the total phenolic content depending upon cultivars (Holtekjolen et al., 2008). Incorporating germinated brown rice flour in wheat flour for chapatti making increased the total phenolic content of the flour blend from 1897 to 2144 µg FAE/g. However, baking of chapatti decreased the total phenolic content significantly by 3 to 29% (Gujral et al., 2012b). Bread prepared by incorporating barley flour (upto 15%) has higher total phenolic content (345.40 mg gallic acid equivalents/g) while wheat bread has (248 mg gallic acid equivalents/g) (Alu’datt et al., 2012).
2.11 Antioxidant properties

Numerous methods have been reported to evaluate antioxidant activity of foods and to explain how antioxidants function. Of these, metal chelating activity, reducing power, 2,2-diphenyl-1-picrylhydrazyl (DPPH) assay and total antioxidant activity are most commonly used for the evaluation of antioxidant activities (Duh et al., 1999; Amarowicz et al., 2000; Chang et al., 2002). DPPH is usually used as a substrate to examine the antioxidative effects of antioxidants (Soares et al., 1997; Duh et al., 2001). DPPH is a stable free radical and acts as a receptor of electron or hydrogen radical, and the reduction in DPPH is determined by the decrease in its absorbance at 517 nm. The results of DPPH radical scavenging activity can be expressed either in percentage decrease in absorbance or half maximal inhibitory concentration ($IC_{50}$) or µmol of appropriate standards.

The antioxidant activity may also be defined by the metal chelating activity, Fe$^{2+}$ is an important transition metal ion that contributes to the initiation of lipid peroxidation in food and biological systems. The interaction of Fe$^{2+}$ with ferrozine produces a dark color complex that is decreased by the action of metal chelator compounds present in the reaction mixture. The reducing power is also a reflection of antioxidant activity and in this assay the presence of antioxidants causes the reduction of the Fe$^{3+}$/ferricyanide complex to the ferrous form (Fe$^{2+}$) and is monitored at 700 nm (Meir et al., 1995). Zielinski and Kozlowska (2000) reported that the total antioxidant activity of different barley cultivars ranged from 0.218 to 0.246 µmol of Trolox equivalents/mg of lyophilizate. Madhujith et al. (2006) reported that the DPPH radical scavenging activity ranged from 0.80 to 69.30 µmol of ferulic acid equivalents per gram of defatted material in pearling fractions of two barley cultivars. DPPH radical scavenging capacity of barley has been reported to be 21.0 µmol/g (Ragae et al., 2006). The $IC_{50}$ values of DPPH free radical scavenging activity for different barley cultivars have been reported to range from 2.12 to 3.33 mg/ml and the metal chelating activity from 1.1 to 2.1 µmol of EDTA equivalents/g of defatted material (Madhujith and Shahidi, 2006). The DPPH radical activity in different colored barley samples varied from 46.4 to 86.3% (Kim et al., 2007). The oxygen radical scavenging capacity and hydroxyl radical scavenging capacity of barley has been reported to be 11.28 to 19.10 and 9.06 to 12.62 µmol of Trolox
equivalents/g of defatted material, respectively (Madhujith and Shahidi, 2007). The DPPH radical scavenging activity of different malting barley cultivars ranged from 9.33 to 11.78 µmol Trolox equivalents/g, the metal chelating activity ranged from 1.15 to 2.06 µmol EDTA equivalents/g and IC\textsubscript{50} values for DPPH free radical scavenging activity in barley pearling fractions has been reported to range from 0.51 to 3.75 mg/ml (Madhujith and Shahidi, 2008). The ORAC antioxidant activity of purple, black and common barley has been reported to be 5601, 3937 and 5437 µmol of Trolox equivalents per 100 g (Bellido and Beta, 2009). Different hull-less barley cultivars were studied for their DPPH radical scavenging activity (as IC\textsubscript{50}) and reducing power, the values ranged from 1.52 to 1.81 mg/g and 1.478 to 1.772 mg ascorbic acid equivalents/g, respectively (Zilic \textit{et al.}, 2011). Germination of eight hulled barley cultivars for 24 h significantly increased the DPPH radical scavenging activity from 17.01-24.92 % to 26.84-35.90% (Sharma and Gujral, 2010b). Duh \textit{et al.} (2001) roasted barley at different temperatures and investigated the antioxidant activity; they reported that the DPPH radical scavenging activity ranged from 16.7 to 35.2%, metal chelating activity ranged from 12.3 to 77.9% and reducing power (absorbance at 700nm) ranged from 0.270 to 0.148. Roasting of barley to prepare different types of malt (pale, green, lager, cara, crystal and chocolate) increased the antioxidant activity and its antioxidant activity was noticed as barley \approx green malt \approx stewed malt \approx pale malt \approx lager malt < cara malt < crystal malt <black malt \approx chocolate malt \approx roasted barley (Samaras \textit{et al.}, 2005). Kilning of barley significantly increased the DPPH radical scavenging activity, reducing power and metal chelating activity. DPPH radical scavenging activity of Gen4 barley variety was increased from 10.55 to 13.42 µmol Trolox equivalents/g after 5\textsuperscript{th} day of germination and the Hamelin variety exhibited increase from 11.90 to 12.56 µmol Trolox equivalents/g. The metal chelating activity of raw barley was reported to be 1.44 (Gen4) and 1.77 µmol of EDTA equivalents (Hamelin), after kilning both cultivars exhibited increase by 9.3 and 31.6%, respectively. The reducing power of Gen4 and Hamelin barley were 16.09 and 14.79 µmol of ascorbic acid equivalents/g of dry weight and after kilning it was increased by 10.7 and 28.5%, respectively (Lu \textit{et al.}, 2007).

Omwamba and Hu (2009) roasted barley in a microwave oven and reported that the DPPH radical scavenging activity ranged from 74.62 to 79.49%. The higher
antioxidant activity (90.5% DPPH radical scavenging activity) of roasted barley in microwave oven can be achieved using 600 W microwave power and 8.5 min roasting time (Omwamba and Hu, 2010). Infant cereal containing barley flour exhibited antioxidant activity (DPPH radical scavenging activity) of 63.19% (Li et al., 2010). The IC_{50} values of DPPH radical scavenging activity was reported to be 4000, 2600, 2000 and 1650 µg/ml for unprocessed, cooked, roasted and germinated barley, respectively (Gallegos-Infante et al., 2010). Sand and microwave roasting of different barley cultivars significantly increased the DPPH radical scavenging activity and it was reported that the Maillard browning was responsible for the increased activity (Sharma and Gujral, 2011).

The extrusion cooking of barley significantly lowered the antioxidant activity and it was reported to be 14.01 to 19.1% after extrusion under different temperature conditions (Altan et al., 2009c). On the other hand Sharma et al. (2012) reported that the extrusion cooking of barley increased the antioxidant activity and the increase depended upon the extrusion parameters such as temperature and feed moisture and the increase was attributed to formation of Maillard browning pigments. It has been reported that the baking time and moisture content significantly affected the antioxidant activity of cookies (Summa et al., 2006). Ajila et al. (2008) reported that the addition of mango peel powder in cookie formulation enhanced the DPPH radical scavenging activity. It was reported that the antioxidant activity of cookies was increased by increasing the baking time, temperature and concentration of glucose (Morales et al., 2009).

It has been reported that the bread prepared by incorporating barley fiber rich fractions in wheat flour has higher antioxidant activity and after baking the antioxidant activity increased due to Maillard browning reactions (Ragaee et al., 2011). The antioxidant activity of wheat flour blends was reported to increase significantly by the addition of control and germinated brown rice flour. Baking of the flour blends into chapatti increased the reducing power and metal chelating activity by three folds and AOA from 64 to 104% (Gujral et al., 2012b).

2.12 Total flavonoid content

Flavonoids have generated interest because of their broad human health promoting effects, many of these effects are related to their antioxidant properties, which
may be due to their ability to scavenge free radicals (Mira et al., 2002) and to synergistic effects with other antioxidants (Filipe et al., 2001). Another antioxidant mechanism of flavonoids may result from the interactions between flavonoid and metal ions (especially iron and copper) leading to chelation of ions (Van-Acker et al., 1996; Miller et al., 1996; Moran et al., 1997; Morel et al., 1998).

Total flavanols in different barley cultivars ranged from 12.4 to 255.6 µg catechin equivalents/g while after malting they were decreased and ranged from 4.9 to 52.4 µg catechin equivalents/g (Goupy et al., 1999). Holtekjolen et al. (2006) reported that the total flavonoids content in different hulled and hull-less barley cultivars ranged from 325 to 527 µg/g of barley flour. The total flavonoids content in different colored barley cultivars ranged from 112.3 to 241.3 µg catechin equivalents/g. (Kim et al., 2007). The total flavonoids content in different barley cultivars after sand and microwave roasting have been reported ranged from 1039.8 to 1277 µg catechin equivalents/g and 991 to 1160 µg catechin equivalents/g, respectively, however the control samples ranged from 1387 to 2246 µg catechin equivalents/g (Sharma and Gujral, 2011). The extrusion cooking of different barley cultivars under different feed moisture and temperature conditions significantly lowered the total flavonoid content and it ranged from 766 to 1223 µg catechin equivalents/g (Sharma et al., 2012). The total flavonoid content (TFC) increased significantly from 632.3 to 1770.9 µg CAE/g when brown rice flour was added to the whole wheat flour, and after baking of chapatti decreased the total flavonoids content by 25 to 42% (Gujral et al., 2012b).

2.13 Polyphenol oxidase (PPO) activity

The polyphenol oxidase is a naturally occurring enzyme present in wheat, barley and their related species. It is also documented that this enzyme is highly concentrated in outer-most layers of the kernel (Hatcher and Kruger, 1993; Hatcher and Kruger, 1997). Thus the degree of milling or pearling also influences the amount of polyphenol oxidase in flour. This enzyme is responsible for the discoloration of food prepared from barley and affects consumer acceptability (Baik and Ullrich, 2008). It is a substrate specific enzyme and requires oxygen for its activity. The discoloration of barley based food can occurs either by the auto-oxidation of polyphenols in presence of oxygen or by oxidation
of phenolic compounds catalyzed by polyphenol oxidase (Quinde-Axtell et al., 2006). PPO reacts with phenolic compounds to produce o-quinones which further react with other phenolic compounds or amino acids to give discoloration in different foods made from barley (Saper, 1993; Fuerst et al., 2006). The discoloration of foods by polyphenol oxidase limits the use of barley in food (Lagasse, et al., 2006). The polyphenol oxidase activity can be retard by inactivation of enzyme by the application of heat, exclusion of oxygen and use of reducing agent (Vadlamani and Seib, 1996). Quinde et al. (2004) reported that the polyphenol oxidase activity of abraded barley kernels was 62.1 units/g in hulled proanthocyanidin-containing barley while it was 116.5 units/g in proanthocyanidin-free barley cultivar. Fuerst et al. (2006) reported that the PPO activity ranged from 0.0018 to 0.0089 Δ 475 /min g in refined flour of different wheat cultivars. Quinde-Axtell et al. (2006) reported that the whole barley flour had PPO activity ranging from 94.6 to 171.4 unit/g and showed that the abrasion of outer layer significantly reduced the PPO activity. Preharvest sprouting of wheat leads to increased polyphenol oxidase activity (Edwards et al., 1989; Kruger and Hatcher, 1993; Kruger et al., 1996). The polyphenol oxidase activity of barley was reported to range from 0.147 to 0.382 Δ 475 /min g, the outer fraction of barley grains ranged from 0.183 to 0.366 Δ 475 /min g while in the endosperm portion the polyphenol oxidase activity ranged from 0.084 to 0.146 Δ475 /min g. The germination of barley for 12 h decreased the polyphenol oxidase activity but upon 24 h germination the polyphenol oxidase activity increased (Sharma and Gujral, 2010b).

It has been reported that the thermal treatment of wheat at different temperature of 95 to 110°C and moisture content of 13 to 17% for 4 to 12 min leads to inactivation of lipolytic and oxidative enzymes (Bookwalter, 1985). Heating of wheat at different moisture (13 to 19%) using rotating drum at temperature of 80 to 100°C and for different time (4 to 12 min) significantly lowered the polyphenol oxidase activity (Vadlamani and Seib, 1996). The processing of barley utilizing heat decreased the polyphenol oxidase activity (Quinde-Axtell and Baik, 2006). The microwave heating of wheat has been noticed to significantly lower the polyphenol oxidase activity. In a study where the moisture content of wheat varied from 12 to 21% and microwave heating time varied from 40 to 100 sec, the polyphenol oxidase activity was reported to be 23 to 155 units.
g/min. Further the microwave treated flour was evaluated for chapatti making properties and it was observed that the chapatti prepared from treated flour had better sensory score (Yadav et al., 2008b). It has been reported that the polyphenol oxidase activity of sand roasted barley cultivars ranged from 0.098 to 0.166 Δ475/min g while for the microwave roasted barley cultivars it varied from 0.081 to 0.104 Δ475/min g (Sharma and Gujral, 2011).

2.14 Non-enzymatic browning

Maillard browning is a common phenomenon in foods produced by thermal processing. This reaction occurs between free amino groups of protein and carbonyl groups of reducing sugars, and generates the brown pigments which have been widely reported to have antioxidant activity and contributes in the aroma, taste and color (Cheftel, 1986; Borrelli et al., 2003; Singh et al., 2007; Xu and Chang, 2008; Sun and Zhuang, 2010). It is well documented that the cereals are rich source of dietary antioxidants (Adom and Liu, 2002) but during the thermal processing of food, some naturally occurring antioxidants may be destroyed, while on the other hand many antioxidant compounds are formed by the Maillard reactions (Morales and Jimenez-Perez, 2001; Liu and Kitts, 2011). Since the formation of Maillard browning pigments largely depends upon the processing conditions and composition of raw materials these includes, temperature, reactant concentration, reaction time and water activity (Nicoli et al., 1997; Manzocco et al., 2000; Stojceska et al., 2009).

The extent of Maillard reaction can be estimated by the quantification of intermediate products formed during browning (Erbersdobler and Hupe, 1991). The hydroxymethylfurfural (HMF) is a intermediate product of Maillard reaction (Kroh, 1994; Morales et al., 1997). Anese et al. (1999) studied the effect of drying process on pasta and reported that the Maillard browning occurred during the process and the products of browning reactions contribute in antioxidant activity. It has been reported that the roasting of barley increased the non-enzymatic browning index. Duh et al. (2001) reported non-enzymatic browning index of 0.048/0.1g for barley sample while after roasting at different temperature it was 0.230 to 0.776/0.1g. The browning reaction can be accelerated by higher heating temperature for longer time (Im et al., 2003). Ramirez-
Jimenez et al. (2003) evaluated the concentration of furosine and hydroxymethylfurfural in infant cereals and reported values of 830 to 1178 mg/100 and 0.71 to 1.86 mg/100g, respectively in control samples and after storage for different duration. The NEB index of flour from sand roasted barley has been reported to be 0.300 to 0.498 / 0.1g flour while for microwave roasted barley it ranged from 0.284 to 0.408 / 0.1g (Sharma and Gujral, 2011).

Extrusion cooking brought about greater changes in Maillard browning, the extrusion cooking conditions like elevated temperature and low moisture of feed material are considered to be favorable conditions for Maillard reaction, also sucrose hydrolyzed products and the fragments of starch and dietary fibers provide the substrates for Maillard browning reactions (Singh et al., 2007). The Maillard browning index of different barley cultivars extruded under different extrusion condition have been reported to be 0.146 to 0.201/ 0.1g (Sharma et al., 2012). Nonenzymatic browning development has been investigated in commercial cookies, crackers and breakfast cereals by determination of maltulose and furosine (Rada-Mendoza et al., 2004) and it was reported that the Maillard browning depends upon the composition of raw material and processing conditions. Ramirez-Jimenez et al. (2000) studied the effect of toasting of bread for different time on Maillard browning and reported the absorbance of water soluble brown pigment ΔA (A_{284}-A_{420}) ranging from 0.024 to 3.13. Capuano et al. (2009) studied the effects of toasting of bread on Maillard browning and reported that increasing the temperature and time of toasting results in increase of the Maillard browning products.